Review Article

Effect of Zero-Tillage and Different Weed Management Practices in Direct Seeded Rice (*Oryza sativa* L.) in Indo-Gangetic Plains: A review

ABSTRACT

Millions of rural and urban residents depend on the rice-wheat cropping system of the Indo-Gangetic plains (IGP) for their food security and means of subsistence. About 18 million hectares (m ha) of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are rotated across Asia, of which 13.5 m ha are in the Indo-Gangetic Plains (IGP) of India. This agricultural system's viability is currently in jeopardy due to static yields of both wheat and rice and a decline in total factor productivity. The North West IGP's high input crop culture has allowed weeds to dominate the weed flora, including *P. minor* in wheat and *Echinochloa crusgalli* L. in rice. Farmers in North West India have largely used zero tillage for growing wheat, and recently, farmers in the eastern IGP have done the same. Perennial weeds in the Eastern Indo-Gangetic Plain, such *Cynodon dactylon* L. and *Cyperus rotundus* L. can occasionally be a nuisance under zero tillage. As an alternative to puddled transplanted rice, the focus is currently on dry direct-seeded rice and machine transplanting of non-puddled rice. As a result of changes in tillage, crop establishment techniques, water use, and weed control brought on by the switch from transplanted rice to direct seeded rice, weed composition and diversity frequently vary. In nations where DSR is frequently used, weedy rice has become a significant concern. Using the Zero Tillage DSR system, certified seed, cultivars that are weed-competitive, stale seedbed procedures, living mulches, and chemical and biological weed control might change weed-crop competition in the crop's favour. However, more research on emergence characteristics and mulching effects of different crop residues on key weeds under zero tillage, cover cropping, and breeding crops for weed suppression will strengthen nonchemical weed management programs. In this review, we examine the extent of weed infestation, weed flora shift and the non-chemical alternative weed management in DSR.

Key words: Zero tillage, zero- tillage Direct seeded rice, conventional tillage, pre-emergence, post-emergence, mulching, land levelling

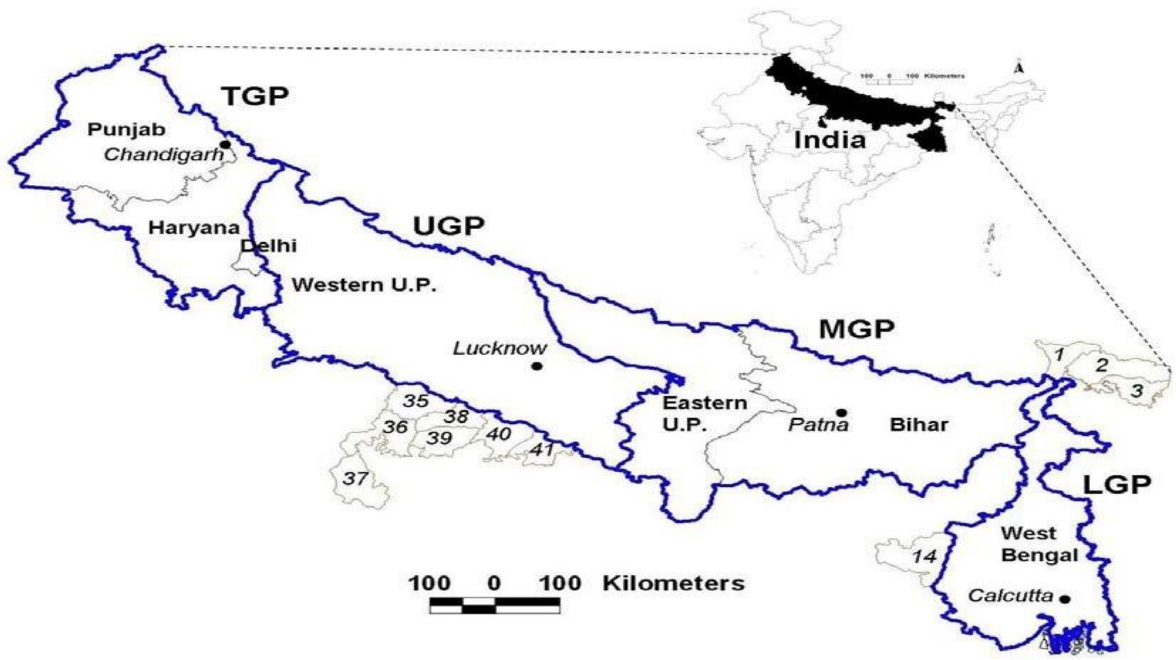
1. INTRODUCTION

The largest food-producing region in South Asia is the Indo-Gangetic Plain (IGP) of India, which spread over 44 million hectares. The states of Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal account for the majority of its land area, which is around 76% of India (Kumar et al., 2021). A broad range of meteorological, edaphic, physiographic, and socioeconomic production characteristics are present in the IGP. The Indian IGP accounts for over 40% of the nation's total cereal production and is dominated by a cereal-based production system. Globally, the human population is increasing at a faster rate and expected to reach 9.8 billion by 2050. The majority of the world's population relies on rice as a staple diet, and Asian nations produce 90% of the world's rice [Kumar and Ladha, 2011, Pooniya *et al*., 2012]. To feed this ever-increasing population, it becomes necessary to increase the anticipated food production either through area expansion or productivity enhancement [Gathala et al., 2020]. Further, the production potential of available resources is restricted due to declining soil health, lower energy use efficiency, water use efficiency, and enhanced greenhouse gases (GHGs) emission under existing production systems [Lin et al., 2019, Singh et al., 2022]. Satisfying the growing food demand with limited farm resources poses an enormous challenge while efficiently utilizing the fresh water supply, energy, and fossil fuel without compromising the ecological sustainability and livelihood security [Babu *et al*., 2020, Gathala *et al*., 2020b].

Under the rice-wheat cropping system, farmers face major problems such as rice straw burning, delayed wheat sowing, abnormal climatic conditions such as cold injury, terminal heat stress, depleting water table, increasing fossil fuel emissions, depleting natural resources, and so on [Chaudhary et al., 2019].

However, weeds are the most important barrier under both conventional tillage (CT) and zero tillage (ZT) practices, diminishing wheat yield up to 60.5% under conventional and 70% under zero tillage practices [Jain et al., 2007, Das et al., 2020]. Crop residue retention on the soil surface combined with zero tillage (ZT), results in enhanced soil quality and over all resource conservation [Das et al., 2018, Ghosh et al., 2019]. These issues necessitate appropriate mitigation measures such as proper crop establishment methods, residue management, and weed management. Traditional puddled transplanting systems effectively suppress live weeds and their viable seeds by submerging them in saturated soil, resulting in delayed weed emergence [Jat et al., 2019, Soni et al., 2020]. The traditional transplanted rice has recently been replaced with DSR, which may be planted at the proper time by rotating with zero tillage wheat. Puddled transplanted rice (PTPR) conventionally tilled wheat system was more expensive than DSR-ZT, which provided equal to or higher system (rice + wheat) yields [IRRI, 2014, Jat et al., 2014, Laik et al., 2014, Singh et al., 2010]. In the 1980s, direct wheat seeding in the Punjab areas of Pakistan and India marked the beginning of conservation agriculture (CA) in South Asian counties [Hafeez-Ur-Rehman et al., 2015]. Conventional transplanted rice is labour intensive, necessitates a lot of water, and is bad for the health of the soil [Gathala et al., 2011, Kumar and Ladha, 2011]. Zero Tillage DSR can minimise the amount of water and labour needed, as well as the negative impact that puddling has on the production of a subsequent wheat crop and the health of the soil [Gupta and Seth, 2007, Kumar and Ladha, 2011, Ladha et al., 2009]. According to Tripathi et al. [2005], each one-day delay in planting wheat past the ideal date causes a yield loss of 26.8 kg ha^{-1}. Weed control is particularly challenging in Zero Tillage-DSR system. Compared to TPR, the DSR fields have more species-rich and diverse weed flora [Tomita et al., 2003].

The diversity and severity of weeds in zero-till DSR is typically associated with a shift away from transplanting and flooding method of practices, both of which play an important role in suppressing weeds under conventional tillage. Weed-related yield losses have been observed to be considerably greater in zero tillage direct seeded rice than conventional transplanted rice [Kumar and Ladha, 2011, Kumar et al., 2008, Rao et al., 2007, Singh et al., 2011]. Moreover, compared to herbicides used in rice pre-emergence herbicides (butachlor, pendimethalin and pretilachlor) are substantially less susceptible to resistance evolution. Due to the simultaneous appearance of weeds and rice as well as the lack of standing water during the early phases of the crop to inhibit weed development, weeds are acknowledged as the principal biological restrictions to the production of DSR [Chauhan and Johnson, 2009, Chauhan and Johnson 2010, Chauhan, 2012, Chauhan et al., 2012a, Chauhan et al., 2012b]. According to recent research, unmanaged weeds in DSR resulted in yield losses of up to 98 percent under zero tillage conditions and 85 percent to 96 percent compared to conventional tillage [Chauhan and Johnson, 2011, Singh et al. 2011].



(Fig.1: TGP- Trans Gangetic Plain , UGP- Upper Gangetic Plain , MGP- Middle Gangetic Plain, LGP- Lower gangetic Plain)

(Fig.2: Different methods of Rice crop production in IGP region)

2. PROMINENCE OF DIRECT SEEDED RICE

Direct seeded rice (DSR) has several advantages over transplanted rice, including ease of mechanisation, quick and easy sowing, reduced labour requirements and drudgery, earlier crop maturity, increased water use efficiency, higher tolerance to water shortages, lower methane emission, and frequently higher profit in areas with guaranteed water supply [Farooq et al., 2011b, Kumar and Ladha 2011, Chauhan et al., 2012b]. Early DSR reaches maturity 12 weeks before to transplanted rice, lowering the danger of terminal drought and enabling the planting of a subsequent non-rice crop early [Saleh et al., 2000]. Furthermore, DSR under zero-tillage systems, leaving agricultural residues on the soil surface, improves soil physical and chemical characteristics, enhances soil organic matter and water penetration rates, conserves soil moisture, and minimises soil erosion [Hajabbasi and Hemmat 2000, Chauhan et al., 2002, Chauhan et al., 2007].

3. METHODS OF DSR CULTIVATION

There are three main ways to establish rice, viz. transplanting, dry-DSR and wet-DSR. These approaches differ from others either in the way crops are established (tillage) or in the way the ground is prepared. In Asia, particularly in the tropical regions, transplanting is the predominant method of crop establishment. This technique involves ponding the ground and transplanting seedlings cultivated in nurseries. Direct seeding is the practise of sowing seeds directly onto the main field as opposed to transplanting rice seedlings. This can be done both dry and wet. The first technique of planting rice is direct sowing, which was afterwards replaced by transplanting.

3.1 Dry- DSR

In Dry-DSR, rice is established using a variety of techniques, such as *(i)* broadcasting dry seeds on unpuddled soil after either zero tillage (ZT) or conventional tillage (CT), *(ii)* using the “dibbled method” in a field that has been well-prepared, and *(iii)* drilling seeds in rows after CT, minimum tillage (MT) using a power tiller-operated seeder, ZT, or raised beds. In both conventional and ZT situations, a seed-cum-fertiliser drill is employed, which drills the seeds and applies fertiliser after preparing the ground or in ZT circumstances.

3.2 Wet- DSR

Pre-germinated seeds (1-3 mm radicle) are sown on or into puddles of soil using the wet-DSR technique. The term “aerobic Wet-DSR” refers to the seed environment created when pre-germinated seeds are placed on the surface of puddled soil. Pre-germinated seeds are usually planted or drilled into soggy soil, which creates an anaerobic Wet-DSR environment. Using a drum seeder or an anaerobic seeder with a furrow opener and closure, seeds may be dispersed or sown in line in wet-DSR under aerobic and anaerobic condition.

4. HISTORY OF ZERO TILLAGE (ZT) IN INDIA

Zero tillage (ZT) for wheat studies in India began over three decades ago [Ekboir, 2002]. In the 1970s, several state agricultural colleges attempted zero tillage practices, but their efforts were unsuccessful owing to technical issues such inadequate planting equipment and challenges with chemical weed control. All except a small group of lone researchers quickly gave up on this avenue of inquiry. Indian researchers were exposed to Inverted-T openers by a regional wheat agronomic from Centro International de Mejoramiento de Maizy Trigo (CIMMYT) in 1990. At the G. B. Pant University of Agriculture and Technology, Pantnagar, the first prototype of the Indian Zero-Tillage seed drill was created in 1991. Within a year, the first ZT seed drill was made available for field testing following a significant expenditure of resources and several design revisions. At the turn of the century, the Indo-Gangetic Plains Rice-Wheat Consortium (RWC) and CIMMYT had a substantial effect on the adoption of zero tillage. One of the finest technologies developed since the green revolution, zero tillage technology is now seeing significant success.

Zero till cultivation in sustainable crop production

The burning of rice leftovers and the deterioration of soil health are two main issues in rice-wheat cropping system in IGP. In the northwest region of India, over 2.5 million farmers burn 23 million tonnes of rice residues [Meena R.P et al., 2020], which has a negative influence on the quality of the air and land. Huge amounts of toxic gases, such as carbon dioxide, methane, nitrous oxide, and carbon mono oxide, are released into the atmosphere, degrading the air quality and causing serious health effects in humans [Jain et al., 2014; Chethan et al., 2020; Venkatramanan et al., 2021]. There is also a loss of important soil nutrients. P, K, and S that are present in the rice residue lose 20–60% of their value when burned, whereas C and N are lost virtually entirely (Porichha et al., 2021). Zero tillage in cereal systems has improved system productivity and soil health while conserving money, water, fuel, and other resources [Malik et al., 2005, Gupta and Sayre 2007a, Gupta and Seth 2007b, Saharawat et al., 2010]. Surface retention, a method of residue management in zero-till systems, reduces greenhouse gas emissions by roughly 13 t ha^{-1} [Mandal et al., 2004] and controls canopy temperature during grain filling stage to reduce the impacts of terminal heat on wheat [Sharma et al., 2008, Jat et al., 2009, Gupta et al., 2010]. In West Bengal, Mukhopadhyay and Rooj [1971] were the first to study zero tillage using the non-selective herbicide paraquat. They found that zero tillage with 3.75 L ha^{-1} of paraquat treatment increased rice production compared to conventional tillage plus one-handed weeding. Wheat was planted as the following crop in the same field, and it yielded more grain with zero tillage than with conventional tillage. It was therefore understood that chemical weeding with non-selective herbicide application and increased residual toxicity would be essential for the success of zero tillage.

Major weed flora in Zero-Tillage DSR system

Based on experiences with ZT-DSR in India and other Asian countries, the shift from conventional tillage transplanted rice to ZT-DSR is expected to favour grass weed species including crowfoot grass (*Dactyloctenium aegyptium*), Chinese sprangletop (*Leptochloa chinensis*), love grass (*Eragrostis spp*.), and weedy rice (*Oryza sativa* L.), along with barnyard grass and jungle rice (*E. colona* L.), sedges such as globe fringe rush (*Fimbristylis miliacea* L.), purple nutsedge (*Cyperus rotundus* L.), and rice flat sedge (*Cyperus iria* L.) would dominate under DSR systems [Kumar and Ladha, 2011]. Other important weeds of rice under ZT in rice-wheat systems (RWS) include broadleaves such as eclipta (*Eclipta prostrata* L.), red stem (*Ammania* spp.), Caesulia (*Caesulia axillaris*), goose grass (*Sphenochloa zeylinica*), horse purslane (*Trianthema portulacastrum* L.), niruri (*Phyllanthus niruri* L.), and *Digera arvensis*. and sedges such as small flower umbrella sedge (*Cyperus difformis* L.). The majority of major weed species in zero tillage rice are highly sensitive to the depth of seed burial. For seeds, maximum emergence often happens at or near the soil surface. Most annual sedges are severely impeded from emerging at depths of 0.5 cm and completely prevented from emerging at depths of 1 cm or deeper [Chauhan and Johnson, 2009a]. Similar to this, at burial depths of 0.5 cm, the emergence of the broadleaf weed eclipta was totally suppressed [Chauhan and Johnson, 2008]. While barnyard grass may sprout from depths of up to 10 cm, jungle rice and crowfoot grass can only emerge as deep as 6 cm [Chauhan, 2011, Chauhan and Johnson, 2009b, Chauhan and Johnson 2011a]. The major weed groups that affect the productivity of DSR in the lowland areas range from grasses such as *Echinochloa spp*. and *Leptochloa chinensis* L., broadleaf species *Melochia corchorifolia* and *Ludwigia octovalvis*, to sedges such as *Fimbristylis miliacea* and *Cyperus spp*. [Martin et al., 2017, Ya et al., 2020]. According to Chhokar *et al.* (unpublished), yield losses caused by weeds were 90 percent with ZT-DSR as opposed to 35 to 42 per cent under zero tillage transplanted tice in the absence of weed management techniques.

Weed Dynamics in DSR

Weeds floral makeup varied widely, and yield losses caused by weeds were more severe in saturated circumstances (54%) than in flooded situations (35%) [Juraimi et al., 2009]. According to field surveys conducted between 2000 and 2004 by Singh et al., *E. crus-galli*, *Commelina diffusa* L. and *Cyperus rotundus* L., all saw synchronous increases in density. India has also documented a rise in sedge dominance in response to DSR [Yaduraju and Mishra, 2008, Singh et al., 2008]. In transplanted rice, broadleaved weeds had great dominance, but in DSR, grasses and sedges were more widely dispersed. There was a shift in weed composition over the four years of experimentation in both ZT-DSR and puddled TPR. Shifts were more pronounced in the former than the latter treatment. In the ZT-DSR weedy plots in the first year, grassy weeds including *D. ciliaris*, *C. dactylon*, and *F. miliacea* had greater biomass than other species. But from the second year onward, weed biomass was greater for C. iria and C. difformis and gramineous species such as *P. scrobiculatum* and E. crusgalli (Hossain et al., 2020).

Table 1: Effect of establishment methods and reduction in grain yield

Sl. No.	Method of rice establishment	Reduction in yield due to weeds (%)
1	Upland rice	97
2	Upland dry seeded rice	94
3	Dry seeded rice	17-73
4	Wet seeded rice	85

Loss of grain yield in different methods of rice establishment in India (Ladu and Singh, 2006, Singh *et al.*, 2011)

Zero till effect on crop yield

According to Busari et al. (2015), conservation tillage (CT), which includes no-tillage and reduced tillage, protects the soil from erosion, reduces soil disturbance, and boosts soil organic matter. Furthermore, recent research has demonstrated that CT influences microbial communities significantly (Morugán-Coronado et al., 2022) and safeguards the life cycle of arthropods while also increasing their variety (Rivers et al., 2016). A similar approach sustains crop yields and increases soil organic matter (SOM) with zero tillage combined with crop residue management (Singh et al., 2018; Das et al., 2021; Saurabh et al., 2021). According to Bhardwaj et al. [2004], Pantnagar might produce up to 8% more wheat than usual. Numerous field tests have contrasted zero tillage (ZT) with conventional tillage (CT) throughout the years. The yield using ZT was comparable to or significantly greater when the crop was seeded under the two techniques on the same day. The varied establishing techniques utilised in a long-term rice-wheat cropping system in Pantnagar (10 years) revealed that the zero tillage approach produced a greater wheat grain yield than the traditional technique. A yield potential of 10% has been noted in zero tilled DSR rice but the yield of following zero tilled wheat increased by 21%, showing the net benefit of it in the rice-wheat cropping system (Sharma et al., 2019).

Alternate weed management practices in DSR system

Cultural methods of weed control

Land levelling: Through the provision of a seed bed free of weeds at the time of planting, proper soil preparation aids in decreasing weed invasion. Before planting crops, the field should be levelled to ensure a consistent crop stand. Due to conventional levelling, an 8–15 cm variance in field level is seen in the Indo-Gangetic plains. Due to the uneven distribution of water in the soil profile and the flooding of recently germination seedlings, rice crops fail to establish well (Gopal et al., 2010). Better crop establishment, accurate water control, and higher pesticide usage efficiency are all guaranteed by laser field levelling (Jat et al., 2009; Chauhan, 2012).

Time of sowing, seed rate and spacing: Before the monsoon season begins, rice is farmed in northern India during the kharif season. The best time to plant DSR is around 10-15 days prior to the beginning of the monsoon in order to maximise the utilisation of monsoon rain [Gopal *et al.*, 2010, Kamboj *et al.*, 2012, Kumar and Ladha 2011, Gopal *et al.*, 2010]. The ideal seeding rate for basmati rice cultivars with a 20 cm spacing has been found to be 20-25 kg ha^{-1} (Yadav *et al.*, 2007).

High seeding rates cause too vigorous vegetative development, which uses up most of the available resources before to anthesis and reduces the formation of dry matter following anthesis (Wells and

Faw, 1978). As a result, the foliage's N content decreases the spikelets become sterile, and there are fewer grains per panicle (Kabir *et al.*, 2008). Additionally, dense plant populations at high seed rates can foster the development of pests and diseases including brown plant hoppers and sheath blight, as well as render plants more susceptible to lodging from weak stems (Islam et al., 2008). For high-tillering cultivars, a lower seed rate can be utilised, while for medium-tillering kinds, a little greater seed rate can be used (Soo et al., 1989). Another crucial factor that has to be considered is the depth of the seeds. When using DSR, precision planters with depth control wheels should be used for the seeding. In DSR, seed depth is crucial for both seedling emergence and germination. Semi-dwarf cultivars' shorter mesocotyl than standard tall kinds make them more sensitive to seeding depth (Blanche et al., 2009).

Cultivar selection

Among the existing varieties and hybrids which are though bred for puddled rice, some hybrids & basmati varieties have been found suitable for DSR.

Stale seed bed technique:

When a certain farming method is employed year after year, the weed seed bank in the soil can be reduced using the stale seedbed approach. In IGP, where rice-wheat is the primary agricultural system, this may be quite helpful. It eliminates 5-10% of the soil's weed seed population. After tillage, mild watering is used in stale seedbeds to promote the correct germination and emergence of weed seedlings. To enhance weed germination, one irrigation is given 15 days prior to planting, and the soil is thereafter kept at the ideal moisture level. To eliminate newly emerging weeds, apply a non-selective herbicide (such as glyphosate or paraquat) or a mechanical technique. When weed species have little dormancy, are planted close to the soil surface (in zero-tillage), and favourable environmental factors (light, ideal temperature) are available, stale seedbed can be particularly effective (Chauhan, 2012). According to Singh et al. (2009), employing the stale seedbed approach in direct seeded rice can lower weed density by 53% compared to the control. Because weed seeds planted deeper than 1 cm do not emerge, Chauhan and Johnson (2010) found that stale seedbeds treated with paraquat and zero-till resulted in superior weed management. Stale seedbed and pendimethalin were used in combination to effectively reduce weeds in DSR in extensive farmer-participatory experiments in India (Singh *et al*., 2005b).

Mulching: Another method of weed management for rice that has been direct sown is to add mulch to the soil. Mulch controls weeds, avoids soil erosion, improves soil health, and lessens diurnal temperature changes in addition to preserving moisture (Qin *et al*., 2010). Mulches are believed to suppress weeds through physically preventing weed seeds from developing, blocking incoming sunlight, and by releasing certain allelochemicals. *Echinochloa crusgalli*, *Echinochloa colona*, *Dactyloctenium aegyptium*, and *Eclipta alba* were among the troublesome weeds of the DSR that were shown to be susceptible to wheat straw mulch, according to Kumar *et al*. (2013). According to Batish *et al.* (2007), *Tagetes minuta* L. residue applied as mulch inhibits the development of E. crus-galli and C. rotundus. *Clerodendrum trichotomum*, *Datura stramonium* L., *Desmodium triflorum* L. and *Melia azedarach* L. were shown to supress weeds in rice by 70-90 percent according to Hong et al. (2004). During the early stage (30 DAS), mulch resulted in the highest reduction in total weed density (54%), which may be due to the inhibitory effect of allelochemicals released by wheat on weed seed germination. Singh *et al*. (2007) studied the effect of weed suppression ability of weeds with wheat straw 4 t/ha spread uniformly at SVBPU and T. Additionally, wheat straw improves weed control and increases rice grain production. Wheat straw increased rice grain production by 22% while reducing grasses and BLW by 46% and 71%, respectively. As a result, there are more economic gains than under the control (Singh *et al*., 2007). According to Hamdi *et al.* (2001), the suppression of ryegrass by wheat straw may be caused by the emission of leachates and organic compounds.

Weed competitive cultivar: Weed-competitive cultivars can be a low-cost yet effective method to increase yield and generate profits (Andrew et al., 2015). The best cultivars for direct sowing include coleoptiles with superior mechanical strength for quick germination and increased seedling vigour to combat with weeds (Jannink *et al.*, 2000, Zhao *et al.*, 2006). Field studies were carried out by Ranasinghe (1995) to determine the morphological characteristics that provide rice plants the capacity to compete successfully with weeds. He discovered that the rivalry between rice and barnyard grass varied greatly depending on the cultivar's shape A cultivar that increases plant height, leaf area, and dry matter accumulation during the seedling stage, as well as increases plant height and leaf area when the plant is mature, gives weeds more competition. The traits linked to weed-suppressing rice cultivars were more fully formed roots, a high leaf area index, and tillering ability (Fofana and Rauber, 2000). According to Perera et al. (1992), rice cultivars suffer from lower root development, root biomass, and nutrient absorption when there is intense crop-weed competition. According to Gealy and Moldenhauer (2012), weed-suppressive rice cultivars contain twice as much root biomass as non-suppressive varieties. Due to higher root biomass and root proliferation, weed suppressive cultivars competed better for resources with weeds and reduced weed loss by 44% and weed prevalence by 30% as compared to non-suppressive cultivars (Gealy and Moldenhauer, 2012).

Brown manuring: In direct seeded rice, brown manuring with sesbania might be a viable alternative to manage weeds, enhance soil health, and increase production. 3 days after direct seeding rice, sesbania seeds at a rate of 20 kg ha^{-1} can be drilled between the rows and sprayed with 2,4-D ethyl ester at a rate of 0.50 kg ha^{-1} to create sesbania brown manure. According to Nawaz *et al*. (2017) evaluation of five alternative rice-wheat cropping systems, brown manuring reduced weed density and bio mass by 62-75 % and 41-56%, respectively, in direct seeded rice with sesbania compared to solitary direct seeded rice.

Seed priming: The main goal of seed priming is to hydrate seeds for a predetermined amount of time in order to finish the pre-germinative metabolic process, although radicle emergence is prevented. Water (hydro-priming), salt solution (halo-priming), or wet sand can all be used as primers (sand matric priming). Priming enhances resilience to water and temperature stress, produced consistent germination, increased germination percentage, and increased yield. Juraimi et al. (2012) discovered that several priming treatments increased the vigour of direct sown Aeron 1 plants. According to their findings, primed seeds generated seedlings that were 50 percent more vigorous than unprimed seeds. Anwar et al. (2012) said that primed seeds reduce weed dry weight by 22 to 27%, primarily because they promote strong seedling growth and rapid canopy formation. Additionally, they discovered that primed rice seeds yield 0.4t ha^{-1} higher than untreated seeds.

Mechanical and manual methods of weed control:

Controlling weeds through any physical activity that inhibits growth of weeds is mechanical control. **Mowing:** Mowing is the process of eliminating or cutting weed shoots with a mower or sickle. It works well to eradicate annual weeds but is less effective on perennial ones since they store their food in underground sections (rhizomes, stolones, etc.) and come in many flushes. To stop seed distribution, mowing must be done prior to blooming or seed germination. Thus collected marijuana should be burned or deeply buried to destroy any viable weed seeds (Matloob *et al.*, 2015).

Mechanical weeder: If appropriately applied, mechanical techniques can effectively control weeds while producing yields comparable to chemical ones. IGP does not use mechanical weeding because of labour and financial restrictions. According to Muthukrishnan and Purushothaman (1992), HW applied twice at 25 and 45 DAS efficiently reduced the weeds and increased grain production compared to the unweeded control. Mehta and colleagues (1993) found that HW twice, at 20 and 30 DAS, generated rice grain yield of 3.2 t ha^{-1} at par with weed free (HW four times), producing 3.3 t ha^{-1} and higher than one HW (2.5 t ha^{-1}) and weedy (1.0 t ha^{-1}). Pendimethalin at 1.0 kg ha^{-1} and farm waste as mulch (7.5 t/ha) added with one HW at 45 DAS decreased weed count and biomass with the highest weed control efficiency (91.3 percent), which was comparable with HW three times at 30, 60, and 90 DAS (farmers' practise), according to Singh *et al*. (2003) report from Pantnagar, India. Only when weeds are large enough to be picked may manual weeding be used since it has an inherent opportunity cost. Due to this, human weeding is frequently done at a later stage of the growing season, as shown by yield loss comparisons between the impacts of hand weeding at 21 to 30 DAS and the usage of early post-emergence herbicides (Singh *et al*., 2005a). Low labour availability, high labour costs, unfavourable weather, and the existence of perennial weeds that disintegrate when pulled may all reduce the effectiveness of manual weeding. For many small and marginal farmers in Asia and Africa, mechanical weeding with inexpensive tools continues to be a viable option. On row-seeded rice, mechanical weeding is nearly always used because interrow cultivation using either hand tools or animal traction equipment shortens the weeding process and causes less crop damage. In rain-fed upland rice in India, Sarma and Gogoi (1996) stated that a manually operated peg-type dry-land weeder with a straight-line peg arrangement has demonstrated outstanding performance over a wide variety of conditions. of soil types with varying soil moisture levels and weed intensity providing a labour saving of 57% compared with hand weeding (127 person-days/ha).

Chemical method of weed control: Hand weeding is the traditional way of controlling weeds in rice, although it is time-consuming, costly, and ineffective. Chemical weed management has been proven to be efficient and cost-effective. Compared to manual weeding alone, chemical weeding is simpler, quicker, and more cost-effective (Brar and Mishra, 1989). A preferable option could be to use chemical weed control (Singh et al., 1998). Herbicidal weed control techniques are advantageous since they allow for labour and financial savings, making them a viable option for weed management (Ahmed et al., 2000). Compared to manual or mechanical techniques of weed management, herbicides offer improved weed control and are more labour-efficient (Chauhan *et al.*, 2014). According to Jacob *et al.* (2014) the main benefit of using herbicidal weed management in DSR is the decrease in cultivation costs. Because of poor weather conditions and sowing pressure, pre-emergence herbicide treatment is not always feasible (Porwal, 1999). The repeated use of large dosages of pre-emergence herbicides, according to Singh *et al*. (2009), causes a shift in the weed flora from grasses to non-grassy weeds and the evolution of herbicide resistance in weeds as a result of the latter's protracted survival in the soil. For weed management in DSR, this calls for the use of post-emergence herbicides, which offer broad-spectrum weed control and address the issue of herbicide resistance. According to Paswan et al. (2012), mixing herbicides with several modes of action prevents target site resistance in vulnerable species by binding to various target sites in weeds. An effective substitute for hand weeding may be herbicides (Chauhan and Johnson, 2010, Anwar *et al*., 2012). According to Singh *et al*. (2017), consecutive application of pendimethalin *fb* penoxsulam resulted in the lowest weed biomass and density over weedy check, as well as consistently superior growth, yield characteristics, and DSR yield.

In order to manage weeds in rice, Singh *et al*. (2013) investigated the effects of various carfentrazone-ethyl dosages. The maximum weed control efficacy was achieved with the application of the herbicide 35 g ha^{-1}, which significantly decreased weed density, dry matter accumulation, and N, P, and K depletion. Additionally, it improved the crop's ability to absorb nutrients, production of grain and straw, and growth metrics. Other herbicide treatments, such as ethoxysulfuron 15 g/ha, metsulfuron 4 g/ha, and carfentrazone 15-35 g ha^{-1} administered as post-emergence treatments, and pendimethalin 1 kg ha^{-1} as a pre-emergence treatment, reported greater yields. Mahajan and Chauhan (2015) revealed that the tank mixtures of the presently available herbicides like azimsulfuron + bispyribac or fenoxaprop, bispyribac + fenoxaprop, and azimsulfuron + bispyribac + fenoxaprop, all applied as post-emergence, rarely resulted in antagonistic effects. Highest weed control efficiency and highest grain yield was recorded with the tank mixture of azimsulfuron + bispyribac + fenoxaprop. Plots treated with the post-emergence application of single dose herbicide (i.e., azimsulfuron, bispyribac or fenoxaprop) had lower grain yield than all the sequential herbicide treatments and tank mixtures (azimsulfuron + fenoxaprop and azimsulfuron + bispyribac), owing to a broad spectrum weed control. Choudhary and Dixit (2018) found that combination of pyrazosulfuron + pretilachlor (15 + 600) g/ha to (30 + 1200) g/ha provided wide spectrum weed control which was comparable to two hand weedings at 15 and 30 days after sowing. Highest weed control efficiency was recorded in two hand weedings and lowest weed control in pendimethalin and lowest dose of pyrazosulfuron + pretilachlor and pyrazosulfuron alone. The crop growth parameters and yield attributes were recorded highest in two hand weedings, followed by pyrazosulfuron + pretilachlor (15 + 600), (16.88 + 675) and (30 + 1200) g/ha, which were the best broad-spectrum herbicide combinations in order to minimize the various weeds in DSR system.

Table 2: Major pre- and post-emergence herbicides identified suitable for weed control in DSR in the IGP

Time of application	Herbicides example
Pre-Emergence Herbicides	Pendimethalin, pyrazosulfuron, Triafamone, Oxadiargyl
Post-Emergence Herbicides	Fenoxaprop-p-ethyl, Ethoxysulfuron, metsulfuron-methyl, chlorimuron-ethyl

Integrated weed Management in DSR

The main hazard to the DSR planting method is now weed. The integrated weed management (IWM) strategy, which integrates all existing weed control techniques, including mechanical, cultural, biological, chemical, and biotechnological techniques, is best suited for eco-friendly environments and sustainable weed management. Due to the variety in growth habits of weeds, a single method of weed control cannot provide effective and sustainable weed control, as a result, it is necessary to integrate various approaches based on location and availability, such as light irrigation in a zero-till system to encourage weed emergence and then killing them with nonselective herbicide that is later used as a residue mulch, mechanical weeding to eliminate escaped weeds and herbicide resistant weeds, etc. (Bhagirath S Chauhan, 2012). In order to manage or control the weed of vast range, effective IWM incorporates several "small harmer technologies" as opposed to a single "big harmer" approach (Kumar

& Ladha, 2011). Weed communities are extremely susceptible to management approaches and environmental circumstances, therefore integrating several technologies is crucial for weed control (Buhler et al., 2000). Chemical weed control techniques should be used in conjunction with other weed management techniques rather than as a replacement for them. Karthika *et al*. (2019) reported that the application of Bensulfuron-methyl + Pretilachlor (10 kg ha^{-1}) fb 2,4-D (1.25 kg ha^{-1}) + one hand weeding @ 45 DAS was found to be the ideal combination for managing the weeds by increasing weed control efficiency under direct seeded condition with higher grain yield.

Impact of cover crops and crop establishment on weed density and dry matter accumulation in general, transplanted rice grown with zero tillage exhibited greater dry matter and weed density than puddled transplanted. Zero Tillage DSR with residue plots reported nearly equal weed densities and less dry matter accumulation over the course of years. In 2008, cowpea as a cover crop (ZTDSR-CP) had more grassy weeds than ZTDSR with residues, but in 2009 and 2010, it had 55.6 and 69.2 fewer grassy weeds than ZTDSR-R, respectively. In comparison to the ZT-DSR-R and puddled transplanted plots, the plots under ZTDSR sesbania and ZT-DSR cowpea reported 7.69, 40 percent and 23, 60 percent reduced dry matter build up in 2010 (Jat *et al*., 2019).

Future research needs

creating cultivars appropriate for DSR for various rice-based systems Create irrigation schedules for various soil types and DSR based systems management procedures. Develop management techniques, such as dosing and application schedule, by understanding nutritional dynamics Under aerobic circumstances, track GHG emissions and create methods to cut N losses relative to N_2O emissions. Crop residue cover optimization from a systems viewpoint defining management measures under DSR and comprehending the dynamics of pests and diseases.

Conclusion

On this premise, the application method such as tank mixing or sequential application and the strategy such as fusing cultural, mechanical, and chemical practices should be selected. Therefore, it's important to create weed management plans that are sustainable and will provide rice a competitive edge over weeds. To achieve efficient, long-lasting, and season-long weed control in DSR systems, the use of herbicides (with appropriate timing, rotation, and combination) must be combined with other cultural approaches, such as the use of weed-competitive cultivars, optimal sowing time, use of stale seedbed practises, use of a high seeding rate and narrow crop row spacing, appropriate fertiliser and water inputs and their application method/timing, mechanical weeding, etc. These agronomic and technological inventions have made weed management very effective and cost-effective by reducing the weed management costs incurred in curative tactics in DSR system. Also, developing new rice cultivars suitable for direct dry sowing and short statured with higher initial vigor would help the wider adoption of DSR.

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