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OPINION ARTICLE

The opportunities and challenges for harvest weed seed control (HWSC) in India: An opinion

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ABSTRACT

Weeds which are escaped during the control measures are one of the source of soil weed seedbank. At the time of crop harvest, several weed species retain a considerable quantity of their seed. These weed seeds are evenly spread across the crop field through various weed seed dispersal mechanisms. By knowing the weed seed retention character of every weed species, their effective weed control can be achieved by the collection and/or destruction of weed seeds during crop harvest using harvest weed seed control (HWSC) methods. Narrow windrow burning, chaff tramlining, chaff carts, chaff lining, the Harrington seed destructor (HSD) and the bale direct system are common HWSC procedures. The crop harvest is a primary contributor to the transmission of weed seeds over the crop fields and with HWSC, we can now skip this process and prevent weed seed spread. This strategy is useful to target weed species that retain a large part of their seed after maturity and was found highly effective in controlling the spread of herbicide resistant weed seeds. HWSC aims to prevent the mature weeds seed from entering the seedbank. Through HWSC, we can prevent the enrichment of soil weed seedbanks and deplete existing soil weed seedbanks in long run. In India, the scope for HWSC is high in organic farming, direct-seeded rice, zero-till wheat, herbicide tolerant rice and high intensive irrigated agriculture while its scope is much limited in rainfed agriculture. However, the efforts on using HWSC are yet to begin in India and should be initiated.

Keywords: Direct-seeded rice, Harvest Weed Seed Control, HWSC, Weed seedbank, Zero tillage

INTRODUCTION

The weed seedbank is an integral part of agricultural systems since it is the major contributor of weeds in croplands and act as a weed biodiversity reserve (Gohil *et al.* 2020). It dictates the kind and intensity of weed menace in subsequent crops, while also reflecting the impact of previous management efforts on weed population dynamics (Legere *et al.* 2011). Weed seed reservoirs in soil seedbanks aid in the persistence of weeds (Gallandt 2006). In most agricultural fields, the soil weed seedbank contains millions of weed seeds per hectare which is the source of recurring weed infestations (Andreasen *et al.* 2018). The usual source of seedbank replenishment is weed seed rain, or the reproduction and spread of seeds by weedy plants. The seedbank composition is influenced by a variety of elements, such as management strategies, weed characteristics (competitiveness, duration, reproduction, stress tolerance) and edaphic environments (Arora and Tomar 2012). Similarly, weed seed production is influenced by a variety of factors, including available plant nutrients and water, as well as competition from other plants (Rao *et al.* 2017). The early-season survivors contribute more to the weed seedbank than late-emerging individuals (Steckel and Sprague 2004). Because late-emerging weed seedlings are harmed by crop competition, particularly for light. Reduced light supply is known to have little effect on seed viability (Baumann *et al.* 2001), and seed production in late-emerging weeds may contribute enough to seedbank persistence (Mayen *et al.* 2008). Late-season weed control was found effective in reducing weed seed rain and seedbank densities (Brewer and Oliver 2007).

Despite the farmer's best attempts to control weeds, the problem endures. The majority of farmer's non-chemical weed management strategies are aimed

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at preventing weed seedlings from interfering with the crop plant at early growth but not on weeds reproduction (Ramesh *et al.* 2022). In case of ineffective weed control, weeds survive and shatter seeds leading to enrichment of soil weed seedbank. Late-season weed escapes are a major contributor to seedbank persistence (Bagavathiannan and Norsworthy 2012). The late-season weed seed development has received a lot of attention with increasing herbicide-resistant weeds and changing weed management paradigm (Norsworthy *et al.* 2012).

The emerging problem of herbicide resistance (HR)

Herbicide resistant (HR) weeds are a major hindrance to agricultural sustainability. In agriculture, weed resistance to popular herbicides is becoming rampant (Duary 2008). Continuing to rely solely on herbicides for managing the weeds will not only expedite the spread of resistance but will also remove the few existing herbicides that are effective against these weeds (Patterson *et al.* 2021). Given the lack of new herbicides modes of action in the near future, precautions must be made to safeguard the efficacy of existing herbicides. To control herbicide-resistant or escaped plants, alternative non-chemical weed control approaches are required as seed produced by resistant weeds, prevailing at crop harvest, are evenly spread across the farm through various weed seed dispersal mechanisms at the time of harvest. HWSC is one such method gaining importance recently in many countries like Australia, USA and have been found to reduce the soil seedbank and minimise the likelihood of herbicide resistance evolution (Walsh and Newman 2007, Walsh and Powles 2007, Walsh *et al.* 2013, Walsh *et al.* 2017). Multiple HR outbreaks were extremely rare to occur and were nearly always avoided by implementing annual, efficient HWSC (Somerville *et al.* 2018). Combining HWSC with effective herbicides offers the potential to minimise future development of herbicide resistance besides decreasing weed populations.

Harvest weed seed control (HWSC)

HWSC is a term that refers to the collection and/or destruction of weed seeds during harvest. HWSC is a novel preventive wave of weed management. HWSC is being increasingly practised in Australia and other parts of the world. The percentage of weed seed retained on the plants at the time of crop harvest ranged from 80 to 90% in the majority of weed species (Schwartz-Lazaro *et al.* 2021a,b). Modeling studies (Shergill *et al.* 2020) report greater than 80% seed retention is needed for HWSC to be viable.

Furthermore, larger plants generated more seeds, and seed retention was significant at harvest regardless of plant size or emergence time. These weed seeds then reach the reaper and are rewarded for their survival by being uniformly disseminated around the field and becoming a weed problem in the following years (Walsh *et al.* 2013). By knowing the weed seed retention character of every weed species, we can plan effective weed control practices against specific weeds by adopting HWSC. Harvest is a primary contributor to the transmission of weed seeds over a crop field; however, with HWSC, we can now skip this process and prevent weed seed spread. This strategy is used to target weed species that have a flaw, such as retaining a large part of their seed after maturity. HWSC is highly effective in controlling the spread of herbicide resistant weed seeds besides other weeds and has matured into an integrated technique for managing herbicide-resistant weeds (Somerville *et al.* 2018). The adoption of HWSC methods prevents the enrichment of soil weed seedbanks and depletes existing soil weed seedbanks in long run (Beam *et al.* 2021).

Soil weed seedbanks are considered a better indicator of the medium and long-term impact of weed management practice (Hawes *et al.* 2010). Reducing the amount of weed seed in the soil, is important for farmers to reduce weed pressure in the long run. The goal of an effective weed management strategy should limit the late-season weed seed production and enrichment of soil weed seedbanks (Walker and Oliver 2008). The soil seedbank is often slower to respond to the seasonal weed management measures due to constant weed seed intake from numerous seasons of escaping weeds (Schwartz *et al.* 2016). At harvest, the seeds present in the weed plants are either shattered or get pulled through the harvester and then returned to the soil seedbank. As a result, weed seeds are dispersed on the soil surface, spreading further and building the soil seedbank (Walsh and Powles 2007). To reduce the number of weed seeds replenishing the soil seedbank, HWSC strategies have been developed, which comprise both cultural and mechanical management practices.

HWSC allows the farmer to gather and kill all the non-shed weed seeds at harvest and this techniques is mostly used in Australia (Walsh *et al.* 2013, Walsh and Powles 2007, Walsh *et al.* 2017). Many HWSC methods were developed specifically to target the seed production of surviving weeds to limit seedbank contribution (Walsh *et al.* 2013, Walsh and Powles 2007, Walsh and Newman 2007). Pre-harvest, at-harvest, and post-harvest measures can also be employed to reduce weed seed shattering.

Narrow windrow burning, the Harrington Seed Destructor (HSD), bale direct systems, chaff carts, and other methods of chaff targeting during harvest are examples of HWSC. These techniques have been demonstrated to destroy 75 to 99% of weed seeds present at harvest (Walsh *et al.* 2013). The practice of some of these methods for several years may lead to considerable weed reductions in subsequent years, while others may only lead to moderate reductions. The different HWSC strategies (Shergill *et al.* 2020) are listed below.

Chaff carts

In this method, chaff are collected and transferred to a cart attached to a grain harvester that delivers the weed seeds into a bulk collection bin (Schwartz *et al.* 2016). The collected weed seeds are either burned along with chaff in the field or removed from the field. However, this method has the disadvantage of attaching the chaff cart behind the lengthy harvester, making manoeuvrability in narrow fields more difficult.

Narrow windrow burning

This technique is the most effective and relatively simple HWSC tactic. A low cost conveyor with a base of 16 to 18 inches wide installed on the back of the combine collects all of the chaff into a small row. These rows should be fired as soon as possible after formation. Firing the entire field does not kill the weed seeds as effectively as firing the chaff in the windrows (Schwartz *et al.* 2016). The abundance of chaff creates significantly more heat and increase the duration of the burning, resulting in less residue loss than traditional burning. Furthermore, this technique does not slow down the harvesting process. Narrow windrow burning is a relatively low-cost, non-chemical weed control approach.

Harrington seed destructor (HSD)

The HSD is a trailer mounted cage mill with chaff transfer systems developed by Ray Harrington, in 2005. An initial study employing the HSD has shown to destroy 95% of weed seed in wheat (Walsh *et al.* 2013). HSD and Redekop (The Redekop Seed Control Unit is an impact mill that incorporates a blade system in the centre of the mill with the goal to increase suction into the mill and airflow through it) work based on the mechanism of crushing weed seeds at the time of harvest utilizing mechanical energy resulting in the reduction of enrichment of soil weed seedbank. HSD was initially manufactured as a trailer unit to be dragged behind the harvester. However, currently, both HSD and Redekop are integrated within grain harvesters. These technologies are highly successful in Australia (Walsh *et al.* 2017) and gaining a foothold in the USA (Shergill *et al.* 2020). These technologies have not been introduced in India yet. Also, the efficacy of these devices needs to be tested in more bulky and complex corn or sorghum straw. Based on the potential, these technologies can greatly impact weed management. However, the present price of the HSD will most likely limit its immediate adoption in USA, Australia (Schwartz *et al.* 2016).

Bale direct systems

A combine harvester is directly attached to the large baler that makes bales from the chaff/straw exiting the combine harvester. The bales capture the weed seeds and can be used as feed for farm animals. The major limitation of this method includes limited demand for bales in the market and high risk in spreading the resistant weed seeds to other fields through the distribution of the bales.

Scope of HWSC in India

The adaption of zero-till seed cum fertilizer drill sowing of wheat in India is increasing over the years especially in rice-wheat cropping system of the Indo-Gangetic Plain (IGP). Till 2014 the area of no-till wheat sowing was nearly 5 Mha in IGP and 1.5 Mha alone in India (Kukal *et al.* 2014, Das *et al.* 2017). The central and state governments are promoting this technology in several states through various schemes by providing machineries/seed drills at a subsidized rate. Thus, the area under zero-till seed cum-fertilizer sowing is expected to boom in the coming years. In long run, this method of wheat cultivation favours weeds flora shift, herbicide use and weed resistant development (Singh *et al.* 2015). In wheat, the transition from conventional to zero till tillage has led to a change in weed flora. The use of herbicides to reduce grassy weeds and the lack of any control measures for broad-leaved weeds in wheat appear to be the main reasons for the shift in weed flora over time (Singh *et al.* 2002). In zero-tillage method, the number of perennial and broad-leaved weeds were found increased (Singh *et al.* 2015, Brar and Walia 2009). The dominant weed species in zero-till wheat sowing are *Cirsium arvense* and *Convolvulus arvensis* (Catizone *et al.* 1990). *Rumex dentatus* has developed resistance to metsulfuron-methyl (Chhokar *et al.* 2013), and the problem of *Rumex dentatus* and *Malva parviflora* in wheat is becoming more prevalent in no-till environments (Singh *et al.* 2015). The threat of these weeds may grow in the future as the area under no-till circumstances expands and resistance evolves. Certain weed species in the rice-wheat cropping system have already evolved resistance to a few herbicides in India (Kaur *et al.* 2022). The adaption of HWSC may avoid the problem of herbicide resistant development under zero-till wheat system. The recruitment of seeds from soil weed seedbank is avoided in zero-till system. The new seed addition to the soil seedbank is prevented by HWSC. Thus, the adoption of HWCS control in zero-till wheat will be a win-win solution.

Similarly, the area under direct-seeded rice (DSR) is increasing in India due to growing labour and irrigation water shortage (Rao *et al.* 2007, Vijayakumar *et al.* 2018, 2019). DSR save water and labour significantly compared to conventional transplanting (Pooja *et al.* 2021). Availability of broad spectrum and wider window herbicides are one of the major reasons for successful adoption of DSR in India (Jinger *et al.* 2016). The government is also promoting DSR since it reduces methane emission, lower production cost, save water and labour (Das *et al.* 2017).

In India, the use of herbicides to control weeds in croplands increasing. The rice-wheat system accounts for the consumption of 60% of the herbicide used in field crops in India. Weeds in the system, *viz. Echinochloa* spp, *Phalaris minor* developed resistance to various herbicides due to dependent on a single herbicide for a long time (Jinger *et al.* 2016). The first case of evolved resistance to bispyribac-sodium in *Cyperus difformis* L. was recently reported in India (Choudhary *et al.* 2021). India released herbicide (imazethapyr) tolerant basmati rice varieties (*Pusa Basmati 1979* and *Pusa Basmati 1985*) for commercial cultivation. The area under DSR is anticipated to increase with the release of herbicide tolerant rice varieties. Also the use of herbicides especially imazethapyr will increase in rice. Many researchers documented weed flora shift in rice cultivation due to change in cultivation method from transplanting to direct seeding (Rao *et al.* 2007, Saravanane *et al.* 2021). Higher use of herbicide without its rotation may favours herbicide resistant development and weed flora shift. The practice of HWSC in herbicide tolerant rice varieties will prevent the development of herbicide resistant weeds. Similarly, HWSC will prevent the weed flora shift and weed pressure in DSR in long run. Thus, the scope for HWSC is more in DSR, zero-till wheat, herbicide tolerant rice cultivation.

The concept of the critical period of weed control (CPWC) focuses on the early stage of the crop but not the later stage (Saravanane *et al.* 2020). It also does not focus on minimizing the weed pressure in the long run. The best weed control method should minimize weed pressure in long run. Unlike developed countries, the yield loss due to weeds in India is relatively higher (>20%) (Oerke *et al.* 1994, Bhan *et al.* 199, Gharde *et al.* 2018). In India weeds are controlled mostly through manual weeding and weed control measures are taken only during the early stage of the crop *i.e.* 20-40 days after sowing. In the later stage, the crop weed competition will be in favour of crops. However, due to the late removal of weed, the germinated weeds already might have removed a significant amount of growth resources (Ramesh *et al.* 2022). In addition, many weeds escape during manual weed control practices and grow along with crop plants. These escaped weeds are not generally controlled till the harvesting of the crop. This negligence causes an unnoticeable increase in soil weed seedbank and yield loss.

Manual harvesting of escaped weeds in rice and wheat before harvesting of the crop possess the problem of damage to crop plants since the crop plants covered the entire field and secondly human penetration may cause shattering loss of grain in crop plants. To overcome these problems, farmers can try to adopt escaped weed seed control at the time of flowering of crop. Mimicry weeds of rice and wheat crops escape weed control measures during the early stage of the crop (Rao and Moody 1988), while it is easy to distinguish in the cropland after the flowering stage (Barrett 1983). These weeds are the dominant weeds in the system for more than six decades. Escaped weed contribution to soil weed seedbank enrichment is largely responsible for this. These weeds also hold the majority of the seeds at the time of harvest.

Organic farming: Weed control in organic farming is a highly labour intensive and costly affair. The number of weed species, or diversity, often increases in organic farming since it does not use herbicide (Hyvönen *et al.* 2003). Moreover, the eradication of perennial weeds like *Cirsium arvense* is very difficult in organic farming (Graglia *et al.* 2006). With the increasing demand for organic products, it is anticipated that more area under organic cultivation will be brought in the coming years. However, the increasing labour shortage demands an alternate method of weed control in organic cultivation which demand less labour and reduce weed pressure in long run. The scope of HWSC in organic farming is very high since it reduces the weed pressure and labour requirement for weed control in long run. HWSC will not be effective unless weed control measures are taken to control off-season weeds. Since weeds are prolific breeders and seeders, farmers should control weeds around the year ideally before their seed set during the off-season to obtain desirable results from HWSC. However, at present the research on HWSC in different crops under organic cultivation is yet to be initiated, and it is need of the hour to promote such research.

The benefit of HWSC will be realized fully only when weeds are controlled during the off-season or round the year. In India, 2/3 of the agricultural land is rainfed, and mono-cropping is more prevalent in these areas (Venkateswarlu 2011). Least care (limited irrigation and manure application, no or one weeding) has been taken in these areas to cultivate the crop. Land fallow during the summer season is a common phenomenon. Thus, adopting HWSC control is not feasible in these areas. Alternatively, in irrigated areas where round the year agriculture is followed, the scope for HWSC is more. In IGP, due to assured irrigation water availability farmers are taking three crops in a year. Also, the use of herbicides for weed control is more here and it is increasing every year. Combining herbicide weed control with HWSC has shown effective results in reducing the weed seedbank and weed pressure in long run (Patterson *et al.* 2021). IGP region has the highest adaption of farm mechanization (Vijayakumar *et al.* 2021) and hence the benefits of HWSC adoption may be more in IGP, and research needs to be started in this area to assess its feasibility.

Required research

HWSC is not a "*magic bullet*" as it needs forethought and expertise, and it is not a standalone solution, but rather a component of weed management approaches (exp. herbicides, hygiene of farm implements, and bund/banks). It functions because of the interaction of numerous practices and possible synergies. The percentage of seeds retention for the predominant weed species is necessary to establish the possibility for using HWSC in each crop. After determining which species may be targeted at harvest, more research can be conducted to discover where the weed seeds end up. What is uncertain is what percentage of the grain, chaff, and straw that enters the combine harvester end up in each of the three fractions. Because of the differences in seed size compared to crop plants, the weed seeds should fall into the chaff portion. A few research finding has shown that HWSC prevents weed resistant development and weed flora shift. Thus, it is need of the hour to test this technology in India under various cropping systems to confirm it.

Integrated Weed Management (IWM) is the common method of weed management suggested in India. However, HWSC is presently not a part of IWM in India. HWSC strategies are adopted as a part of IWM in USA and Australia (Shergill *et al.* 2020). In India too, the HWSC strategies should be tested with existing IWM practices in various location and cropping system to find out the effectiveness and feasibility this noval technology under Indian condition.

Study on impact of HWSC on parasitic weeds are not available. Similarly, very few studies were conducted on mimicry weeds. Therefore, conducting HWSC trial in parasitic and mimicry weeds holds important. It is possible to establish which of the weeds species would most like, or need, to target with HWSC based on the results of reseach trial. The development of low cost tools and machineries for HWSC and its validation in India is yet to begin.

The study on negative impact of HWSC on environment like damage to native soil microbiome; emission of GHG, smoke, loss of carbon and nutrients due to biomass burning; soil compaction due to movement of heavy vehicles; higher cost of HWSC is also highly important (Patterson *et al.* 2021). The long term adaption of HWSC in agricultural fields may promote the extinction of weed species and cause biodiversity loss, which needs to be studied.

Conclusion

Harvesting weed seeds at the time of crop harvest is one of the finest preventive management tactics commonly known as HWSC, has potentiality for usage in Indian agro-ecosystems and hence research efforts need to be initiated and intensified. For the successful development and implementation of HWSC, it is critical to learn more about weed seed retention during crop harvest in different agro-ecological zones of India. HWSC is a cultural/ mechanical weed management strategy that should be used in conjunction with other nonchemical weed control methods.

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