Weeds Management Strategies in Conservation Agriculture

Chapter · September 2023

DOI: 10.30954/NDP-farming.2023.2

Masina Sairam
Centurion University of Technology and Management

Sagar Maitra
Centurion University of Technology and Management

Tadiboina Gopala Krishna
Centurion University of Technology and Management

Upasana Sahoo
Visva Bharati University

Weeds Management Strategies in Conservation Agriculture. *In:* Farming for the Future: Smart Agriculture Innovations edited by Santosh, D.T. *et al.* © Renu Publishers, New Delhi: 2023, (pp. 21-42).
ISBN: 978-93-92597-88-6, **DOI:** 10.30954/NDP-farming.2023.2

Chapter

2

Weeds Management Strategies in Conservation Agriculture

Masina Sairam[1], Tadiboina Gopala Krishna[1], Upasana Sahoo[1]*, Sarthak Pattanayak[2], Lalichetti Sagar[1] and Sagar Maitra[1]

[1]*M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha*

[2]*Krishi Vigyan Kendra, Puri, Orissa University of Agriculture and Technology, Odisha*

**Corresponding author email: upasana.sahoo@cutm.ac.in*

ABSTRACT

The significance of sustainable crop production for both global food security and environmental preservation cannot be overstated. Conservation agriculture (CA) has garnered widespread recognition for its sustainable methods, particularly its emphasis on permanent soil cover, minimal soil disturbance, and integrated weed management. However, weed control still poses a challenge for the widespread adoption of CA, as the weed ecology and management practices are vastly different from those in conventional agriculture. This is because of the reduced tillage of the soil and the diverse flora that thrives in CA, which affects the effectiveness of traditional herbicides and mechanical weed control methods. This review focuses on the changing dynamics of weeds in CA, emphasizing the most efficient and sustainable weed management strategies, such as modified tillage operations, enhanced cultural practices, bioherbicides, chemical herbicides, allelopathy, and crop nutrition. No single strategy can provide complete control, but the effective combination of these tools can provide results. It also examines the prevalence of small-seeded and perennial weeds in CA, the impact of herbicide resistance and herbicide-tolerant crops, and the role of allelopathy and crop nutrition as modern weed management tools. Additionally, the review delves into the weed responses to fertilizer management options. For successful implementation of CA, integrated weed management practices must be utilized, tailored to the cropping patterns and climatic conditions. In the future, efforts should be directed towards optimizing and integrating these weed management practices for the best results.

Keywords: Bioherbicides, allelopathy, sustainable production

2.1 Introduction

Crop production plays a vital role in ensuring global food security and is a fundamental component of agriculture. The present-day agriculture is in a tremendous pressure because of declining productivity or yield plateauing of major food crops (Gaikwad *et al*. 2022), climate change impacts (Sagar *et al*. 2022, 2023), deterioration of the quality of natural resources such as soil and water, pollution of natural resources (Sairam *et al*. 2023a) and shortage of land and water. Under such circumstances, there is an urgent need for adoption of proper improved crop production technologies inclusive of cropping system which are ecologically friendly and sustainable (Sarkar *et al*. 2000; Billah *et al*. 2021; Nandi *et al*. 2022; Panda *et al*. 2022a; Maitra *et al*. 2022, 2023; Sahoo *et al*. 2023a). The foundation of successful crop production lies in effective soil management, which stands as a core principle in agronomy (Sahoo *et al*. 2022; 2023a). In contemporary agriculture, conventional tillage is closely linked to this process (Bajwa, 2014). Conventional tillage refers to a method involving initial deep primary tilling followed by subsequent secondary tillage, as defined by Holland (2004). The practice of tillage dates back thousands of years, originating during the transition from nomadic lifestyles to settled agricultural communities near rivers such as the Nile, Euphrates, Yangtze, and Indus (Hillel, 1991). The concept of tillage was notably prevalent in Mesopotamia around 3000 B.C., as evidenced by research of Hillel (1998) and Lal (2001). Tillage encompasses the deliberate manipulation of soil to enhance its structure, leading to the creation of a finely pulverized and optimal seedbed prior to sowing (Fanigliulo *et al*. 2021; Wang *et al*. 2023). Tillage facilitates the proper emergence of seeds by ensuring optimal placement, thereby providing adequate access to water, light, and nutrients (Liu *et al*. 2021). Moreover, it guarantees nutrient availability and promotes proper aeration within the soil layer (Sahoo *et al*. 2022). Incorporating various soil amendments into the field is another aspect of tillage (Zhou *et al*. 2022; Shaukat *et al*. 2023). Furthermore, this practice contributes to the control of soil-borne diseases and pests (Panth *et al*. 2020; Palojärvi *et al*. 2020). In the realm of conventional agriculture, tillage holds indispensable significance. It is utilized for essential tasks such as soil preparation, integrating crop residues, planting, and incorporating organic manures and herbicides (Shahane and Shivay, 2021).

In contrast to the favourable aspects, conventional tillage is exerting detrimental effects on natural landscapes and soil fertility. The widespread use of heavy tillage machinery within the conventional system often occurs without proper consideration of soil capabilities and fertility status. Escalating energy source costs, labour expenses, and input expenditures render this system financially unviable due to the elevated production expenses.

Furthermore, the environmental safety and global preservation concerns associated with this system make it problematic. However, an alternative solution called conservation agriculture (CA) gained traction, proving suitable for today's limited natural resources and changing climate (Zahan *et al*. 2021; Manoj *et al*. 2021; Islam *et al*. 2023; Bhattacharya *et al*. 2023). As defined by FAO (2001), CA involves minimal soil disturbance (such as no-till practices) and the maintenance of permanent soil cover (mulching), often combined with crop rotations (Hossain *et al*. 2021a; Tufa *et al*. 2023). This relatively recent agricultural management system is gaining popularity across various regions globally, particularly semi-arid, tropical and subtropical zones (Hossain *et al*. 2021b; Sairam *et al*. 2023b). CA emerges as a pragmatic solution to agricultural challenges faced by small-scale farming communities, especially in tropical regions (Francaviglia *et al*. 2023; Islam *et al*. 2023). The foundational principles of CA, which include minimal soil disturbance and permanent soil cover, are achieved through practices like no-tillage, zero-tillage, minimum tillage/ ridge tillage, reduced tillage, direct seeding, and mulch tillage (Busari *et al*. 2015). Collectively, these practices are referred to as conservation tillage and are chosen based on the specific farming system, crop rotation, and prevailing climatic conditions (Ngoma *et al*. 2016; Teravest *et al*. 2019). Zero tillage, for instance, involves the least amount of soil disturbance during a single tillage operation to prevent soil degradation (Choudhary *et al*. 2021; Hussain *et al*. 2021). Although it mainly involves the planting process, it also includes minimal soil manipulation (Astatke *et al*. 2003). The precise definition of CA is challenging due to the diverse climatic conditions and varied management practices worldwide. Its specifics vary based on geographical area and climate (Lyon *et al*. 2004).

Weed management holds a crucial role within the realm of CA and thus requires dedicated attention (Derrouch *et al*. 2020). Weeds exhibit varying behaviours within different environments by competing with crops for available resources (Horvath *et al*. 2023). Additionally, weeds can serve as habitats for insects and disease-causing pests, thereby diminishing crop quality and elevating the risk of crop damage by pests (Kubiak *et al*. 2022). The practice of tillage creates diverse natural and manipulated habitats for weeds. Tillage has proven to be a significant management option for weeds and it has retained its efficacy (Cordeau *et al*. 2020). In the context of CA, specific environmental conditions influence weed populations. Addressing weed infestations within CA remains a pivotal concern and a principal reason behind farmers' cautious approach toward adopting this system. CA predominantly emphasizes minimal tillage supplemented by targeted herbicide applications to achieve optimal weed control (Alhammad *et al*. 2023). The management of weeds in the CA involves a multifaceted approach encompassing diverse tillage methods, agronomic strategies, engineering techniques, and contemporary crop establishment technologies (Lafond *et al*. 2009). Effective weed control within CA necessitates an integrated approach, thoughtfully tailored and optimized to suit each unique context. Understanding the ecological, biological, and social implications associated with weeds within CA system is imperative. Furthermore, a systematic approach is required to adopt diverse management options according to the ecological attributes of a specific agroecosystem. This approach aids in identifying innovative strategies for site-specific weed management and sustainable control. In the following sections, suitable options for weed management especially integrated weeds management (IWM) strategies have been narrated.

2.2 Integrated Weed Management Strategies for CA

The reduction in crop productivity caused by weed presence warrants the necessity to effectively manage weed infestations. Implementing an appropriate strategy for effective weed management not only enhances productivity but also fosters an environment free from pollution. Despite the advantages of CA, its global adoption has remained limited to approximately 9% of total cultivated land (Friedrich *et al*. 2012). Global adoption of CA is hindered by challenges in weed management (Cordeau, 2022). Given the potential benefits of Integrated Weed Management (IWM), it is imperative to reevaluate its integration within the CA framework. Regardless of the farming system, IWM maintains a consistent approach involving diverse tactics, with economic and environmental considerations forming its core. Nevertheless, the application of IWM differs between CA and conventional agriculture due to the constraints posed by limited weed control options. Environmental safety is the central goal of both IWM and CA. Weed management strategies in CA are confined to methods aligned with the principles of CA (Lee and Thierfelder, 2017). For instance, conventional tillage is unsuitable for weed management in CA (Nichols *et al*. 2015; Fonteyne *et al*. 2022). Similarly, the burning of crop residues is incompatible as they are to be incorporated in CA as per its principle (Pramanick *et al*. 2022).

The limitations on weed control in CA lead to an increased reliance on herbicides, which in turn contributes to the development of weed resistance (Singh *et al*. 2015). The persistent nature of certain herbicides poses challenges for the crop rotation aspect of CA, especially when the herbicide lacks selectivity for the subsequent crop in the crop rotation (Dash *et al*. 2020). This situation creates a compatibility issue among weed control strategies, given that crop rotation is integral to the weed management tactics within

CA (Nichols *et al*. 2015). The strategic implementation of crop rotation disrupts weed life cycles and enhances crop-specific weed control, leading to reduced weed persistence and associated difficulties (Fonteyne *et al*. 2022; Panda *et al*. 2022b). The practice of retaining crop residues in CA establishes an environmental barrier that hampers weed seed germination by limiting sunlight penetration (Dash *et al*. 2020). However, the efficacy of pre-emergence herbicides applied to the soil surface is diminished due to the presence of crop residues, which interferes with their effectiveness. Moreover, crop residues can serve as a potential source of weed seeds. Nevertheless, the preventive weed management and cultural management aspects of IWM can effectively address this issue. IWM revolves around the management of weeds through factors like thresholds and critical periods (Harker and O'Donovan, 2013). IWM operates within the framework of integrated pest management (IPM), incorporating diverse control strategies by leveraging knowledge about weeds biology for effective weed management (Riemens *et al*. 2022). Unlike aiming for complete eradication, IWM concentrates on diminishing the competitive advantage of weeds to a level below the economic thresholds and this highlights the capacity of IWM to ensure a balance between effective weed management and environmental preservation. IWM does not prioritize one method over another, but rather encourages the balanced and judicious use of all available weed control techniques (Harker and O'Donovan, 2013). IWM serves as a valuable complement to counter the declining effectiveness of single control methods. Relying solely on a successful pest management approach without integrating or alternating with other methods eventually leads to diminished control efficiency. Similarly, an overreliance on herbicides for weed control results in issues like herbicide resistance, shifts in weed flora, and environmental pollution (Chhokar *et al*. 2014). IWM proves effective in cases where single weed management methods fall short. Parasitic weeds, for instance, can be effectively managed through a combination of cultural weed control (crop rotation) and biological weed control (using trap crops) (Singh *et al*. 2015). Preventive weed control prevents the establishment of weeds in the subsequent growing season (Bàrber, 2003), particularly when weeds or their propagative parts are already present and need to be inhibited from progressing to the next season. In contrast, preventive weed management methods prevent the introduction of weeds into a new environment (Monteiro and Santos, 2022). Considering these distinctions, the following strategies of weed management could prove beneficial within a CA cropping methodology.

2.3 Preventive Weed Management Method

Preventive weed management involves strategies aimed at stopping the introduction and spread of weeds (Sims *et al*. 2018). These measures are implemented from the beginning of crop cultivation to mitigate potential weed-related issues. Planting high-quality, weed-free seeds helps prevent the initial introduction of weed seeds into the field. Clearing these areas minimizes weed habitats and prevents the migration of weed seeds into the cultivated area. Regularly cleaning and sanitizing tools and equipment reduce the chances of weed seed transfer. Focusing on controlling weeds within smaller sections of the field or even individual plants (localized weed control), such as through hand-rouging or removing weeds by hand, helps to prevent the spread of weeds across the entire field. However, preventive methods are important because they check weed establishment which is generally easier and more cost-effective than trying to manage established weed populations.

2.4 Physical Weed Management

Physical weed control includes the use of force, heat or some other physical forms of energy to break, cut off, destroy, burn or severely injure weeds. Manual weeding, mechanical weeding, and thermal weeding are examples of physical weed control. Manual weeding involves hand weeding and the use of simple hand tools. Mechanical weed control involves the cutting, uprooting, and burying of weeds (Riemens, 2016) using machinery (Ehi-Eromosele *et al*. 2013). Mechanical weed control or hand weeding is not cost-effective which increases cost of cultivation.

2.5 Cultural Weed Management

Cultural weed management pertains to the adjustment of agricultural methods to promote the thriving of crops while inhibiting weed growth. It employs the following practices for reduction of weeds population.

2.5.1 *Proper Land Levelling*

The crop field should always be leveled with a gentle slope. Proper land levelling ensures even distribution of soil moisture that facilitates a uniform stand establishment which ultimately reduces the weed growth due to the uniform crop growth. Land leveling increases rice yield to a large extend because it improves weed control (IRRI, 2023). Improved water coverage from better land levelling reduces weeds by up to 40%. This reduction in weeds results in less time for crop weeding and saves weeding costs in rice. Jat *et al*. (2009) recorded a reduced weed population in wheat under precisely levelled fields compared to the traditional leveled field.

2.5.2 *Optimum Plant Stand and Plant Geometry*

It is a well-established fact that using the appropriate seed rate can significantly reduce weed infestations. Chauhan (2012) emphasized that in Zero Tillage-Direct Seeded Rice (ZT-DSR) systems, weed competition with crops can be minimized by adopting an optimal seed rate and suitable crop geometry. The recommended seed rate for Direct Seeded Rice (DSR) in the Indo-Gangetic Plains (IGP) ranges from 20 to 25 kg/ha (Kumar and Ladha, 2011; Gill *et al*. 2013). However, Chauhan *et al*. (2011) mentioned that to attain maximum yields while competing with weeds, inbred varieties require a seeding rate of 95 to 125 kg/ha, and hybrids should be sown at rates of 83 to 92 kg/ha. Increasing the seed rate enhances the crop's competitiveness against weeds, as suggested by Bhuller *et al*. (2016). Crop cultivars possessing traits such as fast germination, quick growth, high biomass, and large leaf area have a competitive advantage over weeds. Sowing such cultivars has been shown to suppress weeds in various crops (Sardana *et al*. 2017). Moreover, narrowing the spacing between rows is an effective method to suppress weed growth as observed in wheat (Mahajan and Brar, 2002). Bhullar and Walia (2004) reported that adopting narrow row spacing (15 cm), a higher seed rate (150 kg/ha), and reducing the recommended herbicide dose by 25% can significantly reduce Phalaris minor weed density.

2.5.3 *Crop Establishment*

Crop establishment methods play a crucial role in weed management (Pattanayak *et al*. 2023), specifically, CA method tends to experience higher weed intensification due to its no-tillage practices (Raj *et al*. 2022). Kumar *et al*. (2013) conducted research indicating that in the absence of effective weed control measures, weed-induced yield losses reached 90% in Zero Tillage-Direct Seeded Rice (ZT-DSR), whereas these losses ranged from 35 to 42% in Zero Tillage-Transplanted Rice (ZT-TPR). ZT-DSR is often favoured for its labour and water-saving attributes. In Zero Tillage systems, rice can be established through direct seeding (ZT DSR) or transplanting (ZT-TPR), either manually or mechanically. Regardless of the method chosen, effective weed management is essential to prevent yield reduction in CA.

2.5.4 *Stale Seed Bed*

Weed seeds are typically found in the upper layer of the soil. Any pre-sowing irrigation or rainfall can create favourable conditions for weed seed germination. These sudden outbreaks of weeds can be effectively eliminated through the application of a non-selective herbicide. Recent research demonstrated that implementing a stale seedbed technique significantly reduces weed pressure in Zero Tillage (ZT) crops cultivation under incorporated crop residue (Shekhawat *et al*. 2020; Alhammad *et al*. 2023). To further enhance weed management strategies in the transition from wheat to rice cultivation, it is recommended to incorporate a fallow period of 45-60 days between wheat harvest and rice sowing. This period offers an excellent opportunity to implement the stale seedbed technique, ensuring that the crop develops in a weed-free environment and gains a competitive advantage over late-emerging weed seedlings. In areas where weedy rice poses a significant challenge in Zero Tillage-Direct Seeded Rice (ZT-DSR) systems, it is recommended to adopt the stale seedbed technique as an integral part of an IWM strategy. This approach has proven effective in many regions affected by weedy rice infestations, providing a sustainable solution for weed control in ZT-DSR (Singh and Singh, 2012; Benvenuti *et al*. 2021).

2.5.5 *Reduced Tillage and Residue Management with Early Sowing*

In Conservation Agriculture (CA), the timing of sowing for various crops undergoes adjustments. In the northwestern Indo-Gangetic Plains (IGP), when wheat is sown approximately two weeks earlier than in the conventional system, it encounters a challenging initial phase in dealing with the presence of *Phalaris minor* weed (Poonia *et al*. 2022). Franke *et al*. (2007) observed that when wheat is sown on the same date, the density of all three flushes of *Phalaris minor* is lower in Zero Tillage (ZT) compared to Conventional Tillage (CT). Additionally, it has been noted that employing zero tillage in conjunction with surface residue retention during early sowing conditions leads to the effective suppression of *Phalaris minor* and other wheat-related weeds. Recent advancements in agricultural technologies have facilitated the cultivation of wheat amidst heavy mulch. The use of the 'Turbo Happy Seeder' allows for the sowing of wheat even in heavy residue mulch, reaching levels of 8 to 10 tons per hectare, without adverse effects on crop establishment (Kumar and Ladha, 2011). This heavy mulch approach holds the potential to significantly reduce weed establishment within crops. Tillage practices have been observed to disrupt the rhizome propagation of perennial weeds. Additionally, retaining crop residues has shown the ability to reduce the soil weed bank (in the 0 to 20 cm layer) and the aboveground biomass of dicotyledonous weeds, ultimately benefiting wheat yields (Zhang and Wu, 2021). A comprehensive weed control strategy has been proposed for wheat-maize double cropping systems, involving the timely removal of surface weeds during the early stages of wheat growth through tillage and straw retention management (Maurya *et* *al*. 2020). The judicious use of various weeding methods not only mitigates weed-related damage but also augments crop yields.

2.5.6 *Crop Rotation*

Adoption of monocropping or consistently following the same crop in recurrent succession can create conditions where specific weed species become dominant, leading to increased difficulty in weed management over time. To address this issue, the introduction of a new crop into the rotation can disrupt the prevalence of common weeds and simplify the process of managing these troublesome weeds species. Crop rotation can affect the weed community and soil seed bank, thus reducing the density of weeds and the number of weed seeds in the soil seed bank (Cheng *et al*. 2013). Diversifying and intensifying the crop rotation system, such as by incorporating short-duration legumes followed by late-sown wheat, offers a promising strategy to enhance weed control without relying on increased herbicide usage (Chhokar *et al*. 2008). The incorporation of diversified crop rotations can prove beneficial in weed management, as it broadens the range of selection methods applied to weeds by altering the patterns of weed management (Bhuller *et al*. 2016). Saulic *et al*. (2022) noted that compared with continuous maize cropping, the introduction of winter wheat could effectively reduce weed density.

2.5.7 *Cover Crops and Brown Manuring*

Crops with rapid growth patterns quickly develop a canopy that covers the soil surface, reducing sunlight penetration and creating unfavourable conditions for weed seeds to germinate and grow during their initial stages. While these fast-growing crops have a relatively short lifespan, their effectiveness in weed control is significant. One common practice to suppress weeds, particularly in rice fields, is brown manuring. This method not only enriches the soil's nutrient content but also effectively inhibits weed growth. In the context of ZT rice production in the Indo-Gangetic Plains (IGP), a common approach is to sow *Sesbania sp*. alongside rice at a seeding rate of 25 kg per hectare. This strategy has demonstrated its potential in weed suppression. *Sesbania sp*. is allowed to grow alongside the rice to hinder weed growth and is subsequently terminated using 2,4-D ester herbicide between 25 to 30 days after sowing (Bhuller *et al*. 2016). The practice of brown manuring is adopted in maize also (Maitra and Zaman, 2017). The weeds account for 40% yield loss and even more than 70% yield loss may be cause under uncontrolled weed growth condition in maize. Ramachandran *et al*. (2012) recorded that brown manuring can reduce 50% weeds population in maize. Research by Singh *et al*. (2007) has documented a substantial reduction in the density of broadleaf weeds, ranging from 76% to 83% lower, and a 20% to 33% decrease in grassy weed density when cultivating a rice-*Sesbania* sp. crop combination compared to cultivating rice alone. This highlights the effectiveness of such cropping practices in weed management.

2.5.8 *Competitive Crop Cultivar*

Crop cultivars exhibit distinct characteristics, and the choice of cultivar can significantly influence the balance between crop growth and weed competition. Fast-growing cultivars, particularly those with vigorous spreading tendencies, can quickly cover the ground during the vegetative stage, effectively suppressing weed growth (Place *et al*. 2011; Caldas *et al*. 2023). It is generally noted that early maturing varieties and hybrids, due to their rapid early growth and ground-covering abilities, are more efficient at outcompeting weeds compared to medium to long-duration cultivars (Aharon *et al*. 2021). Crops that rapidly shade the soil surface with their canopy show a more pronounced competitive ability against weeds (Holt, 1995; Milan *et al*. 2020).

2.5.9 Soil Moisture Condition and Water Management

Adequate soil moisture levels are conducive to the establishment of weeds (Matloob *et al*. 2020; Singh *et al*. 2022). In rice-wheat cropping system, high soil moisture tends to favour the growth of moisture-loving weeds like *P. minor*, *Rumex dentatus*, and *Polypogon monspeliensis* (Chaudhary *et al*. 2021). Wheat seeds, on the other hand, can germinate even under conditions of lower soil moisture (Wuest and Lutcher, 2012). Therefore, sowing crops under drier conditions can facilitate a reduction in weed populations and lessen crop-weed competition (Shekhawat *et al*. 2020). Effective water management plays a crucial role in weed control. In conventional rice cultivation, maintaining submergence from planting helps suppress weeds. However, in ZT-DSR, flooding can only be applied after the crop has established itself, giving weeds ample time to germinate and making weed management more challenging (Chauhan, 2012). It is highly recommended to develop rice cultivars that can germinate under anaerobic conditions, as this would simplify weed management through flooding in DSR systems (Chauhan, 2012).

2.6 Chemical Weed Control Method

Chemical weed control encompasses the application of synthetic herbicides to either eliminate or hinder the growth of weeds. Herbicides can be applied either as foliar sprays or directly to the soil. Based on the timing of their application, herbicides are categorized into pre-emergence and post-emergence types.

Additionally, depending on how they move within plants, herbicides can be classified as either systemic or non-systemic (contact) herbicides. The selectivity of herbicides is a critical factor, as it determines their compatibility with specific crops and the types of weeds they effectively target. The utilization of herbicides represents an efficient approach to weed management which is cost effective. However, this practice is not without its challenges, including concerns related to shifts in weed populations, the development of herbicide-resistant weeds, and potential environmental contamination. Moreover, the widespread adoption of chemical weed control faces obstacles such as herbicide availability, the cost of herbicides, the risk of herbicide adulteration, and farmers' difficulties in comprehending label instructions. However, in CA, chemical herbicides are applied and some of the key findings from earlier research has been documented as follows (Table 2.1).

Table 2.1: Weed management practices using herbicides in conservation agriculture

Sl. No	Description	References
1	Population of *Echinochloa colonum*, *Polygonum alatum* and *Bidens pilosa* was 35%, 61% and 64% lower in the herbicide treatment atrazine followed by 2,4- D when compared to hand weeding in Crop under conservation tillage conditions.	Kumar *et al*. 2023
2	Sequential application of glyphosate at 1 kg ai ha^{-1} + pendimethalin at 1 kg ai ha^{-1} as PE fb PoE application of imazethapyr at 100 g ai ha^{-1} at 30 DAS showed the 67% reduction in weed density, 75% increase in grain yield and 300% higher nutrient uptake than the hand weeding.	Vishwakarma *et al*. 2023
3	Pendimethalin 1.5 kg ha^{-1} at pre-emergence fb bispyribac-Na 25 g ha^{-1} at post-emergence and hand weeding at 35 DAS produced better results in weed control, increased the rice yield by 123-130% and net returns by 327- 806%.	Baghel *et al*. 2020
4	Application of pendimethalin as PE and imazethapyr as PoE under zero tillage conditions proved to be the best treatment among the others for weed management in Soybean leading to higher grain yield and net returns. But pendimethalin + hand weeding recorded 6.3% increase in grain yield over pendimethalin + imazethapyr.	Sepat *et al*. 2017
5	Application of Atrazine with hand weeding gave and Atrazine along with glyphosate at the time of sowing showed 41% and 76% lower weed density than hand weeding respectively in maize under zero tillage condition and 2.5t/ha maize crop residue.	Muoni *et al*. 2013

PE= pre-emergence; PoE= post-emergence; DAS= days after sowing; fb= followed by

2.7 Biological Weed Control Method

Biological weed control entails the utilization of living organisms to manage weeds. This approach encompasses the deployment of various organisms and biologically derived products (Ehi-Eromosele *et al*. 2013). Bio-herbicides are a prominent component of biological weed control, consisting of phytopathogenic microorganisms or microbial phytotoxins employed in a manner similar to conventional herbicides (Boyetchko and Peng, 2004). Additionally, biological weed control methods include allelopathy, animal grazing, the cultivation of crop varieties resistant or tolerant to weeds, and the utilization of phytophagous insects (Table 2.2 and 2.3).

Table 2.2: Biological weed management practices using biocontrol agents

Sl. No.	Biocontrol agent	Weed	Type of insect	Reference
1	*Larinus planus*	*Cirsium pitheri*	Weevil	Havens *et al*. 2012
2	*Cactoblastis cactorus*	*Opuntia sp.*	Moth	Mann, 1970
3	*Dactylopium tomentosus*	*Opuntia dileni*	Scale insects	Narayan, 1954
4	*Zygogramma sp.*	*Parthenium hysterophorus*	Beetles	Muniyappa, 1980
5	*Rhizaspidiotus donais*	*Arundo donax*	Scale insects	Hardion *et al*. 2014
6	*Hydrellia pakistanae*	*Hydrilla verticillate*	Leaf mining fly	Baloch *et al*. 1980

Table 2.3: Use of bioherbicides in weed management

Sl. No	Bioherbicide (Commercial name)	Weed	Type	References
1	*Colletotrichum gloeosporioides* (Collego)	*Aeschynomene virginica*	Fungus	Daniel *et al*. 1973
2	*Phytopthora palmivora* (Devine)	*Morrenia odorata*	Oomycetes	Brunett *et al*. 1973
3	*Puccinia canaliculate* (Dr. Biosedge)	*Cyperus esculentus*	Fungus	Greaves and MacQueen, 1992
4	*Colletotrichum gloeosporioides* (BioMal)	*Malva pusilla*	Fungus	Mortensen, 1988
5	*Bipolaris sorghicola* (Bipolaris)	*Sorghum halepense*	Fungus	Acciaresi and Monaco, 1999
6	*Cantharellus cibarius*	*Eichhornia crassipes*	Fungus	Hsiao *et al*. 2007
7	*Alternaria tenuis*	*Galium aparine*	Fungus	Meiss *et al*. 2008

8	*Colletotrichum gloesporoides* (Luboa- 2)	*Cuscuta sp.*	Fungus	Wang, 1989
9	*Xanthomonas campestris* (Camperico)	*Cynodon dactylon, Poa annua*	Bacteria	Imaizumi *et al.* 1997
10	*Puccinia thlaspeos* (Woad Warrior)	*Isatis tinctoria*	Fungus	Lovic *et al.* 1988
11	*Alternaria destruens* (Smolder)	*Cuscuta sp.*	Fungus	Bewick *et al.* 2000

2.8 Conclusion

Modern agriculture relies on sustainable food production practices, and Conservation Agriculture (CA) stands out as the most effective system for achieving both sustainability and environmental safety simultaneously. While the adoption of CA is on the rise, it comes with its share of challenges, with weed control being a prominent issue. The limited weed management options in CA can lead to increased dependence on herbicides, which in turn may result in water contamination, the development of weed resistance, shifts in weed flora, and herbicide carryover. To address these challenges, various strategies have been developed for weed management. However, the evolving characteristics of CA systems make the situation more complex. It is essential to integrate a combination of cultural, mechanical, biological, ecological, and chemical weed control methods judiciously within the framework of CA. This approach takes into account the ecological, geographic, climatic, and agronomic aspects of a specific cropping system. The practice of Integrated Weed Management (IWM) plays a crucial role in reducing the overreliance on herbicides. Therefore, incorporating IWM into CA not only contributes to the sustainability of this agricultural system but also strengthens its focus on environmental protection.

References

Acciaresi, H. and Mónaco, C.1999. First report of *Bipolaris sorghicola* on Johnsongrass in Argentina. *Plant Disease.*, **83**(10): 965-965.

Aharon, S., Fadida-Myers, A., Nashef, K., Ben-David, R., Lati, R.N. and Peleg, Z. 2021. Genetic improvement of wheat early vigor promotes weed-competitiveness under Mediterranean climate. *Plant Sci.*, **303**: 110785.

Alhammad, B.A., Roy, D.K., Ranjan, S., Padhan, S.R., Sow, S., Nath, D., Seleiman, M.F. and Gitari, H. 2023. Conservation Tillage and Weed Management Influencing Weed Dynamics, Crop Performance, Soil Properties, and Profitability in a Rice–Wheat–Greengram System in the Eastern Indo-Gangetic Plain. *Agronomy*, **13**(7): 1953.

Astatke, A., Jabbar, M. and Douglas-Tanner, D. 2003. Participatory conservation tillage research: an experience with minimum tillage on an Ethiopian highland Vertisol. *Agric. Ecosys. Environ.*, **95**(2-3): 401-415.

Baghel, J.K., Das, T.K., Mukherjee, P.I., Nath, C.P., Bhattacharyya, R., Ghosh, S. and Raj, R. 2020. Impacts of conservation agriculture and herbicides on weeds, nematodes, herbicide residue and productivity in direct-seeded rice. *Soil & Tillage Res.*, **201**(2): 104634.

Bajwa, A.A. 2014. Sustainable weed management in conservation agriculture. *Crop Protect.*, **65**: 105-113.

Baloch, G.M., Sana-Ullah. and Ghani, M.A., 1980. Some promising insects for the biological control of Hydrilla verticillata in Pakistan. Trop. *Pest Manage.*, **26**: 194–200.

Bàrber, P. 2003. Preventive and cultural methods for weed management. In R. Labrada (Ed.), Weed management for developing countries. Rome: FAO. Retrieved from: http://www.fao.org/docrep/006/Y5031E/y5 031e0e.html

Benvenuti, S., Selvi, M., Mercati, S., Cardinali, G., Mercati, V. and Mazzoncini, M. 2021. Stale seedbed preparation for sustainable weed seed bank management in organic cropping systems, *Scientia Horticulturae*, **289**: 110453.

Bhattacharya, U., Naskar, M.K., Venugopalan, V.K., Sarkar, S., Bandopadhyay, P., Maitra, S., Gaber, A., Alsuhaibani, A.M. and Hossain, A. 2023. Implications of minimum tillage and integrated nutrient management on yield and soil health of rice-lentil cropping system – being a resource conservation technology. *Front. Sustain. Food System*, **7**: 1225986.

Bhullar, M.S. and Walia, U.S. 2004 Effect of seed rate and row spacing on the efficacy of clodinafop for combating isoproturon resistant Phalaris minor Retz. in wheat. *Plant Prot. Q.,* **19**(4): 143-46.

Bhullar, M.S., Pandey, M., Kumar, S. and Gill, G. 2016 Weed management in conservation agriculture in India. *Ind. J. Weed Sci.*, **48** (1): 1-12.

Billah, M., Aktar, S., Brestic, M., Zivcak, M., Khaldun, A.B.M., Uddin, M.S., Bagum, S.A., Yang, X., Skalicky, M., Mehari, T.G., Maitra, S. and Hossain, A. 2021. Progressive genomic approaches to explore drought-and salt-induced oxidative stress responses in plants under changing climate. *Plants*, **10**(9): 1910.

Boyetchko, S.M. and Peng, G., 2004. Challenges and strategies for development of mycoherbicides. *Mycol. Series.*, **21**: 111-122.

Burnett, H.C., Tucker, D.P.H., Patterson, M.E. and Ridings W.H. 1973. Biological control of milkweed vine with a race of *Phytophthora citrophthora*. *Proc. Florida State Horti. Soc.,* **86**: 111–115.

Busari, M.A., Kukal, S.S., Kaur, A., Bhatt, R. and Dulazi, A.A. 2015. Conservation tillage impacts on soil, crop and the environment, *Int. Soil Water Conserv. Res.,* **3**(2): 119-129.

Caldas, J.V.d.S., Silva. A.G.d., Braz, G.B.P., Procópio S.d.O., Teixeira, I.R., Souza, M.d.F. and Reginaldo, L.T.R.T. 2023. Weed Competition on Soybean Varieties from Different Relative Maturity Groups. *Agriculture*, **13**(3): 725.

Chaudhary, A., Chhokar, R.S., Dhanda, S., Kaushik, P., Kaur, S., Poonia, T.M., Khedwal, R.S., Kumar, S. and Punia, S.S. 2021. Herbicide Resistance to Metsulfuron-Methyl in *Rumex dentatus* L. in North-West India and Its Management Perspectives for Sustainable Wheat Production. *Sustainability*, **13**(12): 6947.

Chauhan, B.S, Singh, V.P, Kumar, A. and Johnson, D.E. 2011. Relations of rice seeding rates to crop and weed growth in aerobic rice. *Field Crops Res.*, **121**: 105-115.

Chauhan, B.S. 2012. Weed ecology and weed management strategies for dry seeded rice in Asia. *Weed Tech*., **26**: 1-13.

Cheng, C., Pan, J. and Wan, K. 2013. Research advances in the effects of rotation on cropland weeds. *Chin. Agric. Sci. Bull*., **29**: 1–9.

Chhokar, R.S., Ram, H. and Kumar, V. 2014. Integrated Weed Management. *In:* R.S. Shukla, P.C. Mishra, R. Chatrath, R.K. Gupta, S.S. Tomar, and I. Sharma, (Eds.), Recent Trends on Production Strategies of Wheat in India. Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur and ICAR-Indian Institute of Wheat and Barley Research, pp. 155-171.

Chhokar, R.S., Sharma, R.K., Singh, R.K. and Gill, S.C. 2008. Herbicide resistance in little seed canary grass (*Phalaris minor*) and its management, pp. 106. *In:* Proceedings of 14th Australian Agronomy Conference Adelaide, South Australia.

Choudhary, S., Pramanick, B., Maitra, S. and Kumar, B. 2021. Tillage practices for enhancing crop productivity under dryland conditions. *Just Agric.*, **1**(5): 206 - 212

Cordeau, S. 2022. Conservation Agriculture and Agroecological Weed Management. *Agronomy*., **12**(4): 867.

Cordeau, S., Baudron, A. and Adeux, G. 2020. Is Tillage a Suitable Option for Weed Management in Conservation Agriculture? *Agronomy*, **10**(11): 1746.

Daniel, J.T., Templeton, G.E., Smith R.J. and Fox, W.T. 1973. Biological control of northern jointvetch in rice with an endemic fungal disease. *Weed Sci.*, **21**: 303–307.

Dash, S., Chowdhury, M.R., Sar, K., Jena, J. and Gulati, J.M.L. 2020. Integrated Weed Management in Conservation Agriculture-A Review. *Int. J. Curr. Microbiol. App. Sci.*, **9**(08): 411-424.

Derrouch, D., Chauvel, B., Felten, E. and Dessaint, F. 2020. Weed Management in the Transition to Conservation Agriculture: Farmers' Response. *Agronomy*, **10**(6): 843.

Ehi-Eromosele, C., Nwinyi, O. and Ajani, O. 2013. Integrated Pest Management. *In:* S. Soloneski, and M. Larramendy (Eds.), Weed and Pest Control Conventional and new challenges, Croatia, pp. 105-115.

Fanigliulo, R., Pochi, D. and Servadio, P. 2021. Conventional and Conservation Seedbed Preparation Systems for Wheat Planting in Silty-Clay Soil. *Sustainability*, **13**: 6506.

FAO, 2001. Summary, Conservation Agriculture, Matching Production with Sustaiablility. Available at: http://www.fao.org/ag/ags/agse/agse e/general/OBJECT.

Fonteyne, S., Leal Gonzalez, A.J., Osorio Alcalá, L., Villa Alcántara, J., Santos Rodriguez, C., Núñez Peñaloza, O., Ovando Galdámez, J.R., Singh, R.G. and Verhulst, N. 2022. Weed management and tillage effect on rainfed maize production in three agro-ecologies in Mexico. *Weed Res.*, **62**(3): 224-239.

Francaviglia, R., Almagro, M. and Vicente-Vicente, J.L. 2023. Conservation Agriculture and Soil Organic Carbon: Principles, Processes, Practices and Policy Options. *Soil Syst*., **7**: 17.

Friedrich, T., Derpsch, R. and Kassam, A. 2012. Global overview of the spread of conservation agriculture. *Field Act. Sci. Rep.*, **6**: 1–7.

Gaikwad, D.J., Ubale, N.B. Pal, A., Singh, S., Ali, M.A., Maitra, S. 2022. Abiotic stresses impact on major cereals and adaptation options - A review. *Res*. *Crop*., **23**(4): 896-915.

Gill, Gurjeet., Bhullar, M.S., Yadav, A., Yadav, D.B. 2013. Technology for Successful Production of Direct Seeded Rice, pp. 32. *In:* A training manual based on the outputs of ACIAR (Australian Centre for International Agricultural Research) funded project CSE/2004/033. A joint Publication of University of Adelaide, South Australia; P.A.U. Ludhiana, Punjab; CCS H.A.U., Hissar, Haryana, India.

Greaves, M.P. and MacQueen, M.D. 1992. Bioherbicides: their role in tomorrow's agriculture, In: *Resistance'91: Achievements and Developments in Combating Pesticide Resistance*. Dordrecht: Springer Netherlands, pp. 295-306.

Hardion, L., Verlaque, R., Saltonstall, K., Leriche, A., Vila, B. 2014. Origin of the invasive *Arundo donax* (Poaceae): A trans-Asian expedition in herbaria. *Ann. Bot.*, **114**: 455–462.

Harker, K.N. and O'Donovan, J.T. 2013. Recent Weed Control, Weed Management, and Integrated Weed Management. *Weed Tech*., **27**: 1-11.

Havens, K., Jolls, C.L., Marik, J.E., Vitt, P., McEachern, A.K. and Kind, D. 2012. Effects of a non-native biocontrol weevil, *Larinus planus*, and other emerging threats on populations of the federally threatened Pitcher's thistle, *Cirsium pitcheri*. *Biol. Conserve.*, **155**: 202-211.

Hillel, D. 1991. Out of the Earth: Civilization and the Life of the Soil. Free Press, New York, NY.

Hillel, D. 1998. Environmental Soil Physics. Academic Press, San Diego, CA.

Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agric. Ecosyst. Environ.*, **103**: 1e25

Holt, J.S. 1995. Plant responses to light: A potential tool for weed management. *Weed Sci*., **43**: 474–482.

Horvath, D.P., Clay, S.A., Swanton, C.J., Anderson, J.V. and Chao, W.S., 2023. Weed-induced crop yield loss: a new paradigm and new challenges. *Trends in Plant Sci*., **28**(5): 567-582.

Hossain, A., Mottaleb, K.A., Maitra, S., Mitra, B., Ahmed, S., Sarker, S., Chaki, A.K. and Laing, A.M. 2021b. Conservation Agriculture: Next-Generation, Climate Resilient Crop Management Practices for Food Security and Environmental Health. *In:* Conservation Agriculture: A Sustainable Approach for Soil Health and Food Security, (Eds. Aftab, T. and Hakeem, K.R.), Academic Press, pp. 585 - 609, https://doi.org/10.1016/B978-0-323-90943-3.00008-0.

Hossain, A., Mottaleb, K.A., Maitra, S., Mitra, B., Alam, M., Ahmed, S., Islam, M., Sarker, K. K., Sarker, S., Chaki, A.K., Muhammad, A.H., Skalicky, M., Brestic, M., and Laing, A.M. 2021a. Conservation Agriculture Improves Soil Health: Major Research Findings from Bangladesh, *In:* Conservation Agriculture: A Sustainable Approach for Soil Health and Food Security, Jayaraman, S. *et al*. (eds.), Springer Nature Singapore, pp. 511 - 561, https://doi.org/10.1007/978-981-16-0827-8_26.

Hsiao, P., Su, R. C., Da Silva, J.A.T. and Chan, M.T. 2007. Plant native tryptophan synthase beta 1 gene is a non-antibiotic selection marker for plant transformation. *Plantation*, **225**(4): 897-906.

Imaizumi, S., Nishino, T., Miyabe, K., Fujimori, T. and Yamada, M. 1997. Biological Control of An- nual Bluegrass (*Poa annua* L.) with a Japanese Isolate of Xanthomonas campestris pv. poae (JT-P482*). Biol. Control*., **8**(1): 7–14.

IRRI. 2023. Preparing the land, Rice Knowledge Portal, International Rice Research Institute, Available online: http://www.knowledgebank.irri.org/ericeproduction/Module_1.htm

Islam, M.A., Sarkar, D., Robiul Alam, M., Jahangir, M.M.R., Ali, M.O., Sarker, D., Hossain, M.F., Sarker, A., Gaber, A., Maitra, S., Hossain, A. 2023. Legumes in conservation agriculture: A sustainable approach in rice-based ecology of the Eastern Indo-Gangetic Plain of South Asia − an overview. *Technol. Agron*., **3**: 3.

Jat, M.L., Gathala, M.L., Ladha, J.K., Saharawat, Y.S., Jat, A.S., Kumar, V., Sharma, S.K. and Gupta, R. 2009 Evaluation of precision land leveling and double zero-till systems in rice-wheat rotation: water use, productivity, profitability and soil physical properties. *J. Pest Manag.,* **56**: 173-181.

Kubiak, A., Wolna-Maruwka, A., Niewiadomska, A. and Pilarska, A.A. 2022. The Problem of Weed Infestation of Agricultural Plantations vs. the Assumptions of the European Biodiversity Strategy. *Agronomy*, **12**(8): 1808.

Kumar, S., Singh, S., Rana., Neelam, Sharma., Rana, Khalid, Iqbal., Huma, Qureshi., Tauseef, Anwar., Asad, Syed., Abdallah, M., Elgorban., Rajalakshmanan and Eswaramoorthy. 2023. Weed phyto-sociology and diversity in relation to conservation agriculture and weed management strategies under Northwestern Indian Himalayas. *J. King Saud University Sci.*, **35**: 102728.

Kumar, V. and Ladha, J.K. 2011. Direct seeding of rice: recent developments and future research needs. *Adv. Agron*., **111**: 299-413.

Kumar, V., Singh, S., Chhokar, S., Ram, K., Malik, S., Daniel, C. and Ladha, J.K. 2013. Weed management strategies to reduce herbicide use in zero-till rice–wheat cropping systems of the IGP. *Weed Tech*., **27**: 241-254.

Lafond, G.P., McConkey, B.G. and Stumborg, M. 2009. Conservation tillage models for small-scale farming: linking the Canadian experience to the small farms of inner Mongolia autonomous region in China. *Soil Till. Res*., **104**: 150e155

Lal, R. 2001. Managing world soils for food security and environmental quality. *Adv. Agron*., **74**: 55e192.

Lee, N. and Thierfelder, C. 2017. Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. Agron. *Sustain. Develop*., **37**(5).

Liu, Z., Cao, S., Sun, Z., Wang, H., Qu, S., Lei, N., He, J. and Dong, Q. 2021. Tillage effects on soil properties and crop yield after land reclamation. *Sci. Rep*., **11**(1): 4611.

Lovic, B.R., Dewey, S.A., Thomson, S.V., Evans J.O. 1988. *Puccinia thlaspeos* a possible biocontrol agent for Dyer's woad. *Proc. West. Soc. Weed Sci.,* **41**: 55–57.

Lyon, D., Bruce, S., Vyn, T. and Peterson, G. 2004. Achievements and future challenges in conservation tillage. In: Proceedings of the 4th International Crop Science Congress, 26 Sepe1 Oct, Brisbane, Australia.

Mahajan, G. and Brar, L.D. 2002. Integrated management of Phalaris minor in wheat: Rationale and approaches- A review. *Agril Rev*., **23**: 241-251.

Maitra, S., Praharaj, S., Brestic, M., Sahoo, R. K., Sagar, L., Shankar, T., Palai, J.B., Sahoo, U., Sairam, M., Pramanick, B., Nath, S., Venugopalan, V.K., Skalický, M. and Hossain, A. 2023. Rhizobium as biotechnological tools for green solutions: An environment-friendly approach for sustainable crop production in the modern era of climate change. *Curr. Microbiol*., **80**: 219.

Maitra, S., Praharaj, S., Hossain, A., Patro, T.S.S.K., Pramanick, B., Shankar, T. and Sahoo, U. 2022. Small millets: The next-generation smart crops in the modern era of climate change. *In:* Pukade, R. N., Solanke, A. U., Sevanthi, A. M., Rajendrakumar, P. (eds) *Omics of Climate Resilient Small Millets*, Springer Nature Singapore Pte Ltd., pp. 1-25.

Manita, S. and Zaman, A. 2017. Brown Manuring, an Effective Technique for Yield Sustainability and Weed Management of Cereal Crops: A Review. *Int. J. Biores. Sci.,* **4**(1): 1-5.

Mann J. 1970. Cacti naturalised in Australia and their control. Cacti naturalised in Australia and their control.

Manoj, P.K.S., Sairam, M., Praharaj, S. and Maitra, S.2021. Soil moisture conservation techniques for dry land and rainfed agriculture. *Ind. J. Natural Sci.,* **12**(69): 37386 - 37391.

Matloob, A., Safdar, M.E., Abbas, T., Aslam, F., Khaliq, A., Tanveer, A., Rehman, A. and Chadhar, A.R., 2020. Challenges and prospects for weed management in Pakistan: A review. *Crop Protect.*, **134**: 104724.

Maurya, R., Bharti, C., Dorench, T. and Singh, V.P. 2020. Crop Residue Management for Sustainable Agriculture. *Int. J. Curr. Microbiol. App. Sci.*, **9**(05): 3168-3174.

Meiss, E., Konno, H., Groth, G. and Hisabori, T.2008. Molecular processes of inhibition and stimulation of ATP synthase caused by the phytotoxin tentoxin. *J. Biol. Che.*, **283**(36): 24594-24599.

Milan, M., Fogliatto, S., Blandino, M. and Vidotto, F. 2020. Are Wheat Hybrids More Affected by Weed Competition than Conventional Cultivars? *Agronomy*, **10**(4): 526.

Monteiro, A. and Santos, S. 2022. Sustainable Approach to Weed Management: The Role of Precision Weed Management. *Agronomy*., **12**(1): 118.

Mortensen, K. 1988. The potential of an endemic fungus, *Colletotrichum gloeosporioides*, for biological control of round-leaved mallow (*Malva pusilla*) and velvetleaf (*Abutilon theophrasti*). *Weed Sci.*, **36**: 473–478.

Muniyappa, T.V. 1980. Biology and Control of *Parthenium hysterophorus* L. and its Allelopathic Effect on FieM Crops. MSc thesis, University of Agricultural Sciences, Bangalore.

Muoni, T., Rusinamhodzi, L. and Thierfelder, C. 2013. Weed control in conservation agriculture systems of Zimbabwe: Identifying economical best strategies. *Crop Protect.*, **53***:* 23–28.

Nandi, S., Panda, M., Sairam, M., Palai, J. B. and Sahoo, U. 2022. Suitable options for agricultural waste management in India. *Ind. J. Nat.Sci.*, **13**(71): 41421-41426.

Narayanan, E.S. 1954. Discussion of the biological control of weeds. JR Williams (ed.) 95-98.

Ngoma, H., Mulenga, B. and Jayne, T. 2016. Minimum tillage uptake and uptake intensity by smallholder farmers in Zambia. *Afr. J. Agric. Resource Ecol*., **11**: 249–262.

Nichols, V., Verhulst, N., Cox, R. and Govaerts, B. 2015. Weed dynamics and conservation agriculture principles: A Review. *Field Crops Res*., **183**: 56-68.

Palojärvi, A., Kellock, M., Parikka, P., Jauhiainen, L. and Alakukku, L. 2020. Tillage System and Crop Sequence Affect Soil Disease Suppressiveness and Carbon Status in Boreal Climate. *Front. Microbiol*., **11**: 534786.

Panda, M., Nandi, S., Sahoo, U. and Sairam, M. 2022a. Integrated Farming System for Agricultural Sustainability. *Ind. J. Nat. Sci.*, **13**(71): 41311-41317.

Panda, S.K., Sairam, M., Sahoo, U., Shankar, T. and Maitra, S. 2022b. Growth, productivity and economics of maize as influenced by maize-legume intercropping system. *Farm. Manage*., **7**(2): 61-66.

Panth, M., Hassler, S.C. and Baysal-Gurel, F. 2020. Methods for Management of Soilborne Diseases in Crop Production. *Agriculture*., **10**: 16.

Pattanayak, S., Jena, S., Das, P., Roul, P.K., Maitra, S., Shankar, T., Sairam, M., Swain, D.K., Pramanick, B., Gaber, A. and Hossain, A. 2023. Crop establishment methods and weed management practices infuence the productivity and proftability of *Kharif* rice (*Oryza sativa* L.) in a hothumid summer climatic condition. *Paddy Water Environon.*, **21**: 447–466.

Place, G.T., Reberg-Horton, S.C., Dickey, D.A. and Carter, T.E. 2011. Jr. Identifying soybean traits of interest for weed competition. *Crop Sci.*, **51**: 2642–2654.

Poonia, T., Gora, M.K., Kakraliya, M., Kakraliya, S.K. and Jat, H.S. 2022. Rice Residue Load Influences the Wheat Crop Associated Weed Flora in Rice-Wheat System. *J. Soil Salin. Water Qual.*, **14**(1): 131-137.

Pramanick, B., Kumar, M., Naik, B.M., Kumar, M., Singh, S.K., Maitra, S., Naik, B.S.S.S., Rajput, V.D. and Minkina, T. 2022. Long-Term Conservation Tillage and Precision Nutrient Management in Maize–Wheat Cropping System: Effect on Soil Properties, Crop Production, and Economics. *Agronomy*, **12**(11): 2766.

Raj, R., Das, T.K., Ghosh, A., Govindasamy, P., Kumar, V., Babu, S., Saha, P., Sen, S., Roy, A., Sharma, T. and Tiwari, G. 2022. Crop-establishment methods and weed management effects on weeds, wheat (*Triticum aestivum*) yield and economics under a conservation agriculture-based rice (*Oryza sativa*)–wheat system. *Indian J. Agron.*, **67**(4): 354-362.

Ramachandran, A., Veeramani, A. and Prema, P. 2012. Effect of brown manuring on weed growth, yield and economics of irrigated maize. *Ind. J. Weed Sci.*, **44**(3): 204–206.

Riemens, M. 2016. Developments in physical weed control in Northwest Europe. Proc. 27th German Conference on Weed Biology and Weed Control. Julius Kühn-Institute, **452**: 24-26.

Riemens, M., Sønderskov, M., Moonen, A.C., Storkey, J., Kudsk, P. 2022. An Integrated Weed Management framework: A pan-European perspective, *Eur. J. Agron.*, **133**: 126443.

Sagar, L., Praharaj, S., Singh, S., Attri, M., Pramanick, B., Maitra, S., Hossain, A., Shankar, T., Palai, J. B. and Sahoo, U. 2022. Drought and heat stress tolerance in field crops: consequences and adaptation strategies. In: Response of Field Crops to Abiotic Stress (pp. 91-102). CRC Press.

Sagar, L., Singh, S., Sharma, A., Maitra, S., Attri, M., Sahoo, R.K., Ghasil, B.P., Shankar, T., Gaikwad, D.J., Sairam, M., Sahoo, U., Hossain, A. and Roy, S. 2023. Role of soil Microbes against abiotic stresses induced oxidative stresses in plants. *In:* Mathur, P., Kapoor, R., Roy, S. (eds) Microbial Symbionts and Plant Health: Trends and Applications for Changing Climate. Rhizosphere Biology. Springer, Singapore. https://doi.org/10.1007/978-981-99-0030-5_7.

Sahoo, S., Mukhopadhyay, P., Mowrer, J., Maity, P.P., Maity, A., Sinha, A.K., Sow, P. and Rakesh, S. 2022. Tillage and N-source affect soil fertility, enzymatic activity, and crop yield in a maize–rice rotation system in the Indian Terai zone. *Front. Environ. Sci.*, **10**: 983973.

Sahoo, U., Maitra, S., Dey, S., Vishnupriya, K.K., Sairam, M. and Sagar, L. 2023a. Unveiling the potential of maize-legume intercropping system for agricultural sustainability: A review. *Farm. Manage.*, **8**(1): 1-13.

Sahoo, U., Maitra, S., Sairam, M. and Sagar, L. 2023b. Potential and advantage of pearl millet -legume intercropping system: A review. *Int. J. Biol. Sci.*, **10**(01): 99-106.

Sahoo, U., Malik, G.C., Banerjee, M., Sahoo, B. and Maitra, S. 2022. Application of nanotechnology in agriculture in India. *Ind. J. Nat. Sci.*, **13**(72): 44422-44429.

Sardana, V., Mahajan, G., Jabran, K., Bhagirath S. and Chauhan, B.S. 2017. Role of competition in managing weeds: An introduction to the special issue. *Crop Protect.*, **95**: 1-7.

Sarkar, R.K., Shit, D. and Maitra, S. 2000. Competition functions, productivity and economics of chickpea (*Cicer arietinum*)-based intercropping system under rainfed conditions of Bihar plateau. *Ind. J. Agron.*, **45**(4): 681-686.

Saulic, M., Oveisi, M., Djalovic, I., Bozic, D., Pishyar, A., Savić, A., Prasad, P.V. and Vrbničanin, S. 2022. How Do Long Term Crop Rotations Influence Weed Populations: Exploring the Impacts of More than 50 Years of Crop Management in Serbia. *Agronomy.*, **12**(8): 1772.

Sepat, S., Thierfelder, C., Sharma, A.R., Pavuluri, K., Kumar, D., Iquebal, M.A. and Verma, A. 2017. Effects of weed control strategy on weed dynamics, soybean productivity and profitability under conservation agriculture in India. *Field Crops Res.*, **210***:* 61–70.

Shahane, A.A. and Shivay, Y.S. 2021. Soil Health and Its Improvement Through Novel Agronomic and Innovative Approaches. *Front. Agron.*, **3**: 680456.

Shaukat, M., Ahmad, A., Khaliq, T., Hoshide, A.K. and de Abreu, D.C. 2023. Organic Amendments and Reduced Tillage Accelerate Harvestable C Biomass and Soil C Sequestration in Rice–Wheat Rotation in a Semi-Arid Environment. *Sustainability.*, **15**: 6415.

Shekhawat, K., Rathore, S.S. and Chauhan, B.S. 2020. Weed Management in Dry Direct-Seeded Rice: A Review on Challenges and Opportunities for Sustainable Rice Production. *Agronomy*, **10**(9): 1264.

Sims, B., Corsi, S., Gbehounou, G., Kienzle, J., Taguchi, M. and Friedrich T. 2018. Sustainable weed management for conservation agriculture: Options for smallholder farmers. *Agriculture,* **8**(8): 118.

Singh, M., Kukal, M.S., Irmak, S. and Jhala, A.J. 2022. Water Use Characteristics of Weeds: A Global Review, Best Practices, and Future Directions. *Front. Plant Sci.*, **12**: 794090.

Singh, M.K. and Singh, A. 2012. Effect of stale seedbed method and weed management on growth and yield of irrigated direct-seeded rice. *Ind. J. Weed Sci.*, **44**(3): 176–180.

Singh, S.R., Chhokar, S., Gopal, R., Ladha, J.K., Gupta, R.K., Kumar, V. and Singh, M. 2007. Integrated weed management. A key to success for direct seeded rice in the Indo-Gangetic Plains. *In:* Integrated Crop and Resource Management in the Rice – Wheat system of South Asia, pp. 261-270.

Singh, V.P., Barman, K., Singh, R. and Sharma, A. 2015. Weed Management in Conservation Agriculture Systems. *In:* M. Farooq, and Siddique K.H.M (Eds.), Conservation Agriculture Springer Nature Publishing Pte, Switzerland, pp. 39-77.

TerAvest, D., Wandschneider, P.R., Thierfelder, C. and Reganold, J.P. 2019. Diversifying conservation agriculture and conventional tillage cropping systems to improve the wellbeing of smallholder farmers in Malawi. *Agric. Syst*., **171**: 23–35.

Tufa, A.H., Kanyamuka, J.S., Alene, A., Ngoma, H., Marenya, P.P., Thierfelder, C., Banda, H. and Chikoye, D. 2023. Analysis of adoption of conservation agriculture practices in southern Africa: mixed-methods approach. *Front. Sustain. Food Syst*., **7**: 1151876.

Venne, J. 2008. Molecular Characterization and Virulence Analysis of *Fusarium oxysporum* Strains Used in Biological Control against *Striga hermonthica*. Master thesis, Department of Plant Science Macdonald Campus of McGill University Montréal. Québec, Canada.

Vishwakarma, A.K., Meena, B.P., Das, H., Jha, P., Biswas, A.K., Bharati, K. 2023. Impact of sequential herbicides application on crop productivity, weed and nutrient dynamics in soybean under conservation agriculture in vertisols of Central India. *PLoS ONE,* **18**(1): e0279434.

Wang, R. 1989. Biological control of weeds in China: a status report. *In:* Proceedings of the VII International Symposium on Biological Control of Weeds (ed. E Delfosse). 689–693. Rome, Italy.

Wang, Y., Yang, S., Sun, J., Liu, Z., He, X. and Qiao, J. 2023. Effects of Tillage and Sowing Methods on Soil Physical Properties and Corn Plant Characters. *Agriculture*., **13**: 600.

Wuest, S.B. and Lutcher, L.K. 2012. Soil Water Potential Requirement for Germination of Winter Wheat. *Soil Sci. Soc. Ame. J.,* **77**: 279–283.

Zahan, T., Hossain, M.F., Chowdhury, A.K., Ali, M.O., Ali, M.A., Dessoky, E.S., Hassan, M.M., Maitra, S. and Hossain, A. 2021. Herbicide in weed management of wheat (*Triticum aestivum* L.) and rainy season rice (*Oryza sativa* L.) under conservation agricultural system. *Agronomy,* **11**(9): 1704.

Zhang, J. and Wu, L-F. 2021. Impact of Tillage and Crop Residue Management on the Weed Community and Wheat Yield in a Wheat–Maize Double Cropping System. *Agriculture*, **11**(3): 265.

Zhou, G., Gao, S., Lu, Y., Liao, Y., Nie, J. and Cao, W. 2020. Co-incorporation of green manure and rice straw improves rice production, soil chemical, biochemical and microbiological properties in a typical paddy field in southern China. *Soil Tillage Res*., **197**: 104499.