

**HERBICIDE OPTIONS FOR EFFECTIVE WEED MANAGEMENT IN ZERO-TILL
WHEAT, MAIZE AND DIRECT-SEEDED AMAN RICE UNDER WHEAT-
MUNGBEAN-RICE AND MAIZE-MUNGBEAN-RICE CROPPING SYSTEMS**



A Dissertation

By

MST. TANJINA ISLAM

Reg. No. 1705204

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Submitted to the

Hajee Mohammad Danesh Science and Technology University, Dinajpur

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MY

BELOVED PARENTS AND FAMILY

DECLARATION

I, **Mst. Tanjina Islam**, hereby declared that this dissertation entitled '**HERBICIDE OPTIONS FOR EFFECTIVE WEED MANAGEMENT IN ZERO-TILL WHEAT, MAIZE AND DIRECT-SEEDED AMAN RICE UNDER WHEAT-MUNGBEAN-RICE AND MAIZE-MUNGBEAN-RICE CROPPING SYSTEMS**' was submitted to Hajee Mohammad Danesh Science and Technology University, Dinajpur in the fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in Agronomy, which is accomplished by me. Any part of this dissertation was produced elsewhere for any degree or publication.

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This is to certify that the work personified in this dissertation is an original research work done by **Mst. Tanjina Islam (Reg. No. 1705204, Session 2017)** under my supervision for the degree of Doctor of Philosophy. The references incited have duly been acknowledged. The style and contents of the dissertation have been approved and recommended for submission.

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BIOGRAPHICAL SKETCH

The author was born on 10 January 1975 in Uttar Munsipara, Dinajpur Sadar, Dinajpur 5200, Bangladesh. The author is the first daughter of Md. Dazrul Islam Chowdhury and Mrs. Abeda Sultana. She completed her Secondary School Certificate (SSC) education in 1990 from Government Girls High School, Dinajpur and her Higher Secondary Certificate (HSC) education in 1992 from Dinajpur Government College, Dinajpur 5200, Bangladesh under the Board of Intermediate and Secondary Education, Rajshahi. She obtained her Bachelor of Science in Agriculture (B.Sc.Ag) degree in 1997 (held in 2000) and Master of Science (MS) in Agronomy degree in 2002 from Bangladesh Agricultural University, Mymensingh 2202, Bangladesh.

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She is married to Dr. Akbar Hossain, Principal Scientific Officer and Head, Soil Science Division, Bangladesh Wheat and Maize Research Institute (BWMRI), Dinajpur and blessed with two sons namely Tanjim Hossain and Tahsin Hossain.

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The Author

ABSTRACT

The information on the efficacy and economics of different pre-and post-emergence herbicides used alone or sequentially in the conservation agriculture (CA)-based zero-till (ZT) wheat, maize and direct seeded (DSR) rice production system is still sporadic or lacking in Bangladesh. In the context, an observation entitled 'Herbicide Options for Effective Weed Management in Zero-Till Wheat, Maize and Direct-Seeded Aman Rice under Wheat-Mungbean-Rice and Maize-Mungbean-Rice Cropping Systems' was conducted in consecutive two years of 2017-2018 and 2018-2019. This observation consisted of three experiments; Expt. 1. Efficacy and Economics of Different Post-Emergence Herbicides for Controlling Weeds in Wheat under Zero-Till Condition; Expt. 2. Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in Maize under Zero-Till Condition and Expt. 3. Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in Zero-Till Direct Seeded Aman rice. Treatments of the first experiment were: ready-mix formulation (Sulfosulfuron + Metsulfuron); ready-mix formulation (Mesosulfuron + Idosulfuron); Pinoxaden; ready-mix formulation (Carfentrazone + Isoproturon); Pinoxaden + Metsulfuron; Pinoxaden + Carfentrazone; Halosulfuron; Halosulfuron + Pinoxaden; Weedy check and Weed free. After two years of observation, the results of the study revealed that the highest yield of ZT-wheat (4860 kg ha⁻¹) was recorded in weed-free treatment in the first season, which was statistically similar to Pinoxaden + Metsulfuron in both years (4643.33 and 5683.33 ha⁻¹) and the lowest grain yield (2595 and 3880 kg ha⁻¹) was recorded in weedy check plots. From an economic point of view, the maximum net benefit (121386 Tk ha⁻¹) in the first year was recorded in Pinoxaden + Metsulfuron treatment, but in the second season, the maximum benefit (212578 Tk ha⁻¹) was recorded in Halosulfuron + Pinoxaden applied plot. In 2nd experiment, treatments were two pre-emergence herbicides (Pendimethalin and Atrazine) and a control (without pre-emergence herbicide) and five post-emergence herbicides (i.e., Atrazine; Tembotrione; Halosulfuron; Tembotrione + Atrazine and Halosulfuron + Atrazine) and a control (without post-emergence herbicide). After two years of observation, the findings of the study revealed that sequential use of pre- and post-emergence herbicides significantly influenced the grain yield of ZT-maize by effectively controlling all types of weeds. In the first year, the highest grain yield was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with post-emergence herbicides Tembotrione + Atrazine (13.9 t ha⁻¹) applied at 15 DAS. However, in the second year, the sequential application of Atrazine applied immediately after maize seeding with post-emergence herbicides Tembotrione (17.2 t ha⁻¹) applied at 15 DAS performed the best, followed by Atrazine as pre-emergence and Tembotrione + Atrazine (16.6 t ha⁻¹) applied as post-emergence and the lowest was recorded in the control plot (10.9 t ha⁻¹). From the economic point of view, the maximum net benefit (two years' averaged) was recorded from Pendimethalin & Atrazine (both applied as pre-emergence) and Atrazine (as post-emergence) (367807 & 362907 Tk. ha⁻¹) applied plots, followed by Pendimethalin & Atrazine (both as pre-emergence) and Tembotrione + Atrazine (as post-emergence) (362582 & 363832 Tk.ha⁻¹), while the minimum net benefit (258907 Tk. ha⁻¹) was recorded in weedy check treatment. In 3rd experiment, treatments were two pre-emergence herbicides (i.e., Pendimethalin and Oxadiazon) and a control (without pre-emergence herbicide) and five post-emergence herbicides (i.e., No-post-emergence; Bispyribac Sodium; Bispyribac Sodium + Pyrazosulfuron; Fenaxoprop + Ethoxysulfuron and Fenoxoprop *fb* Halosulfuron. Results of the two years of the study showed that all types of weeds were effectively controlled by the sequential use of pre-and post-emergence herbicides. Considering plant growth, yield and yield attributing of ZT DSR Aman rice, all parameters were significantly influenced by pre-emergence herbicides (Pendimethalin & Oxadiazon) applied immediately after rice seeding followed by post-emergence herbicides (sole application of Bispyribac-sodium, and combination of Bispyribac-sodium + Pyrazosulfuron, Fenaxoprop + Ethoxysulfuron and Fenoxoprop *fb* Halosulfuron) applied as post-emergence. Among these herbicides, the highest grain yield in both years was found in the sequential use of pre-emergence herbicide Pendimethalin followed by the application of post-emergence herbicides 'Bispyribac Sodium + Pyrazosulfuron' (5.3 t ha⁻¹ in the first year) and 'Bispyribac-sodium' (5.2 t ha⁻¹ in second year). From the economic point of view, the maximum net benefit was recorded in the plot, where Pendimethalin was applied as pre-emergence in combination with Bispyribac-sodium + Pyrazosulfuron (two years' average 100179 Tk. ha⁻¹) applied as post-emergence, followed by Oxadiazon as pre-emergence in combination with the sole application of Bispyribac-sodium (two years' average 95873 Tk. ha⁻¹). Based on the two years of yield and the economic benefit of these three observations the combination of herbicides Pinoxaden + Metsulfuron and Halosulfuron + Pinoxaden may be recommended for weed control in ZT-wheat. In the case of ZT-maize, the sequential application of Pendimethalin and Atrazine applied as pre-emergence immediately after sowing of maize seeds in combination with sole Atrazine or in combination with Tembotrione + Atrazine as post-emergence may be recommended for weed control in the ZT-maize. While, in ZT DSR Aman rice, the sequential application of Pendimethalin and Oxadiazon as pre-emergence immediately after sowing of rice seeding in combination with Bispyribac + Pyrazosulfuron or Fenaxoprop + Ethoxysulfuron or sole application of Bispyribac Sodium as post-emergence may be recommended for weed control in ZT-DSR Aman rice.

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ABBREVIATION AND ACRONYMS

a.i.: Active Ingredients

AEZ: Agro-Ecological Zone

BARI: Bangladesh Agricultural Research Institute

BBS: Bangladesh Bureau of Statistics

BpLB: Bipolaris leaf blight

BRRI: Bangladesh Rice Research Institute

BWMRI: Bangladesh Wheat and Maize Research Institute

CE: Crop Establishment

CIMMYT: International Maize and Wheat Improvement Centre

CT: Conventional Tillage

CT: TPR: Conventional Tillage-transplanted Puddled Rice

CV: Co-efficient of Variation

DAE: Department of Agricultural Extension

DAS: Days after Sowing

DAT: Days after Transplanting

DSR: Direct-Seeded Rice

EC: Emulcifiable Concentrate

FGP: Eastern Gangetic Plain

EPE: Early Post Emergence

g: Gram

GU: Guri urea

HW: Hand Weeding

IFPRA: International Food Policy Research Institute

IRRI: International Rice Research Institute

PTR: Puddled Transplanted Rice

R-W: Rice-Wheat systems

TSP: Triple Super Phosphate

WAS: Week after Sowing

WCE: Weed Control Efficiency

WRC: Wheat Research Centre

ZT: Zero-Tillage

ZT-DSR: Zero-tillage Direct Seeded Rice

CHAPTER 1

GENERAL INTRODUCTION

Bangladesh is a deltaic country located in South Asia, with a relatively small land area (147,570 km²) but the 8th largest world population (168,600,747 as of Tuesday, November 22, 2022, based on World meter elaboration of the latest United Nations data) (<https://www.worldometers.info/world-population/bangladesh-population/>; accessed on 23 November 2022) and the 13th highest world population density (Rahman *et al.*, 2020). According to the medium variant UN projection (UN, 2015), Bangladesh's population will further increase to 186 and 202 million by the years 2030 and 2050, respectively (Hossain and Teixeira da Silva, 2013; Timsina *et al.*, 2018). Increasing income levels and urbanization may lead to diet changes such as switching from traditional rice to wheat and to livestock, poultry, and fish products, which in turn require large amounts of maize for their production (Alkanda, 2010; Mukherjee *et al.*, 2011; Timsina *et al.*, 2018). The land suitable for cropping in the country is already under cultivation. Arable land area is even decreasing over time due to increasing demand for residential and industrial use (Hasan *et al.*, 2013). Bangladesh also suffers from periodic natural calamities such as drought, flooding, and cyclones (Hossain and Teixeira da Silva, 2013). Due to its location as a deltaic country, climate change and associated sea level rise are expected to increase the risk for flooding and salinization of agricultural lands, especially near the southern coast (MOA-FAO, 2012; Hossain and Teixeira da Silva, 2013).

In several Asian countries (including India, Bangladesh, Sri Lanka and Nepal) improved economy has increased the labour demand for non-agricultural sectors and reduced the availability of labour in the agricultural sector (Kelegama, 2011), because of the increasing labour scarcity and

also labour wages; for example, in 1960, the wage was less than US\$ 0.25 day⁻¹ labour⁻¹, but it has increased to 0.75, 1.25, 1.50 and \$5.50 day⁻¹ in Bangladesh, India, Sri Lanka, and the Philippines, respectively, leading to make the traditional crop production system uneconomical in these countries (Kumar and Ladha, 2011; Hasan and Barua, 2015). On the other hand, for the increasing population in Asia, more water is required for urbanization, whereas the variation of water resources is being depleted. The share of agriculture water is also declining because of competition with increased domestic and industrial uses (Wijngaard *et al.*, 2018; Amin *et al.*, 2020). Therefore, in the future, a noteworthy crop production (rice, wheat and maize area) will face water shortage, and farmers will not have enough water for crop production, particularly in puddled transplanted rice systems (Mahajan *et al.*, 2012). Therefore, dry-zero-tillage (ZT)-direct-seeded rice (DSR), ZT-maize and CA-based ZT-wheat production (CIMMYT, 2015) are emerging production systems (Chauhan *et al.*, 2012; Mahajan *et al.*, 2012; Ahmed *et al.*, 2013; Gathala *et al.*, 2014) to solve the future water shortage as well as labours problem in the modern era of the changing climate.

In Bangladesh, wheat is the most important cereal after rice and plays a significant role in meeting the food security of the increasing population (Timsina *et al.*, 2018). According to the BBS (2016), the present demand for wheat is 5.9 million tonnes, but production is only 1.35 million tonnes, and the demand for wheat is increasing at a rate of 10% year⁻¹ (BWMRI, 2022). However, the average yield of wheat was only 3.64 t ha⁻¹ in 2015-2016 (BWMRI, 2022). According to the Bangladesh Agricultural Research Institute (BARI), the attainable average yield of current wheat varieties is 4.0–4.5 t ha⁻¹ (BARI, 2016), with climatic yield potential as high as 6.0 t ha⁻¹ (Timsina *et al.*, 2010). Such wide gaps among potential, attainable and actual yields need to be reduced to improve food security in Bangladesh (Timsina *et al.*, 2018). Presently wheat is grown more than 80% by manual sowing after intensive 5-6 tillage operations, leading to a delay in the wheat sowing

by at least 1-2 weeks (BWMRI, 2022). On the other hand, the number of repetitive tillage operations increases the cost of cultivation, and fuel consumption and delays planting in two ways repetitive tillage operations followed by manual sowing (Gathala *et al.*, 2015; Jaskulska *et al.*, 2020a,b; Rahman *et al.*, 2021). Late planting of wheat was identified as a major problem. To improve productivity wheat crops must be sown at the optimum time at the end of November followed by a decline in yield of 1-1.5% day⁻¹ after that date. The problem has been resolved by directly seeding wheat into undisturbed soil after the immediate rice harvest in combination with proper agronomic management practices (Hossain *et al.*, 2012a,b; Hossain and Teixeira da Silva, 2012; Hossain *et al.*, 2018; Hossain *et al.*, 2020).

Besides the problem of late planting, weeds are also found one of the major constraints to the sustainability of wheat cultivation (Kumar *et al.*, 2013). However, weed flora in wheat differs from field to field, depending on environmental conditions, irrigation, fertilizer use, soil type, weed control practices, and cropping sequences. The predominant weeds associated with conventional till wheat are one of the major concerns in irrigated wheat under the R-W system of South-Asia (Chhokar *et al.* 2006; Monsefi *et al.*, 2016). Almost 16 to 42 % of yield reduction occurred due to weed infestation and one-third of the total cost of cultivation is spent on weeding (Ramgasamy *et al.*, 1993; Mandal *et al.*, 2014; Islam *et al.*, 2018; Zahan *et al.*, 2021). An average of 13.1% of crops reproduced are lost in the farmers' fields even after adopting traditional weed control in Bangladesh (Mamun, 1990; Jabran *et al.*, 2017; Ahmed *et al.*, 2019). Our farmers are usually reluctant to control weeds in the wheat field, due to the increasing labour wages as well as the lack of labourers due to migrating from the villages to urban areas for better livelihood (Hossain *et al.*, 2010a,b,c; Hossain and Teixeira da Silva, 2012a). Hand labour-based weed control in many developing countries consumes up to half of the total labour demand (Islam *et al.*, 2018; Zahan *et al.*, 2021). On the other

hand, after post-seeding wheat, growers face major challenges in weed management due to the lack of appropriate pre-and post-emergence herbicides in the region (Hossain *et al.*, 2010a,b,c; Hossain and Teixeira da Silva, 2012a,b).

Therefore, conservation agricultural (CA)-based new agronomic management practices are advocating to overcome these challenges (Malik *et al.*, 2014; Hossain *et al.*, 2020). The zero/zero-tilled wheat/permanent beds or till the soil with fresh beds is an alternate option through mechanized precision planting in a single pass (Islam *et al.*, 2018; Zahan *et al.*, 2021). The CA-based crop management technique faces the major concern of weed management initially (Derrouch *et al.*, 2020; Cordeau, 2022). To address the weed management problems in CA-based wheat production under no-till systems with different chemical weed control is a potential means for controlling weeds, and is more economical compared to hand weeding (Jahan *et al.*, 2003; Zahan *et al.*, 2021). Now some herbicides are available in the market which are needed for validation for controlling weeds (Singh *et al.*, 2015; Hossain *et al.*, 2015; Zahan *et al.*, 2020). However, information on herbicide efficacy in wheat is sporadic or lacking in Bangladesh (Jahan *et al.*, 2021; Ali *et al.*, 2022).

Although maize is not a staple food cereal yet in Bangladesh, it is the 2nd most important cereal after rice and in the case of food crops, it ranked third after wheat (BWMRI, 2022). The maize area and production in Bangladesh are increasing day by day at high speed because of the increasing demand for poultry, animals and fish feeds, and also in starch industries (BBS, 2016). The farmers are also interested in growing it, so the crop has been included in the crop diversification programme (Mottaleb *et al.*, 2019). During 2021-22, 5.63 million tons of maize was produced from 0.55 million ha of land, whereas the annual grain requirement is about 7.0 million tons (BWMRI, 2022). The current national average yield of maize is 10.2 t ha⁻¹ which is

due to the introduction of hybrids and the adoption of appropriate crop management practices (BWMRI, 2022). The demand for maize is increasing in Bangladesh day by day due to its increasing demand for poultry, fish and animal feed and production of different types of processed foods, and also for export (BWMRI, 2022). Maize grain flour is also used for human consumption by mixture with wheat flour (Sarwar and Biswas, 2021; Islam and Hossain, 2022).

However, in the Indo-Gangetic Plain (IGP) of South Asia including Bangladesh, the average yield of maize is not comparable with that of maize-growing countries for many reasons. Among them, cultivation methods and weed infestation are probably the most important. Presently, maize is grown more than 90% by manual dibbling after intensive 5-6 repeated tillage operations which delayed the maize sowing at least 1-2 weeks (Islam *et al.*, 2013) and also the number of repetitive tillages increases the cost of production and delays planting (Jin *et al.*, 2007). Manual dibbling requires a large number of labourers which further reduces the net margins (Díaz-Zorita, 2000; Gathala *et al.*, 2015; 2016). On the other hand, in the traditional weed management in maize after 30-40 days after sowing (DAS), generally farmers cut the weeds with spading and simultaneously earthing up maize plants to make furrows and ridges which further consumed more labourers (Gathala *et al.*, 2015; 2016). In an increasingly competitive agricultural scenario, no-tillage farming systems are gaining rising attention worldwide; since this system does not need tillage, and not even superficially. There are many benefits associated with these no-tillage systems, particularly economic advantages (Gathala *et al.*, 2015, 2016). The CA-based direct-seeded maize in no-till/zero-till/ has already been established as an environmentally friendly and cost-effective approach through mechanized precision planting in a single pass (Tuti *et al.*, 2022). In addition, environmental benefits are also attributed to no-tillage farming regarding soil structure, aquatic resource variations and positive effects through the storage of organic carbon, which, as CO₂, acts

in the atmosphere as a greenhouse gas (Kimaro *et al.*, 2016). The CA-based new agronomic management practices are advocating overcoming those above challenges (Gathala *et al.*, 2015, 2016).

However, CA (Zero-Till; ZT)-based crop cultivation generally faces the major concern of weed infestation initially (Rao *et al.*, 2009; Mukundam *et al.*, 2011; Chauhan and Mahajan, 2012; Reddy *et al.*, 2012; Parameshwari, 2013). To address the weed management problems in CA-based maize production under no-till systems, different weed management options should be designed to convince different stakeholders including farmers, input dealers, extension officers, private sectors, researchers and policymakers for the sustainability of maize production (Ramesh, 2015). Mechanical methods including hand weeding are still useful but are getting expensive, laborious and time-consuming (Somasundaram *et al.*, 2020). In less developed countries, the situation still exists where the peak labour requirement is often for hand weeding (Chikoye *et al.*, 2002; Chikoye *et al.*, 2004; Chikoye *et al.*, 2007; Bhan and Behera, 2014; Hossain *et al.*, 2019). Weed control in maize with herbicides has been suggested by many researchers (Singh *et al.*, 2015; Lee and Thierfelder, 2017; Hossain *et al.*, 2019); since herbicides-based weed control is an important alternative to manual weeding because it is cheaper, faster and gives better weed control (Chikoye *et al.*, 2005; Mitra *et al.*, 2018) and significantly increased maize yield and through decreasing weed density. However, the efficiency and efficacy of herbicides in maize depend on several factors including years, weed species, and environments as well as residual effects on the succeeding crops (Maqsood *et al.*, 2020). As per the information from previous studies, the sequential applications of pre-and post-emergence herbicides were found very effective in controlling weeds in ZT (zero-till)-based crop production systems (Chhokar *et al.*, 2012; Yakadri

et al., 2015), then a single application of herbicides (Singh *et al.*, 2006; Chauhan *et al.*, 2013; Mahajan and Chauhan, 2013; Ahmed and Chauhan, 2014).

Similarly, zero-till (ZT) dry-direct seeded rice (DSR) is an emerging production system in Asia (Prasad, 2011; Mahajan *et al.*, 2013). DSR system is expected to increase in the future due to concerns over labour and water shortages as well as input use efficiency (Mahajan and Chauhan, 2011). The DSR production system requires 35-57% less water and 67% less labour than the conventional system (puddled transplanted rice) (Farooq *et al.*, 2011). Furthermore, the accumulation of arsenic in the grain and straw is much less if the soil is allowed to dry between irrigations to let air (oxygen) into the soil (aerobic conditions) than in continuously flooded rice (Gathala *et al.*, 2014). DSR can be established directly in the field with no prior tillage (zero tillage) or following dry tillage. Dry seeding reduces labour requirements by eliminating seedling rearing in nursery beds, seedling uprooting, repeated tillage under wet conditions to puddle the soil and manual transplanting (Farooq *et al.*, 2011; Chauhan *et al.*, 2012). DSR can be readily adopted by small farmers as well as large farmers, provided that the required machinery is locally available (e.g., through custom hire from agricultural service providers). Best practice involves using a 2- or 4-wheel tractor-drawn drill to seed in rows into non-tilled or dry-tilled soil, as for wheat (Gathala *et al.*, 2014). However, similar to CA-based (ZT-based) wheat and maize cultivation systems, weeds are also a major problem in CA-based rice systems, particularly DSR rice cultivation systems (Rao *et al.*, 2007; 2017). Weeds are one of the most important biological constraints in DSR systems since the DSR system is subjected to much higher weed pressure than transplanted rice because of dry ploughing and aerobic soil conditions (Balasubramanian and Hill, 2002; Chauhan *et al.*, 2012; Ahmed *et al.*, 2014; Matloob *et al.*, 2015; Hossain *et al.*, 2016). Yield loss in DSR rice due to weeds ranges from 27-80% in Pakistan (Khaliq *et al.*, 2012), and 40-70% in the

Philippines (Chauhan and Opena, 2013). Proper weed management is considered one of the most important prerequisites in the DSR system to ensure high crop yield. High weed pressure in dry-seeded rice lowers the economic returns and, in extreme cases, causes complete failure of the rice crop (Jabran *et al.*, 2012). Hence, judicious weed management in DSR is a critical factor for securing and sustaining food security in Asia's developing countries (Timsina and Connor, 2001; Rao *et al.*, 2017; Chauhan *et al.*, 2013; Singh *et al.*, 2009).

Weed control by chemical means in zero-till (ZT)/CA-based crop production systems is a common practice in many countries of the world due to its advantages over other methods. Although newly available herbicides may provide satisfactory weed control in DSR, excessive use of herbicides may increase the risk of herbicide resistance, and shift towards problematic weed species (Singh *et al.*, 2014; Ahmed and Chauhan, 2015; Hossain *et al.*, 2016; Kumar *et al.*, 2016; Gopal *et al.*, 2019), can cause environmental contamination and the development of herbicide resistance in weeds (Heap, 2014). The increased use of herbicides, risk of herbicide resistance, rising costs of production, and concerns about environmental pollution are creating interest among researchers in exploring non-chemical (cultural) methods of weed control (Chauhan, 2012; Beckie *et al.*, 2020). However, sequential use of pre-emergence and post-emergence herbicides for controlling weeds in DSR has been found cost-effective and environmentally friendly approach (Ahmed and Chauhan, 2015; Kumar *et al.*, 2016; Gopal *et al.*, 2019). In Bangladesh, weeds in rice fields are controlled manually and through different cultural practices. There is a lack of control of weeds in the ZT-DSR production system in Bangladesh, due to the lack of proper knowledge of the system and also the availability of pre-emergence and post-emergence herbicides.

From the above information for weed control in ZT-based wheat, maize and rice, the selection of herbicides needs to consider environmentally friendly and economically viable

chemicals. However, such information is not available for the use of different pre- and post-emergence herbicides in ZT-based rice, wheat and maize production systems in Bangladesh. To provide wider options to farmers for economic weed control in a ZT-based system, it is necessary to evaluate the efficacy and economics of different pre- and post-emergence herbicides when used solely and sequentially. Therefore, three studies were undertaken to achieve the following objectives:

- i) To identify the suitable herbicides to get the best weed control efficacy and economics of CA-based wheat, maize and rice under wheat-mungbean-rice (M-M-R) and maize-mungbean-rice (M-M-R) cropping systems;
- ii) To find out the specific herbicides for weed control in ZT-based wheat, maize and rice under W/M-M-R cropping systems, and
- iii) To investigate the effect of different herbicides on growth, yield attributes and yields of CA-based wheat, maize and rice under wheat-mungbean-rice (M-M-R) and maize-mungbean-rice (M-M-R) cropping systems;

CHAPTER 2

REVIEW OF LITERATURE

The background of the study confirmed that weed is one of the most important biotic constraints that limit crop production significantly. Their competition with crops reduces agricultural output in terms of quantity as well as quality, ultimately increasing the cost of cultivation. Almost 16 to 42 % of yield reduction occurs due to weed infestation, and one-third of the total cost of cultivation is spent due to weed control (Mandal *et al.*, 2014; Islam *et al.*, 2018; Zahan *et al.*, 2021). An average of 13.1% of crops reproduced are lost in the farmers' fields even after adopting traditional weed control in Bangladesh (Jabran *et al.*, 2017; Ahmed *et al.*, 2019). Hand labour-based weed control in many developing countries consumes upto half of the total labour demand (Islam *et al.*, 2018; Zahan *et al.*, 2021). In Bangladesh, farmers are usually reluctant to control weeds in the wheat field. However, sometimes they weeded by hand, which proves uneconomical due to the increasing labour wages as well as the lack of labourers due to migrating from the villages to urban areas for better livelihood (Hossain *et al.*, 2010a,b,c; Hossain and Teixeira da Silva, 2012). Therefore, CA-based new agronomic management practices are advocating to overcome these challenges (Malik *et al.*, 2014; Hossain *et al.*, 2020). The zero/dry-tilled wheat/permanent beds or till the soil with fresh beds is an alternate option through mechanized precision planting in a single pass (Islam *et al.*, 2018; Zahan *et al.*, 2021). However, CA-based crop management techniques face the major concern of weed management initially (Derrouch *et al.*, 2020; Cordeau, 2022). To address the weed management problems in CA-based wheat production under no-till systems with different chemical weed control is a potential means for controlling weeds and is more economical compared to hand weeding (Jahan *et al.*, 2003; Zahan *et al.*, 2021). Recently many herbicides have

been available in the market which are needed for validation for controlling weeds as well as saving the environment from pollution and also to limit herbicides resistant to weeds (Singh *et al.*, 2015; Hossain *et al.*, 2015; Zahan *et al.*, 2020). However, information on herbicide efficacy in wheat is sporadic or lacking in Bangladesh (Jahan *et al.*, 2021; Ali *et al.*, 2022). At present, many pre- and post-emergence herbicides are available for controlling weeds. Several earlier findings pertinent to the performance of pre- and post-emergence herbicides for controlling weeds, and their effectiveness in ZT-rice, wheat and maize production systems have been reviewed in this chapter.

2.1. Yield losses of crops due to weeds in Bangladesh

The agroecological condition of Bangladesh is highly congenial for a huge diversity and vigorous growth of weeds throughout the year. More than 65 weed species were found in the crop fields, of which 16 were found grasses, 8 were sedges and 41 were recorded as broadleaved (Karim *et al.*, 1999; Shrestha *et al.*, 2021). The majority of the weed species belonged to the families Poaceae (16), Cyperaceae (8), Amaranthaceae (5), Solanaceae (4), Asteraceae (3), Pontederiaceae (3), Fabaceae (3) and Commelinaceae (3). Among these aquatic weeds (54) in monsoon rice in Bangladesh, 37 were noted as broadleaved, 12 were grasses and 5 were recorded as sedges (Mamun *et al.*, 1987; Shrestha *et al.*, 2021). Mamun *et al.* (1987) conducted a survey and found 26 weeds in transplant Aman rice, 19 weeds in boro rice, 26 weeds in deep-water rice and 57 weeds in other non-cropped areas, respectively. Among these species generally growing in crop fields, around 20% have been recognized as naturalized exotic weeds (Karim, 2008; Shrestha *et al.*, 2021).

A study found that the number of weed species in an area generally depends on the land use pattern and its ecological conditions (Khatun *et al.*, 2019). The common weeds in a cultivated field in Bangladesh are about 350 species. Of these weeds, about one-third of the plants are

monocotyledonous, and the remaining plants are dicotyledonous. Considering the major families of common weed species, Poaceae, Cyperaceae, Leguminosae, Asteraceae, Euphorbiaceae, Amaranthaceae, Solanaceae Scrophulariaceae and Acanthaceae are the most important. The most successful and common genera are Cyperus, Lindernia, Eragrostis, Panicum, Cynodon, Hygropylla, Euphorbia, Phyllanthus, Leucas, Scoparia, Croton, Celosia, Alternanthera and Solanum. In aquatic conditions, Eichhornia, Potamogeton, Pistia and Monochoria spp. are the most common weeds in deep-water rice fields (Karim *et al.*, 1999; Khatun *et al.*, 2019).

A survey was conducted by Chanda *et al.* (2021) at farmers' fields in five Upazilas of the Sirajganj district of Bangladesh to find out farmers' knowledge of crop-weed association in different field crops, crop yield losses and weeds act as alternate hosts for insect-pathogen during 2019 to 2020 cropping seasons. A total of 40 weed species belonging to 35 genera under 21 families were identified from 8 different field crops. The highest crop-weed association was found in the rice field (40:192), and the lowest was observed in the mustard field (106:50). Yield loss due to weed was recorded between 8 to 51% in different field crops. The maximum weed management cost occurred in rice (Tk 38,900 ha⁻¹). Among these observed weeds, *Cyperus rotundus* L. emerged as the major noxious weed for five field crops in this district (Chanda *et al.*, 2021).

Another observation was conducted by Kobir *et al.* (2021) in the south-western part of Bangladesh and found 13 weed species under 12 genera and 08 families with various ailments. Considering weeds' families, Amaranthaceae is the highest-represented family with 03 species. Among the genera, the largest genera Amaranthus represented two species. The weed species *Cyperous rotundus*, *Cynodon dactylon*, *Chenopodium album*, *Amaranthus spinosus*, *Croton bonplandianum*, and *Coccinia grandis* were found common and major weed species in the field of pulse crops recorded in this area.

An estimation of crop losses of 27 crop species due to weed competition has been done based on several experimental data available in Bangladesh as reported by Karim (1998), who stated that on average, 37.33% of crop production is damaged due to weeds. However, an average of 13.1% of crop production is lost in the farmers' fields even after adopting traditional weed controls. For example, yield losses due to weeds in food crops including cereals, pulses, oilseeds, fibre crops and rice are 33.16, 41.26, 31.88, 40.82, 34.23 and 40.28%, respectively. Valued of these crops' loss approximately Tk 59665.70 million might be lost annually due to the weeds in the country. However, weeds may cause a loss of 9.66 million tons of food valued at Tk 56711.12 million (US\$1383 million) annually if weeds are not controlled in crop fields as reported by Karim (1998).

2.2 Weed management in zero-till wheat

2.2.1 Importance of zero-till wheat production

In recent years there has been an increasing interest in the research of rational tillage systems such as reduced, minimum or no-tillage for cereal crops in Croatia as an alternative to conventional soil tillage because of environmental and economic reasons (Košutić *et al.*, 1998; Jug *et al.*, 2006). Reduced tillage systems have a major impact on the composition of weed species and the density of weed populations (Arshad *et al.*, 1994). Considering the wheat season, particularly in temperate regions, generally weed infestation is greater in winter wheat than in spring wheat (Knežević, 2003, 2008, 2012). Weed control programs developed under conventional tillage (CT) systems are seldom appropriate for reduced tillage systems. Therefore, introducing reduced soil tillage systems in cereal cropping, and weed control programs must be accommodated to tillage systems (Pallut and Bennewitz, 1996). Rational tillage systems and the usage of environmentally safe herbicides in post-emergence weed control are compatible with integrated weed management (Swanton and

Weise, 1991). Zero tillage allows early and timely sowing of wheat and reduces the cost of production. In zero-tillage, the crops are sown with minimum disturbance of soil by placing the seeds in a narrow slit 3-4 cm wide, and 4-7 cm deep without land preparation. The proper tillage operation saves water, reduces lodging, and ensures better fertilizer use (Monsefi *et al.*, 2016).

2.2.2 Constraints of zero-till wheat production

The weeds are one of the major constraints in the adoption of zero-tillage (ZT) technology in wheat. Although ZT reduces the infestation of *Phalaris minor*, it aggravates the problem of broad-leaved weeds (Yaduraju and Mishra, 2002). Effective weed control is important not only to check the yield losses due to weeds but also to reduce nutrient losses. In a long-term experiment conducted in Karnal (Haryana-India), Singh *et al.* (2002) found that the intensity of *P. minor* decreased by 30-40% in the ZT system compared to conventional tillage, while the intensity of broadleaved weeds increased. Laxmi *et al.* (2003) and Singh *et al.* (2010) also reported that 51% of farmers in Haryana and 85% of farmers in Bihar perceived that weed infestation had decreased due to the adoption of ZT in wheat. They also found a lower *P. minor* population and dry weight recorded under ZT and higher under the CT system of wheat cultivation. Therefore, optimizing tillage, crop establishment and weed control are essential for improving resource use efficiency and crop productivity (Monsefi *et al.*, 2016).

2.2.3 Weed flora in association with zero-till wheat

The predominant weeds associated with wheat under the rice-wheat (R-W) system are little seed canarygrass, annual bluegrass (*Poa annua* L.), foxtail grass (*Polypogon monspeliensis* Desf.), wild oat (*Avena ludoviciana* Durieu), Indian sorrel or toothed dock (*Rumex dentatus* L.), pimpernel

(*Anagallis arvensis* L.), field bindweed (*Convolvulus arvensis* L.), little mallow (*Malva parviflora* L.), bur clover (*Medicago 15endimethal* Willd), common lambs quarters (*Chenopodium album* L.), common vetch (*Vicia sativa* L.), meadow pea (*Lathyrus aphaca* L.), Canada thistle (*Circium arvense* L.), white sweet clover (*Melilotus alba* Lamk), swine grass (*Coronopus didymus* L.), alpine knotweed (*Polygonum plebejum* R. Br.), purple nutsedge (*Cyperus rotundus* L.), bermudagrass (*Cynodon dactylon* L. Pers.), and corn spurry (*Spergula arvensis* L.) (Kumar *et al.*, 2013).

Weed flora in wheat differs from field to field, depending on environmental conditions, irrigation, fertilizer use, soil type, weed control practices and cropping sequences as reported by Chhokar *et al.* (2006). They also reported that the predominant weeds associated with conventional till wheat are *Phalaris minor*, *Poa annua*, *Polypogon monspeliensis*, *Avena ludoviciana*, *Rumex dentatus*, *R. spinosus*, *Anagallis arvensis*, *Convolvulus arvensis*, *Malva parviflora*, *Medicago 15endimethal*, *Chenopodium album*, *Vicia sativa*, *Lathyrus aphaca*, *Circium arvense*, *Melilotus alba*, *Coronopus didymus*, *Polygonum plebejum* and *Spergula arvensis*. Among grassy weeds, *P. minor* and among broad-leaved weeds, *Rumex dentatus* and *Medicago 15endimethal* are of major concern in irrigated wheat under the rice-wheat system in India (Chhokar *et al.* 2006). Another observation conducted by Monsefi *et al.* (2016) reported that the major weed flora in the wheat field is *Chenopodium album* (12%), *Melilotus indica* (11.5%), *Anagallis arvensis* (10%), *Cricium arvensis* (15%) and *Rumex dentatus* (9%). Among broad-leaved species *Phalaris minor* (20%) is the most important one and among grassy species *Avena fatua* (17%) is the most infesting weed species. Chhokar and Malik (2002); Chhokar and Sharma (2008) and Franke *et al.* (2003) stated that among noxious weeds in wheat fields, little seed canary grass is the single most important grassy weed; since it has a highly competitive ability leads to a significant yield loss ranging from 25 to 80% depending on the severity of infestation. They also found that little seed canary grass

species have evolved resistance to multiple herbicides, especially in the northwest IGP, leading to limit wheat productivity. The ability of this weed to survive the anaerobic conditions in rice has made it fit for the R-W system (Chhokar, 1998). In contrast, the sensitivity of wild oat to prolonged water stagnation in rice is responsible for their elimination from the R-W system, except in very light soils (Kumar *et al.*, 2013).

The shift from CT to ZT in wheat has resulted in a shift in weed flora. The emergence of little seed canary grass is lower under ZT than CT in wheat (Chhokar *et al.*, 2007; Franke *et al.*, 2007), but higher for some of the broadleaved weeds, such as Indian sorrel (Chhokar *et al.*, 2007). Lower little seed canary grass emergence under ZT is unlikely due to differences in the vertical distribution of seeds in soil under the two tillage systems because seeds are thoroughly mixed during puddling operations done in the rice season (Franke *et al.*, 2007). The lower emergence of little seed canary grass under ZT may be attributed to higher soil strength in ZT because of crust development in the absence of tillage after rice harvest, which can mechanically impede seedling emergence (Chhokar *et al.*, 2007).

2.2.4 The critical period of crop weed competition in wheat

Weeds are an important biological factor in crop production that causes yield reduction and it contributes around 45% of crop yield loss. The weed life cycle is similar to crops and some weeds have the same morphological character as crop plants and farmers difficult to identify them at the early crop growth stage. So, the main concern is to know the critical time for crop weed competition, the effect of weeds on plant growth and development, physiological changes, yield performance weeds studies including density, different weed floras and its dry matter accumulation, and final competition of weeds with crops. Increasing the initial weed competition

period reduces crop germination, and at the later stage of crop growth reduces the growth and development parameters like plant height, dry matter accumulation, leaf area index, physiological parameters like crop growth rate, relative growth, net assimilation rate, chlorophyll content, leaf thickness are reduced. Similarly, increasing weed competition reduces crop yield drastically (Korav *et al.*, 2018).

Crop-weed competition is nothing but the struggle for existence and superiority. Competition exerts a powerful force in the plant community, irrespective of the mechanism, tending towards the limitation or extinction of the weaker competitors (Froud-Williams, 2002). Other findings stated that weed competition is maximum when available resources for crop growth become limited (Buhler, 2004; Hossain *et al.*, 2010a). Competition is a negative interaction where individuals make simultaneous demands that exceed limited resources, while both suffer, one individual suffers less. So, crop weed competition indicates competition between crops and weeds in a natural ecosystem in response to resources' struggle for their existence and superiority. Crop weed competition occurs in two broad aspects: i) Direct competition- for nutrients, moisture, light and space, and ii) Indirect competition- through exudation and/or production of allelopathic chemicals (Curran, 2004). The critical period of weed growth can be defined as the shortest period in the ontogeny of crop growth when weeding results in the highest economic returns (Agostinetto *et al.*, 2008).

Chopra *et al.* (1999) conducted a field experiment in consecutive two Rabi seasons in Karnal, India to study the weed crop competition in wheat (cv. HD-2329) and found that uncontrolled weeds caused 30.7% seed yield loss as compared to season-long weed-free conditions. They also noted that weed competition for the first 30 days did not reduce the yield significantly; but when weeds were allowed to compete beyond 30 days i.e., up to 45 days or longer, a significant reduction in yield was observed. Keeping the crop free from weeds for initial 30 days only yields were

reduced significantly. Therefore, the critical period of weed crop competition was worked out to be the first 32 to 40 DAS in springer wheat (Chopra *et al.*, 1999).

A field experiment was conducted at the Agronomy Field of Bangladesh Agricultural University (BAU), Mymensingh during the period from November 2001 to March 2002 to investigate the effect of *Chenopodium album* competition on the growth and yield of wheat, and to determine the critical period of weed (*C. album*) competition in wheat (Mondol *et al.*, 2007). Yield reduction of wheat due to *C. album* competition at 20, 40, 60, 80, and 110 DAE were 12.65, 28.10, 29.11, 31.64, and 32.9%, respectively. The highest rate of yield decrease was between 20 and 40 DAE. The highest reduction of wheat yield under weedy check treatment (32.91% grain and 33.75% straw) was the result of a 31% reduction of total tillers/plant, 43.34% reduction of effective tillers/plant, 14.57% reduction of grains/spike, 34.5% reduction of the total dry weight of wheat. The plant height of *C. album* was reduced due to wheat competition by 32.3% and that of total dry matter by 34.2 %. The critical period of weed competition lies between 20 and 40 DAE (Mondol *et al.*, 2007).

2.2.5 Weed control in zero-till wheat through post-emergence herbicides

The use of herbicides is increasing with cropping systems day by day due to providing effective and economical weed control, which has become more scarce and expensive (Rao *et al.*, 2007). Hence, it is of paramount importance to work out weed management technology in ZT wheat. Mukhopadhyay and Roj (1971) conducted a zero-till experiment in West Bengal (India) by using the non-selective herbicide paraquat and reported that in zero tillage 3.75 L/ha of paraquat application produced more rice yield as compared to CT supplemented with one hand weeding (HW). A study revealed that wheat grown as a succeeding crop in the same field also obtained

more grain yield in ZT as compared to CT. Walia *et al.* (2005) reported that wheat sown with zero till after spray of paraquat exhibited significantly less dry matter of *P. minor* as compared to zero till sown wheat without paraquat application as well as CT sown crop. Hence, it was realized that chemical weeding with the application of non-selective herbicide would be a key factor in the management of weeds and the success of zero tillage in wheat.

A study was conducted in Punjab-India by Singh *et al.* (2015), who observed that *P. minor* is not evolved resistance to isoproturon, and application of isoproturon at 600-1000 g/ha before or after first irrigation provided effective control of *P. minor*, *A. ludoviciana* and *Poa annua*, and many broad-leaved weeds in CA-based ZT-wheat. They also observed that in areas, where *P. minor* has evolved resistance to isoproturon, application of Pinoxaden 50 g, Sulfosulfuron 25 g, Clodinafop 60 g, fenoxaprop 100 g ha⁻¹ at 30-35 DAS of wheat provided effective control of *P. minor* and *A. ludoviciana* in ZT wheat. In the case of broad-leaved weeds like *C. album*, *Anagallis arvensis*, *Medicago endimethal*, *Coronopus didymus*, *R. dentatus* etc., 2,4-D sodium salt or 2,4-D ethyl ester at 400-500 g ha⁻¹ at 35-45 DAS in normal sown and at 45-55 DAS in late sown wheat crop (December) are effective (Singh *et al.*, 2015).

Another study was conducted in Pakistan by Naseer-ud-Din *et al.* (2011) to know the efficacy of various pre- and post-emergence herbicides viz., Pyroxasulfone @ 0.15 kg a.i. ha⁻¹, Terbutryn + Triasulfuron @ 0.18 kg a.i. ha⁻¹, and Flufenacet + Pyroxasulfone @ 0.24 + 0.15 kg a.i. ha⁻¹ as pre-emergence, and Flufenacet @ 0.24 kg a.i. ha⁻¹, Carfentrazone ethyl + Isoproturon @ 0.018 kg a.i. ha⁻¹, Bromoxynil + MCPA @ 0.49 kg a.i. ha⁻¹ as post-emergence and hand weeding at (20 & 40 DAS) with a weedy check against narrow and broad-leaved weeds in wheat during Rabi season 2008-09. The results revealed that *Fumaria indica*, *Melilotus indica* and *Rumex dentatus* density significantly decreased by all the herbicides compared with the control.

Bromoxynil + MCPA @ 0.49 kg a.i. ha⁻¹ as the post-emergence application was most effective in controlling *F. indica*, *M. indica* and *R. dentatus* with the maximum mortality at both (30 & 60 DAS) without being phytotoxic to wheat. Bromoxynil + MCPA @ 0.49 kg a.i. ha⁻¹ as post-emergence spray proved significantly better than other herbicide treatments as it severely reduced the weeds' biomass as compared to weedy check (Naseer-ud-Din *et al.*, 2011).

The performance of two herbicides was evaluated in consecutive two wheat seasons under strip-till planted wheat, for example, Pendimethalin as pre-emergence and Carfentrazone-ethyl + isoproturon as post-emergence. After two years of observation, eight weed species were recorded during the first year and 14 species were identified in the second year. Among them, three grasses such as *Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop., and *Echinochloa colona* (L.) Link., and one broadleaved weed *Physalis heterophylla* (L.) Nees., were found to be the dominant weed species in both years. During the first season, the dominant weed species in strip-planted wheat were *Physalis heterophylla* (L.), and *Digitaria sanguinalis* (L.) Scop. Was dominant in the second year. The study revealed that the sequential application of Pendimethalin as pre-emergence treatment followed by Carfentrazone-ethyl + isoproturon as post-emergence treatment was most effective and economically viable for weed control in strip-till wheat because they achieved the highest grain and straw yields (Zahan *et al.*, 2021).

2.3 Weed management in zero-till maize

Weed is one of the major problems in the maize field. Therefore, weed control is one of the important means of successful maize production. Weed control by chemical means is a common practice in many countries of the world due to its advantages over other methods like cost-effectiveness and time-consuming. In Bangladesh, the availability of pre-and post-emergence

herbicides is still lacking in the market and farmers do not have proper knowledge for their proper use. Considering the issue, some earlier studies relevant to the performance of pre- and post-emergence herbicides for controlling weeds, and the effectiveness of weed reference to ZT maize have been reviewed in this section.

2.3.1 Importance of zero-till maize production

Increasing population, as well as land and water scarcity, have become the main challenges for food security which creates pressure on agricultural production. Therefore, ZT maize production is gaining increasing importance. The farmers are required to increase resource of variation use efficiency, to meet the growing food demand as well as to reduce the pressure on the natural resource of variations. Thus, consumers can get quality food at affordable prices. Another requirement is the increment of production, to the background of meeting the demand along with protection of soil, water, biodiversity, etc., and to contribute to the mitigation of greenhouse gases (Basch *et al.*, 2012). However, to achieve agricultural sustainability or sustainable intensification, many problems have to be solved including land degradation, water stress, climate change, deforestation, overexploitation of resource variations, etc. (Lopez-Bermudes *et al.*, 1998). Land degradation is one of the most severe and important problems as it involves soil, water, rocks, climate, relief and forestation (Stocking and Murnaghan, 2001).

Soil erosion is also one of the major causes of land degradation. The total land area affected by soil erosion through water and wind is 1643 million ha, while the area affected by water erosion is 1094 million ha of which 751 million ha is severely affected (Lal, 2003). Soil erosion-affected areas in Asia and Africa are 407 and 267 million ha, respectively. There is a 132 million ha area under soil erosion in Europe, in which 93 million ha is affected by water erosion and 39 million is

from wind erosion (Lal, 2003). ZT maize production is one of the practices to mitigate this problem. Therefore, CA-based cultivation is the prerequisite for mitigating future food security under the changing climate. CA is based on the principles of soil reconstruction, maximizing crop production inputs, including labour, and optimizing profits (Dumanski *et al.*, 2006). The main characteristics of CA production systems are optimization of the crop yield, farm income and minimization of the negative environmental impacts associated with conventional agriculture. Reduced tillage maintains at least 30% residue coverage on the soil surface (Morris *et al.*, 2010). Residue coverage influences lower moisture evapotranspiration, higher soil water content and soil structural stability, which is considered as more effective prevention of soil erosion (Romaneckas *et al.*, 2013), and higher economic effectiveness (Sarauskis *et al.*, 2013). Limousin and Tessier (2007) reported that each year a large area of arable land in the world is destroyed due to compaction and soil erosion. The use of appropriate strategies to reduce nutrient losses and soil erosion is essential. CT systems include reduced tillage and no-tillage is one of the useful methods to avoid this problem (Limousin and Tessier, 2007). In a study conducted in the Philippines, it was found that the CT system resulted in a 9 to 18% increase compared to the no-tillage corn yield, and the seed rate was 17 to 19% (Chen *et al.*, 2011). CT can increase soil moisture and reduce soil temperature increasing the yield of maize. Zero tillage Rabi maize resulted in higher net returns when compared to CT-grown Rabi maize. Studies reported variability in net returns from high to low depending on the cost of inputs and variations in crop yields (Khakbazan *et al.*, 2012). Farmers found a significant change in yield levels, and this technology has demonstrated much yield increase by gains in net returns, and the reduction of tillage cost is around 152.96 US\$ to 91.77 US\$ from an attractive proposition to adopt this technology in future (Jeengar *et al.*, 2006).

2.3.2 Constraints of zero-till maize production

Weeds are among the serious constraints that limit maize production. The competition between weeds and maize is induced by reducing the quality and quantity of maize yield by over 30% (Mahmoodi *et al.*, 2009). In addition, weeds interfere with crop growth and yield through the acquisition of required resources of variations including light, water and nutrients, and are potentially a major constraint on crop production if not controlled (John *et al.*, 2010). To minimize weed losses, several methods are available such as mechanical, cultural, biological and chemical control methods. Exhausted by cultural methods, farmers are moving towards other alternative methods of weed control (Varga *et al.*, 2011). In this respect, chemical weed control may be considered the best option than others (Ahmed *et al.*, 2008). Mechanical methods including hand weeding are still useful but are getting expensive, laborious and time-consuming. In less developed countries, the situation still exists where the peak labour requirement is often for hand weeding (Chekoye *et al.*, 2007). Herbicide-based weed control is an important alternative to manual weeding because it is cheaper, faster and gives better weed control (Chikoye *et al.*, 2005). Chemical control is a better alternative to manual weeding because it is cheaper, faster, and gives better control (Chikoye *et al.*, 2004).

2.3.3 Weed flora in association with zero-till maize

In clay loam soils of Guntur (Andhra Pradesh), the dominant weed flora in maize fields were *Echinochloa colona* (L.) Link (41%), *Dinebra retroflexa* (Vahl) Panzer (4%), *Panicum repens* L. (3%) and *Cynodon dactylon* (L.) Pers. (2%), *Leptochloa chinensis* (L.) Nees (5%) (Grasses), *Cyperus rotundus* L. (5%) (Sedges), *Chrozophora rottleri* (Geisel) A. Juss. Ex Spreng. (15%), *Trianthema portulacastrum* L. (13%), *Digeraarvensis* (4%), *Merremia emerginata* (Burm. F.)

Hall. F. (3%), *Phyllanthus niruri* (3%) and *Euphorbia hirta* L. (2%) (Broad-leaved weeds) (Rao *et al.*, 2009). Another study conducted by Mukundam *et al.* (2011) reported that *C. rotundus* and dicots *T. portulacastrum*, *D. arvensis*, *P. niruri* and *C. dactylon* among grasses were the most dominant in the maize field.

In clay loam soils of Warangal, India, Reddy *et al.* (2012) found the dominant weed species in maize fields of *E. colona* (13%), *D. retroflexa* (11%), *P. repens* (8%) and *L. chinensis* (7%) as grasses, *C. rotundus* L. (8%) as sedges and *C. rotlieri*. (11%), *T. portulacastrum* (9 %), *D. arvensis* (9%), *M. emerginata* (12%), *P. niruri* (3%) and *E. hirta* (9%) as broad-leaved weeds. Another study carried out by Parameshwari (2013) in sandy loam soils of Hyderabad, India revealed that grasses *E. colona*, sedges *C. rotundus* and predominant broad-leaved weeds *Ageratum conizoides* and *T. portulacastrum* were the most important weeds in maize fields.

A weed survey for three years in the Krishna zone of Andhra Pradesh revealed that a ZT-sown maize crop was infested with a total of 21 weed species, of which grasses, sedges and broad-leaved weeds were 7, 3 and 11, respectively. Among the weeds, *E. colona* was the most dominant species (37.64), followed by *P. repens* (32.29), *T. portulacastrum* (16.33), and *D. arvensis* (13.37) (Kiran and Rao, 2014). In sandy loam soils of Rajendra Nagar during Rabi 2014, the predominant weed flora observed in ZT maize during crop growing season at 30 DAS were *C. rotundus*, *E. crusgulli*, *Paspalum distichum*, *T. portulacastrum*, *Parthenium hysterophorus*, *Sonchus oleraceus*, *Acalypha indica* and *Eclipta alba* (AICRP-WM, 2014). Pleasant *et al.* (1995) conducted a field experiment in the USA, and the most common broad-leaved weed species observed in a maize crop were *Chenopodium album*, *Asclepias syriaca*, *Anbrosia artemisiifolia*, *Physalis heterophylla* and *Polygonum rensvlanicum*, and the most common grasses were *Elymus repens* and *Setaria pumila*. Bernhardt *et al.* (1991) conducted a weed survey in a total of 250 maize and beet fields in the

Osnabruk region in 1987 and identified *Chenopodium album*, *Polygonum persicaria*, *Lamium purpureum* and *Viala arvensis* as the most common weed in the maize and beet fields.

2.3.4 The Critical period of crop weed competition in maize

For better yield and quality, controlling weeds during the critical period of crop growth is important. Identification of the critical period for weed control (CPWC) in major crops is one of the first steps in designing a successful integrated weed management (IWM) program (Knezevic *et al.*, 2013; Knezevic and Datta, 2015; Tursun *et al.*, 2016), and the use of the critical period threshold model will assist in improved farm level decision making (Knezevic *et al.*, 2015). The CPWC is the length of time that the crop must be kept weed-free to prevent yield losses at a certain level (Knezevic *et al.*, 2013). The CPWC is determined by measuring the time interval between two separately measured crop-weed competition components: (i) the critical duration of weed interference, and (ii) the critical weed-free period (Knezevic and Datta, 2015; Tursun *et al.*, 2016).

The critical duration of weed interference is defined as the maximum length of time early emerging weeds can interfere with the crop without causing any unacceptable yield loss (Knezevic and Datta, 2015). The critical weed-free period is defined as the minimum length of time required for the crop to be maintained weed-free before yield loss caused by late emerging weeds is of no practical concern (Knezevic *et al.*, 2013). From a practical standpoint, crop yield losses from weed interference before or after the CPWC will be of limited interest (Knezevic *et al.*, 2013). Many studies have been conducted worldwide to determine the CPWC in various crops under a range of environmental conditions (Knezevic *et al.*, 2013, Tursun *et al.*, 2016). Several studies conducted in different crop fields under diversified environmental conditions might not apply to all kinds of

systems due to location differences including soil and climatic conditions as well as weed populations (Tursun *et al.*, 2016).

2.3.5 Importance of herbicides in weed control in maize

Traditionally, manual hand weeding has been the predominant method of weed control used by maize farmers in Asia (Shad *et al.*, 1993). If performed with enough frequency and at the right times, hand weeding is equivalent to the use of herbicides concerning the yield of maize (Prasad *et al.*, 2008). However, because of the shortage of labour and frequent monsoon rains during the early growth period of maize, hand weeding is often delayed or neglected altogether (Prasad *et al.*, 2008). As a result, severe uncontrolled weed infestations have been identified as one of the major reasons for low maize yields in Asia (Hussain *et al.*, 2010). In India, research demonstrated that herbicide treatments in maize produced 83% more yield in comparison with the practice of ploughing the fields to remove weeds (Tareen *et al.*, 1991). In Japan, herbicide adoption reduced the amount of time required for weeding operations by 97% (Takeshita and Noritake, 2001). In the United States, increased herbicide use accounted for 20% of the increase in corn yield, and 62% of the increase in soybean yield from 1964 to 1979 (Schroder *et al.*, 1984). The falling price of the predominant knockdown herbicide, glyphosate, had a significantly positive effect on the adoption of ZT, with 78% of farmers practising ZT in 2008 (Llewellyn and D’Emden, 2009). In Africa, shortages of labour early in the season result in delayed weeding and subsequent maize yield losses of 15-90% due to weed competition (Kibata *et al.*, 2002). The use of herbicides in Kenyan weed trials resulted in 33% higher maize yields than with the farmer’s practice of hand weeding on account of better weed control (Muthamia *et al.*, 2001).

2.3.6 Weed control in zero-till maize by chemical measures

Weed control in maize is the most important treatment. Management of weeds is considered to be an important factor in achieving higher productivity. To minimize weed losses, several methods are available such as mechanical, cultural, biological and chemical control methods. Exhausted by cultural methods, farmers are moving towards other alternative methods of weed control (Mahmoodi *et al.*, 2009; Varga *et al.*, 2011). Again, due to increased cost and non-availability of manual labour in the required quantity for hand weeding, the role of herbicide is significant preposition herbicides not only control the weeds timely and effectively but also offer great scope for minimizing the cost of weed control irrespective of the situation (Mahmoodi *et al.*, 2009; Varga *et al.*, 2011).

In this respect, chemical weed control may be considered the best option. The chemical control method is a quick, more effective, time and labour-saving method than others (Ahmed *et al.*, 2008). However, it is important to use a broad-spectrum herbicide program including pre-and post-emergence herbicides for season-long effective weed control, and to avoid shifts toward problematic weed species (Singh, 2008) or evolution of herbicide-resistant weed biotypes. On the other hand, it is crucial to select the right herbicide depending on the weed flora present in a given field. In addition, the correct rate, timing, and application techniques should be used. A variety of herbicides have been screened and found effective pre- and post-emergence weed control in dry direct drill-seeded rice systems, including under ZT conditions (Kumar and Ladha, 2011).

The use of pre- and post-emergence application of herbicides would make herbicidal weed control more acceptable to farmers which will not change the existing agronomic practices but will allow for complete control of weeds. Pre-emergence application of herbicides will control the weeds for upto 25 days and after that post-emergent application is given so that further growth of

weeds can also be controlled. Pre-emergence and post-emergence herbicides will be an ideal means for controlling weeds because of the economics and effectiveness of maize (Singh, 2008; Kumar and Ladha, 2011).

2.3.7 Pre-emergence herbicides for weed control in zero-till maize

Herbicides applied after corn planting, but before emergence and having soil residual activity, are known as pre-emergence herbicides. Wilson and Sbatella (2014) showed that pendimethalin can be utilized pre- to provide acceptable weed control and crop selectivity. Fazal *et al.* (2009) reported that Pendimethalin at pre-emergence decreased weed population, and increased grain yield over weedy control. Thus, Mekky *et al.* (2002) reported that the use of herbicides successfully reduced the infestation of weeds and increased maize yield. The variation in the reduction of the dry weight of total annual weeds among various herbicidal treatments might have been due to differences in the mode of action and inhibition effect on the growth and development of weeds (Ahmed *et al.*, 2008). They also reported that there had been significant differences in the dry weight of weeds at different weed control treatments. Also, differences in weed control efficiency (WCE) among herbicidal treatments may be due to the spectrum of weed control, whereas metribuzin and acetochlor gave effective control of many grass and broad-leaf weeds, however, Pendimethalin and Sulcotrione are effective in controlling different types of grasses and broad-leaf weeds, which resulted in significantly different weed control. These results are in close agreement with the results obtained by Varga *et al.* (2011) who concluded that there were significant differences among different herbicides regarding weed control efficiency (WCE).

In clay loam soils of Guntur, Andhra Pradesh (India), Rao *et al.* (2009) conducted a field experiment with zero tillage maize without using non-selective herbicides. Among herbicides, pre-

emergence application of Atrazine 1.5 kg ha^{-1} *fb* hand weeding (HW) at 30 DAS or pre-emergence application of Atrazine 1.5 kg ha^{-1} alone recorded higher plant height and dry matter over an unweeded check at all stages of crop growth. A study conducted by Parameswari (2013) revealed that significantly higher plant height and dry matter production of maize was obtained when maize was grown after transplanted rice under ZT conditions among different crop establishment methods. Higher plant height and crop dry matter were observed with HW twice at 20 and 40 DAS, and it was *fb* pre-emergence application of Atrazine 1.0 kg ha^{-1} *fb* Topramezone 0.030 kg ha^{-1} (Parameswari, 2013). In clay loam soil of Hyderabad under Rajendranagar conditions (Telangana) the highest crop dry matter was noticed with hand weeding twice at 20 and 40 DAS and was at par with the pre-emergence application of Atrazine 1.0 kg ha^{-1} + paraquat 0.60 kg ha^{-1} , and pre-emergence application of oxyfluorfen 0.150 kg ha^{-1} + paraquat 0.60 kg ha^{-1} (AICRP-WM, 2014).

In another study, either two HW at 3 and 6 WAS or inter-cultivation with a power weeder at 4 WAS recorded significantly higher grain yield under CT and ZT methods. Among the herbicides sequential application of either Atrazine as pre-emergence 1.25 kg/ha *fb* Paraquat 0.6 kg ha^{-1} at 3 WAS or Pendimethalin as pre-emergence 1.5 kg ha^{-1} *fb* Paraquat 0.6 kg ha^{-1} at 3 WAS (Srividya *et al.*, 2011). Reddy *et al.* (2012) experimented with herbicides alone and tank mix application of selective and non-selective herbicides showed that the grain yield obtained with tank mix application of Atrazine + Glyphosate (5.25 kg ha^{-1}) was 170 and 70% more than weedy check and sole Atrazine, respectively. In sandy clay loam soils of Kampasagar (Telangana), Pasha *et al.* (2012) reported that tank mix application of Atrazine 1.25 kg ha^{-1} + Paraquat 0.75 kg ha^{-1} as pre-emergence produced significantly higher grains cob^{-1} , cob diameter and 1000-grain weight than other herbicides. Comparable grain yields were recorded with Atrazine alone as pre-emergence 1.25 kg ha^{-1} (6.7 kg ha^{-1}), and Atrazine 1.25 kg ha^{-1} + Glyphosate 0.5 kg ha^{-1} (7.0 kg ha^{-1}) as pre-

emergence application. Under sandy loam soil of Hyderabad, two HW at 20 and 40 DAS resulted in the highest yield attributes and yield, followed by pre-emergence application of Atrazine 1.0 kg ha⁻¹ *fb* (followed by) Topramezone 30 kg ha⁻¹ at 30 DAS, and Atrazine 1.0 kg ha⁻¹ as pre-emergence alone (Parameswari, 2013).

Under sandy clay loam soils of Rajendranagar, significantly higher grain yield (5.63 kg ha⁻¹) and stover yield (6.11 kg ha⁻¹) was obtained with HW twice at 20 and 40 DAS and was at par with either tank-mixture pre-emergence application of Atrazine 1.0 kg ha⁻¹ + Paraquat 0.60 kg ha⁻¹ or Oxyfluorfen 0.15 kg ha⁻¹ + Paraquat 0.60 kg ha⁻¹ (AICRP-WM, 2014). Under irrigated conditions of clay loam soils of Bapatla, Srividya *et al.* (2011) reported that pre-emergence application of Atrazine 1.5 kg ha⁻¹ or Pendimethalin 1.5 kg ha⁻¹ *fb* Paraquat 0.6 kg ha⁻¹ at 3 WAS recorded significantly lower N, P and K uptake by weeds over-application of Atrazine or Pendimethalin alone. The application of Atrazine 1.0 kg ha⁻¹ pre-emergence *fb* Topamazon 0.030 kg ha⁻¹ at 30 DAS was found effective in reducing nutrient uptake by weeds. A 3-year study conducted in Canada reported that the addition of Atrazine to pre-emergence herbicides increased weed control (25%), improved herbicide performance consistency, increased corn yields (8%), increased adjusted gross return, and reduced risk over sites and years (Swanton *et al.*, 2007).

2.3.8 Post-emergence herbicides for weed control in zero-till maize

Herbicides applied after corn and weed emergence are known as post-emergence herbicides. Post-emergence herbicides can be broadcast-applied on crops and weeds or with the equipment that directs the herbicide to weeds and minimizes exposure of the crop. Herbicides that were found to be effective for post-emergence weed control in the zero-dry till maize and DSR rice system are Atrazine, Tembotrione, Halosulfuron methyl, Tembotrione + Atrazine, Halosulfuron methyl +

Atrazine, Pyrazosulfuron, Bispyribac-sodium, Fenoxaprop-ethyl, Penoxsulam, Fenoxaprop-ethyl + Safner, Cyhalofop-butyl, Propanil, Azimsulfuron, Ethoxysulfuron, Triclopyr, 2,4-D Ethyl Ester, Carfentrazone, Chlorimuron + Metsulfuron, Bispyribac + Azimsulfuron (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015).

However, continuous use of a single herbicide on a long-term basis should be avoided; rather, it should be rotated with another herbicide with a different mode of action to avoid/delay resistance development. Tank mixtures of herbicides can be used when two or more herbicides are compatible to broaden the spectrum of weed control in such a way that each herbicide controls the weeds missed by the other one (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). The herbicide mixtures listed above were found effective for controlling various types of weeds, including grasses, broadleaves, and sedges (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). Atrazine has been in use since 1958 and is applied on several million hectares of crop fields in the USA and several other countries. Atrazine is the base for the weed control program in corn in the USA. It is widely used because of its low cost, control of a broad spectrum of broadleaved weeds, flexible application timing, such as pre-emergence or post-emergence and compatibility with several other herbicides as a mixture. However, a long-term finding revealed that continuous use of Atrazine resulted in the accumulation of Atrazine, and its breakdown products in the environment, groundwater, and aquatic systems (Ahel *et al.*, 1992; Ying *et al.*, 2005).

2.4 Weed management of zero-till direct seed rice (DSR)

Weed is one of the major problems in the ZT direct-seeded rice (DSR) fields. So, weed control is one of the important means for successful rice production in ZT conditions. Weed control

by chemical means in ZT-based crop production systems is a common practice in many countries of the world due to its advantages over other methods. Research work in the field of weed control related to ZT-based rice production systems is still scanty in Bangladesh. In developed countries, herbicides are extensively used to control weeds in DSR rice fields. However, in Bangladesh, weeds in rice fields are controlled manually and through different cultural practices. In Bangladesh, there is a lack of control of weeds in the rice field through pre- and post-emergence herbicides, due to their availability. Considering the issue, some studies relevant to the performance of pre and post-emergence herbicides for controlling weeds, and the effectiveness of weed reference to zero/strip DSR rice have been reviewed in the following sub-sections.

2.4.1 Importance of zero-till direct-seeded rice production

Production of conventional puddled transplanted rice is facing severe constraints because of water and labour scarcity and climatic changes. ZT-DSR is a feasible alternative to conventional puddled transplanted rice with good potential to save water, reduce labour requirements, mitigate greenhouse gas emissions and adapt to climatic risks (Pathak *et al.*, 2011). ZT-DSR reduces labour requirements by eliminating seedling rearing in nursery beds, seedling uprooting, repeated tillage under wet conditions to puddle the soil and manual transplanting (Farooq *et al.*, 2011; Chauhan *et al.*, 2012). ZT-DSR is an alternative labour- and water-saving rice production system. Because of farm labour and irrigation water shortage, farmers in some Asian countries are becoming interested in dry-seeded rice systems (Mahajan *et al.*, 2013). In addition, to save labour and water, dry-seeded rice improves the soil's physical and chemical properties, which facilitate the growth and yield of non-rice crops grown in rotation with rice (Gathala *et al.*, 2011). One way to reduce water and labour demand is to grow ZT-DSR instead of the puddled transplanted rice (Mahajan *et al.*, 2009).

Dry seeding of rice is one of the options to reduce the water and labour requirements for growing rice (Mahajan *et al.*, 2011). There are indications that mechanized dry-seeded rice will possibly increase in the future because it saves labour and time (Chauhan, 2012). Cabangon *et al.* (2002) in the Muda region of Malaysia found that irrigation water application in ZT-DSR was about 200 mm (40%) less than that in transplanted rice under CT. Similarly, 10-50% savings in water have been claimed with ZT-DSR compared with conventional tillage-transplanted puddled rice (CT-TPR) from India when irrigation application criteria after crop establishment (CE) were either the appearance of hairline cracks or tensiometer-based (-20 kPa at 20-cm depth) (Bhushan *et al.*, 2007; Jat *et al.*, 2009). Similar to water saving, ZT-DSR can reduce total labour requirements from 11 to 66% depending on the season, location, and type of ZT-DSR compared with conventional transplanted rice (Isvilanonda, 2002; Pandey *et al.*, 2002). Labour requirements for CE decreased by more than 75% with direct seeding compared with transplanting (Isvilanonda, 2002). Dry-seeded rice systems require 35-57% less water, and 67% less labour than transplanted rice (Farooq *et al.*, 2011). Dry-seeded rice systems are subjected to much higher weed pressure than transplanted rice because of dry ploughing and aerobic soil conditions (Balasubramanian and Hill, 2002).

2.4.2 Constraints of direct-seeded rice production

Weeds are a major constraint to the success of ZT-DSR in general and dry-ZT-DSR in particular (Singh *et al.*, 2006; Rao *et al.*, 2007). Research has shown that, in the absence of effective weed control options, yield losses are greater in ZT-DSR than in transplanted rice (Rao *et al.*, 2007). Weeds are more problematic in ZT-DSR than in puddled transplanting because the emerging ZT-DSR seedlings are less competitive with concurrently emerging weeds, and the initial flush of weeds is not controlled by flooding in Wet- and dry-ZT-DSR (Rao *et al.*, 2007; Kumar *et al.*, 2008).

Weeds are comparatively greater in number in the ZT-DSR system than in traditional transplanted rice, because of the simultaneous emergence of rice and weeds, and the absence of standing water at this stage (Rao *et al.*, 2007; Chauhan, 2012). If weeds are not controlled in dry-seeded systems, yield loss can be greater than 90% (Chauhan and Johnson, 2011). Yield loss in ZT-DSR depends on weed infestation level, and varies from country to country; for example, yield loss is up to 93% in Nepal, more than 80% in Pakistan (Khaliq *et al.*, 2012), more than 70% in the Philippines (Phoung *et al.*, 2005; Chauhan and Opeña, 2012), and up to 78% in Bangladesh (Ahmed *et al.*, 2014). ZT-DSR system reduces irrigation water requirement through the elimination of puddling, but weeds are major constraints to its success when grown under non-ponded conditions (Singh *et al.*, 2007; Mahajan and Chauhan, 2011; Chauhan and Opeña, 2012). In the ZT-DSR system, weeds and rice germinate simultaneously, and most often weeds show more vigorous growth than rice, so the rice seedlings are suppressed by weeds at an early growth stage (Chauhan and Johnson, 2010; Chauhan, 2012). Yield loss in dry-seeded rice due to weeds is 27-80% in Pakistan (Awan *et al.*, 2006; Khaliq *et al.*, 2012), and 40-70% in the Philippines (Chauhan and Opeña, 2013). In ZT-DSR, the fields should be well levelled, if possible by using a laser leveller. Uneven land levelling may result in poor crop establishment (Jat *et al.*, 2009). Direct drilling under zero tillage is advantageous as far as weed control is concerned, but severe yield penalties were also noted by many workers (Brar *et al.*, 2002). Heavy weed infestation is the major disadvantage of ZT-DSR because of cultivation in aerobic soil conditions as compared to puddled-transplanted rice systems (Balasubramanian and Hill, 2002). ZT-DSR systems can produce yield levels similar to those of TPR if weeds are controlled effectively (Mahajan *et al.*, 2009). The high weed pressure in ZT-DSR reduces economic returns and, in extreme cases, a complete failure of the crop occurs (Jabran *et al.*, 2012).

2.4.3 Crop competitiveness against weeds in zero-till direct-seeded rice

This is one of the most important plant traits required for the success of ZT-DSR. As discussed earlier, weeds are a major constraint in ZT-DSR cultivation. The development of weed-competitive cultivars is an attractive low-cost strategy for an overall integrated weed management program for both low- and high-input cropping systems (Dingkuhn *et al.*, 1999), and the most efficient way of delivery to farmers (Caton *et al.*, 2003). Cultivar differences in weed competitiveness have been reported in many crops, including rice (Fischer *et al.*, 2001; Haefele *et al.*, 2004). Cultivar–weed competitiveness has two components: weed tolerance and weed-suppressive ability (Jannink *et al.*, 2000; Zhao *et al.*, 2006). Weed tolerance is the ability of plants to maintain high yields despite weed competition, whereas weed suppressive ability is the ability to suppress the growth of weeds through competition. Breeding for weed-suppressive ability is being advocated over weed tolerance because suppressing weed growth will reduce weed seed production, and minimize contributions to the weed seed bank (Jannink *et al.*, 2000). Rice characteristics reported to be associated with weed competitiveness include (a) plant height together with early and rapid growth rate (Caton *et al.*, 2003), (b) higher tiller number (Fischer *et al.*, 1997), (c) droopy leaves (Dingkuhn *et al.*, 1999), (d) relatively high biomass accumulation at the early stage (Ni *et al.*, 2000), (e) high leaf area index (Dingkuhn *et al.*, 1999), and high specific leaf area (Dingkuhn *et al.*, 1999) during vegetative growth, (f) rapid canopy ground cover (Lotz *et al.*, 1995), and (g) early vigour. It is argued that the introduction of some of these traits in a variety may result in some yield loss (Dingkuhn *et al.*, 1999). However, it is also argued that the benefit of having these traits is likely to be higher than when not having those (Gibson *et al.*, 2003). Although tall plants are linked to weed competitiveness, they often have low yield potential and

tend to lodge. Fischer *et al.* (1997) also reported that semi-dwarf varieties can be as competitive as tall plant-type varieties.

2.4.4 Weed flora in association with direct-seeded rice

Weed flora in ZT-DSR consists of various kinds of grasses, broadleaved weeds and sedges (Mahajan *et al.*, 2009). The community composition of these weeds varies according to crop establishment methods, cultural methods, crop rotation, water and soil management, location, weed control measures, climatic conditions, and inherent weed flora in the area. *Echinochloa colona* and *E. crus-galli* are the most serious weeds affecting ZT-DSR. The density of these weeds in ZT-DSR depends upon moisture conditions in the field. *E. colona* requires less water, so it is more abundant in ZT-DSR. *Cyperus rotundus* and *Cynodon dactylon* may be major problems in poorly managed fields or where un-decomposed farm yard manure has been applied. The other weeds of major concern in ZT-DSR are *Leptochloa chinensis*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Caesulia axillaris*, *Paspalum* spp., *Alternanthera* spp., *Trianthema monogyna*, *Cyperus iria*, *Cyperus difformis*, and *Fimbristylis miliacea* (Mahajan *et al.*, 2012). ZT-DSR may result in weed flora shifts toward more difficult-to-control competitive grasses and sedges.

For example, the common weed species of ZT-DSR in Bangladesh were *Ageratum conyzoides*, *Cleome rutidosperma*, *Celosia argentea*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Digitaria ciliaris*, *Echinochloa colona*, *Eleusine indica*, *Galinsoga ciliate*, *Murdannia nudiflora* and *Phyllanthus niruri*. Results were presented only for the top five dominant species because of the non-uniform distribution of other weed species (Ahmed and Chauhan, 2015).

In Malaysia, at the time of the introduction of direct seeding (Wet-DSR) in the 1970s, easy-to-control broadleaved weeds were dominant but, by the 1990s, grass species such as *Echinochloa*

crus-galli, *Leptochloa chinensis* (L.) Nees, and *Ischaemum rugosum* Salisb. became dominant (Azmi *et al.*, 2005). In a long-term and more detailed field study conducted in Malaysia, weedy rice and *L. chinensis* were absent in wet-DSR plots at the start of the experiment in 1989. However, *L. chinensis* appeared after only two-year (in 1991) and weedy rice after 4 years (in 1993) of experimentation. By 2001, weedy rice, *Echinochloa* spp., *L. chinensis*, and *Fimbristylis miliacea* became the dominant species (Azmi and Mashor, 1995).

In Vietnam also, shifts toward more difficult-to-control grass-weed species (*E. crus-galli*, *L. chinensis*, and weedy rice) were observed with the introduction of ZT-DSR (Chin *et al.*, 2000). Vongsaroj (1997) reported dicotyledonous weeds as dominant in transplanted rice, but annual grasses such as *E. crus-galli* and *L. chinensis* and sedges such as *F. miliacea* in ZT-DSR fields in Vietnam.

In India, Singh *et al.* (2005) observed that *E. crus-galli*, *Commelina diffusa* Burm., *Cyperus rotundus* L., *Cyperus iria* and *L. chinensis* were dominant in non-weeded Dry-ZT-DSR plots in comparison with *C. iria*, *Echinochloa colona*, and *Caesulia axillaris* Roxb. in conventional rice transplanted plots after four seasons of rice cropping. Awan *et al.* (2015) found the dominant weeds in ZT-DSR: three grass species: *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees, and *Echinochloa crus-galli* (L.) Beauv.; two broadleaved species: *Eclipta prostrata* (L.) and *Ludwigia hyssopifolia* (G. Don) Exell; and two sedge species: *Cyperus iria* L. and *Fimbristylis miliacea* (L.) Vahl.

2.4.5 The Critical period of crop weed competition in direct-seeded rice

Singh *et al.* (2014) conducted a field experiment in the summer seasons of 2012 and 2013 at the Punjab Agricultural University, Ludhiana, India, to determine the extent of yield loss in two

different rice cultivars with different periods of weed interference. After two years of experimentation, they noticed that the critical crop-weed competition period in a dry-seeded rice system is an important consideration in formulating weed management strategies. They found 5 days difference in critical weed-free periods between the two rice varieties. In dry direct drill-seeded rice, the “critical period” of weed competition has been reported to be 15-45 DAS. If weeds can be suppressed effectively during this period, minimal yield losses occur (Yaduraju and Mishra, 2002). In a recent study, critical periods for weed control, to obtain 95% of a weed-free yield were estimated at between 17 to 56 DAS of the ZT-DSR crops at 15 cm row spacing. Crop geometry, including row spacing and planting patterns, can also influence crop-weed competition. Narrow row spacing can shift the competitive balance in favour of rice by achieving faster canopy closure and reducing light availability to weeds (Chauhan and Johnson, 2011). The competition beyond 15 DAS may cause a significant reduction in the grain yield. However, competition for the first 15 days only may not have many adverse effects on the crop (Singh, 2008). Weeds are comparatively greater in number in this system than in traditional transplanted rice, because of the simultaneous emergence of rice and weeds and the absence of standing water at this stage (Rao *et al.*, 2007; Chauhan, 2012). Weed competition can also be reduced for some cultivars by sowing rice in a paired-row pattern (Mahajan and Chauhan, 2011).

2.4.6 Weed control in zero-till direct seeded rice by chemical measures

The traditional methods of weed control in rice include hand weeding by hoe or hand pulling, but this is becoming less common because of labour scarcity at the critical time of weeding, and increasing labour costs (Kumar and Ladha, 2011; Chauhan, 2012). Moreover, seedlings of some grassy weeds such as *Echinochloa crus-galli* (L.) look similar to rice seedlings (Rao and Moody,

1988), making hand weeding more tedious, difficult, and less effective. However, the adoption of ZT-DSR technology usually leads to a shift in weed flora composition towards difficult-to-control weeds (Singh *et al.*, 2015). In this situation, the use of herbicides is becoming more popular in ZT-DSR because they are more effective, easy to apply, provide selective control, save on labour and cost less (Singh *et al.*, 2015). Chemical control measures are generally more targeted at the early stage of weed emergence and growth when weed control is easier. Once weeds become big, they are difficult to control (Bastiaans *et al.*, 2008). However, it is important to use a broad-spectrum herbicide program including pre- and post-herbicides for season-long effective weed control and to avoid shifts toward problematic weed species (Chauhan, 2012) or the evolution of herbicide-resistant weed biotypes. On the other hand, it is crucial to select the right herbicide depending on the weed flora present in a given field. In addition, the correct rate, timing, and application techniques should be used. A variety of herbicides have been screened and found effective pre- and post-emergence weed control in dry direct drill-seeded rice systems, including under ZT conditions (Kumar and Ladha, 2011).

2.4.6.1 Pre-sowing herbicides for weed control in zero-till direct-seeded rice

These herbicides are used to control existing annual and perennial weeds before rice sowing, especially under the ZT system. Glyphosate (1 kg ai ha⁻¹ or 0.5-1.0% by volume) and Paraquat (0.5 kg ai ha⁻¹ or 0.5% by volume) were recommended for burn-down application (Gupta *et al.*, 2006). Glyphosate is a systemic nonselective herbicide, and it controls most annual and perennial weeds. To be effective, it should be applied when weeds are growing actively so that the herbicide is absorbed and translocated into the entire plant system (Kumar and Ladha, 2011).

Herbicides are considered to be the best tool to manage weeds in ZT-DSR. Herbicides can be applied as a pre-emergence (control weeds before emergence) spray and/or a post-emergence (control weeds after emergence) spray. However, the pre-emergence herbicides are essential to manage weeds effectively in ZT-DSR (Singh *et al.*, 2007; Khaliq *et al.*, 2011). Pendimethalin (1.0 kg ai ha⁻¹), Oxadiargyl (0.09 kg ai ha⁻¹), and Pyrazosulfuron (0.02 kg ha⁻¹) have been reported to be effective pre-emergence herbicides to control weeds in dry direct-seeded rice (Gupta *et al.*, 2006; Gopal *et al.*, 2010). Good soil moisture is essential for the activation of pre-emergence herbicides. Pendimethalin should be applied after the rice seed has imbibed germination water, that is, 2-3 DAS to avoid crop injury (Kumar and Ladha, 2011). Several herbicides, with pre-activity, such as Oxadiazon, Oxadiargyl, Butachlor, Pendimethalin, Thiobencarb, Oxyfluorfen, and Pyrazosulfuron, applied solely or with hand weeding, have been reported to provide effective control of weeds (Chauhan, 2012; Chauhan and Opena, 2012). However, some issues related to the use of pre-herbicides exist, such as their limited window of application timing and an adequate soil moisture requirement at the time of their application (Singh *et al.*, 2006). In an earlier study, Pendimethalin as pre- alone reduced the biomass of this weed by 94% and the sequential application of Pendimethalin pre- and Azimsulfuron post-emergence herbicides reduced *L. chinensis* and large crabgrass (*Digitaria sanguinalis* (L.) Scop. DIGSA] biomass by more than 96% (Mahajan and Chauhan, 2013). Results are consistent with an earlier study conducted in Sri Lanka, in which Pendimethalin and Oxadiazon used as pre-herbicides controlled total weed density by 85-87%, and the plots treated with these pre-herbicides followed by the application of Fenoxaprop plus Ethoxysulfuron controlled the weeds by 95-98% (Chauhan *et al.*, 2013). Oxadiazon and Pendimethalin are commonly used as pre-herbicides to control a broad spectrum of weeds in dry-seeded rice systems (Singh *et al.*, 2007; Chauhan and Opena, 2012; Chauhan *et al.*, 2013).

Therefore, the use of pre-emergence herbicides is a good option to achieve effective weed control and higher yield in ZT-DSR systems (Mahajan and Chauhan, 2013).

2.4.6.2 Post-emergence herbicides for weed control in zero-till direct seeded rice

Herbicides that are effective for post-emergence weed control in the dry-ZT-DSR system are Pyrazosulfuron, Bispyribac-sodium, Fenoxaprop-ethyl, Penoxsulam, Fenoxaprop-ethyl + Safner, Cyhalofop-butyl, Propanil, Azimsulfuron, Ethoxysulfuron, Triclopyr, 2,4-D Ethyl Ester, Carfentrazone, Chlorimuron + Metsulfuron, Bispyribac + Azimsulfuron (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). Continuous use of a single herbicide on a long-term basis should be avoided; rather, it should be rotated with another herbicide with a different mode of action to avoid/delay resistance development. Tank mixtures of herbicides can be used when two or more herbicides are compatible to broaden the spectrum of weed control in such a way that each herbicide controls the weeds missed by the other one. The herbicide mixtures listed above were found to be effective in better controlling a combination of weeds, including grasses, broadleaves, and sedges (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). If optimum conditions are not available, post-herbicides may be a better option to manage weeds in dry-seeded rice systems (Singh *et al.*, 2006; Mahajan and Chauhan, 2013). In another study, Bispyribac-sodium was similar to manual weeding in controlling weeds and increasing rice yield (Khaliq *et al.*, 2012).

2.4.7 Effect of different herbicides on weed dry biomass

The use of herbicide mixtures is essential in response to changes in the weed community structure in dry-seeded rice (Yaduraju and Mishra, 2002; Maity and Mukherjee, 2008). Khaliq *et*

al. (2012) conducted a field experiment in Pakistan, with three post-emergence herbicides (i.e., Bispyribac-sodium, Ethoxysulfuron ethyl and Penoxuslam) applied 15 DAS in dry direct-seeded rice. After two-year experiments, they found that Bispyribac-sodium suppressed both weed density (75%) and dry weight (80%) over control which was the highest among all herbicides. Mahajan and Chauhan (2013) found the lowest weed dry weight with the sequential application of Pendimethalin as pre- *fb* Azimsulfuron post. For post-application, the tank mixture of Bispyribac-sodium *p* Azimsulfuron would be a potential herbicide combination if both grassy and broadleaved weeds are present in the field. The inclusion of Azimsulfuron with Bispyribac-sodium for post-application widens the spectrum of weed control because Azimsulfuron effectively controls sedges and broadleaved weeds (Walia *et al.*, 2008). The maximum weed dry weight reduction (82-91%) was observed with the sequential application of Pendimethalin pre-*fb* Bispyribac-sodium + Azimsulfuron post at 45 DAS. Azimsulfuron effectively controls a wide variety of weeds, including broadleaved and sedges like *Cyperus rotundus* and *Dactyloctenium* spp. (Mahajan and Chauhan, 2013). Khaliq and Matloob (2012) also reported that the density of jungle rice was reduced to a great extent with the pre-application of Butachlor and Pendimethalin. The effectiveness of Pendimethalin pre- in reducing weed density has been reported by several authors (Moody, 1991; Valverde and Gressel, 2005).

2.4.8 Effect of weed on yield and yield components of direct seeded rice

Weeds are a serious problem because dry tillage practices and aerobic soil conditions are conducive to the germination and growth of weeds, which can cause grain yield losses from 50 to 90% (Rao *et al.*, 2007; Chauhan *et al.*, 2011; Prasad, 2011). In a recent study, critical periods for weed control, to obtain 95% of a weed-free yield were estimated between 17 and 56 DAS of

the ZT-DSR crops at 15 cm row spacing (Chauhan and Johnson, 2011). Khaliq *et al.* (2012) noticed that post-emergence application of Bispyribac-sodium appeared to be a viable strategy for weed control in direct-seeded rice with higher economic returns. Despite its effectiveness against weeds and scoring higher rice yields, manual weeding was uneconomical primarily due to the higher costs involved. Higher rice grain yield and economic returns with post-application of Bispyribac-sodium were reported earlier by Khaliq *et al.* (2012). The tank mix application of Bispyribac *p* Azimsulfuron increased broad-spectrum weed control (grass and broadleaved) but at the same time also increased the total cost of herbicide application. Kumar and Ladha (2011) reported that the increase in net returns with dry-ZT-DSR over conventional rice production was US\$ 51 ha⁻¹ (averaged across 5 Asian countries). The use of Fenoxaprop or other weed-specific herbicides either in a tank mix with Bispyribac-sodium and Azimsulfuron (Mahajan and Chauhan, 2015) as an early post or at a later stage for effective weed control, would further increase the herbicide application cost. Farmers in the state of Haryana and Punjab, India, even use one-hand weeding (US\$50-US\$100 ha⁻¹) in addition to sequential herbicides in ZT-DSR for effective weed management (Singh, 2008). The use of one-hand weeding in ZT-DSR at 35-60 DAS along with sequential herbicides has also been suggested by many studies (Ahmed and Chauhan, 2014). This makes ZT-DSR more challenging not only from a weed management perspective but also considering economics.

CHAPTER 3

EXPERIMENT 1

Efficacy and Economics of Different Post-Emergence Herbicides for Controlling Weeds in Wheat under Zero-Till Condition

3.1 Abstract

The CA-based ZT-wheat cultivation system in Bangladesh is still in the initial stage and the system initially faces weed pressure. Herbicides are the best option for controlling weeds in the system. Therefore, the information on the application of herbicides for controlling weeds in the CA-based zero-till wheat is important for getting desirable yields. In this context, an observation entitled ‘Efficacy and Economics of Different Post-Emergence Herbicides for Weed Control in Wheat under Zero-Till Condition’ was conducted in consecutive two years of 2017-18 and 2018-19. Treatments were: T1: ready-mix formulation (Sulfosulfuron + Metsulfuron); T2: ready-mix formulation (Mesosulfuron + Idosulfuron); T3: Pinoxaden; T4: ready-mix formulation (Carfentrazone + Isoproturon); T5: Pinoxaden + Metsulfuron; T6: Pinoxaden + Carfentrazone; T7: Halosulfuron; T8: Halosulfuron + Pinoxaden; T9: weedy check and T10: weed free. Based on the two years of yield and the economic benefit of these three observations the combination of herbicides Pinoxaden + Metsulfuron and Halosulfuron + Pinoxaden may be recommended for weed control in CA-based ZT-wheat.

3.2 Introduction

Countries under the Eastern Gangetic Plains (EGP) have a high yield potential of wheat, including Bangladesh, Bihar & West Bengal in India, and Nepal. In the EGP, the area and production of wheat are intensifying day by day at high speed because of the increasing demand for human consumption and food industries. Presently, more than 80% of wheat is grown by manual sowing after intensive 5-6 tillage operations which delay the wheat sowing at least 1-2 weeks and also increase production cost. Several repetitive tillage operations increase the cost of cultivation due to fuel consumption and delayed planting followed by manual sowing (Gathala *et al.*, 2015; Rahman *et al.*, 2021). However, the late planting of wheat was identified as a major problem due to the late harvesting of monsoon rice (Fujisaka *et al.*, 1994; Badaruddin *et al.*, 1994; Hossain *et al.*, 2014). In addition, after post-seeding, wheat growers face major challenges in weed management due to the lack of pre- and post-emergence herbicides in the region. The infestation of weeds is considered a major hindrance in the transformation of a conventionally tilled field to a CA-based field.

To improve the productivity of wheat, it is a prerequisite to sow wheat at the optimum time (Hobbs and Giri, 1997; Hobbs, 2021). It has been reported to overcome the problem by adopting CA-based ZT-wheat directly seeded into undisturbed soil after the immediate rice harvest (Justice *et al.*, 2004; Hossain *et al.*, 2015; Hossain *et al.*, 2021). The ZT wheat/permanent beds or till the soil with fresh beds is an alternate option through mechanized precision planting in a single pass. In the conventional system, heavy tillage offers benefits in suppressing weeds by incorporation under the soil (Weber *et al.*, 2017; Jorgensen, 2018), but in the traditional weed management in wheat during 30-35 DAS, farmers generally control the weeds with hand weeding which further consumed more labour, as well as greatly influence the enrichment of weed seeds bank (Steckel *et al.*, 2007), due to the deposition of weed seeds at different layers of soils. Weed infestation remains

high under the CA-based cultivation system in the initial few years due to the absence of the pulverization of soil or limited tillage. That is why weed seeds of the CA field mostly remain on the sub-surface layer of soil, and germinate earlier under favourable conditions. Later on, the rate of weed infestation declines in the CA system over time due to very limited weed seeds staying behind in the sub-surface layer of soil to germinate, and the CA practices ensure no chance for further weed seeds to emerge from the deep soil. Therefore, it is established that in the CA system, weed management practices play a vital role in obtaining an attainable yield (Derpsch and Friedrich, 2009; Zahan *et al.*, 2016, 2020a,b, 2021). This system highly relies on using herbicides for weed control. The cost and unavailability of labour are now forcing farmers to shift from manual weeding to the application of herbicides for controlling weeds (Islam *et al.*, 2017; Zahan *et al.*, 2020a,b).

In Bangladesh, farmers are not well aware of the proper use of herbicides. They apply the same herbicides in the same field for several years influencing the development of herbicide-resistant weeds (Hossain *et al.*, 2010). Therefore, the selection of suitable herbicides for the crops in a cropping pattern is very important to avoid the risk of rapid herbicide-resistant weeds in the intensive cropping systems of Bangladesh. Moreover, most available herbicides are intended for rice in our markets, and very few are available for other crops. On the other hand, most of the registered herbicides are not out of the market and are not available all over the country. Therefore, farmers often face a problem obtaining appropriate herbicides for managing weeds effectively in crops including wheat. Therefore, it is important to find a list of suitable pre- and post-emergence herbicides for the farmers to apply sequentially in a whole crop growing period for effective weed control. The CA-based crop management techniques face the major concern of weed management

initially. To address the weed management problems in CA-based wheat production under no-till systems, different weed management options trial was designed to fulfil the following objectives:

- i) To identify the efficacy and economies of different post-emergence herbicides for weed control in CA-based ZT wheat under the W-M-R cropping system,
- ii) To know the effect of different herbicides on growth, yield-attributes and yield of CA-based ZT-wheat under the W-M-R cropping system.

3.3 Materials and Methods

3.3.1 Location and site characteristics

The experiment was conducted at the Research Field of Bangladesh Wheat and Maize Research Institute (BWMRI), Nashipur, Dinajpur for consecutive two years (from November 2017 to March 2018, and November 2018 to March 2019). The Agro-Ecological Zone (AEZ) of the area is the Old Himalayan Piedmont Plain (AEZ-1) (FAO and UNDP, 1988). The geographical position of the area is between 25°38'N, 88°41'E and 38.20 m above sea level. However, the soil was sandy-loam, and its reaction was strongly acidic ranging from 4.9 to 5.7, with organic matter content below 1%, N, K (potassium), S (sulphur), B (boron), Mg (magnesium) and Zn (zinc) was below the critical level, but P (phosphorus) level was higher than critical level, but not plant available form (Appendix 2).

The geographical location of the experimental site was under the subtropical climate and its climatic conditions were characterized by three distinct years, namely the winter season from November to February, the pre-monsoon period or hot season from March to April and the monsoon period from May to October. Weather data on weekly average temperature, humidity and rainfall during the experimental period were recorded regularly at the meteorological station of BWMRI, Nashipur, Dinajpur are presented in Appendix 3.

3.3.2 Experimental details

3.3.2.1 Experimental Treatments and Design

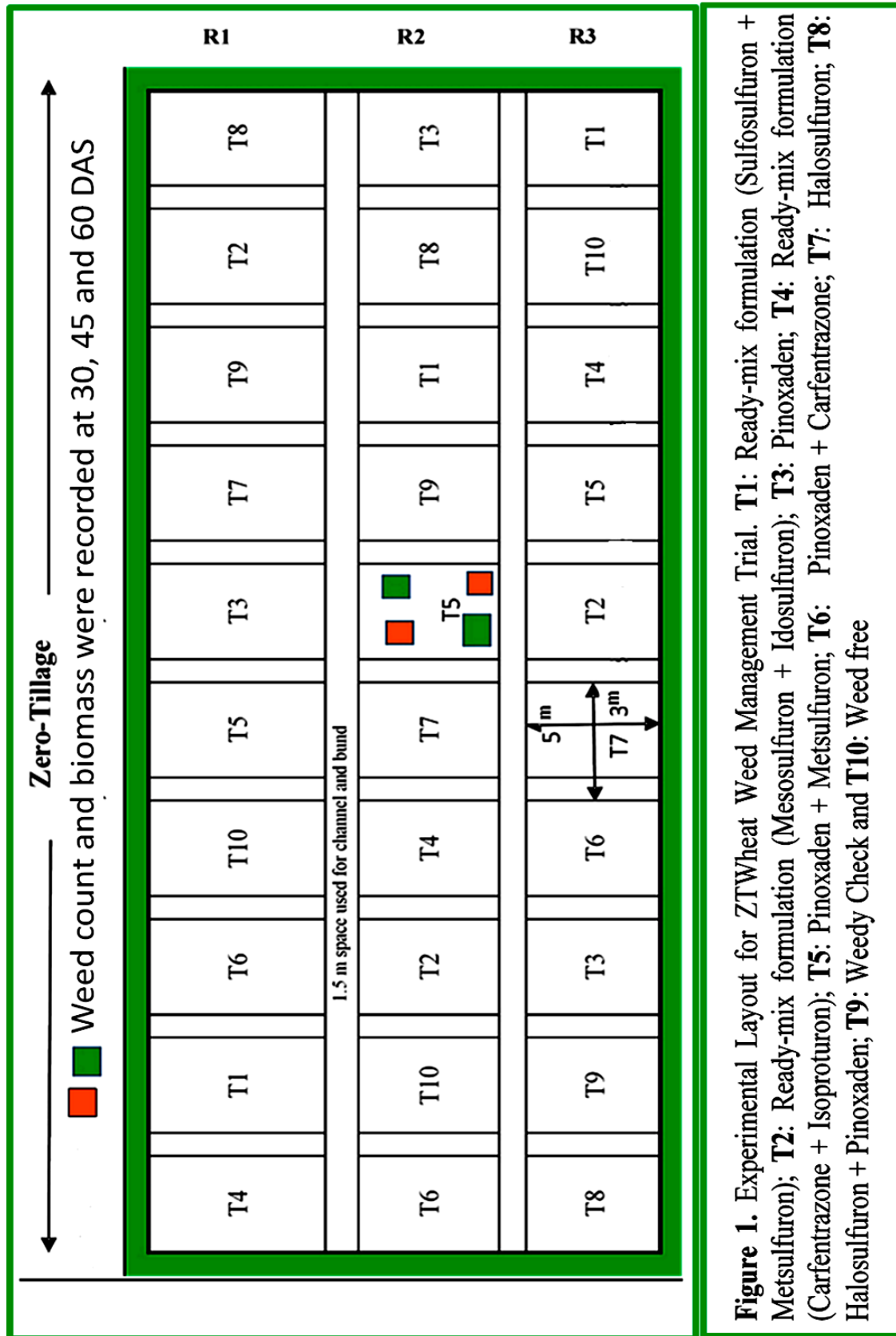
There were 10 weed management treatments among them 8 were different post-emergence herbicides (Table 1), with a weedy check and a weed-free treatment. Treatments details are: T₁: Ready-mix formulation (Sulfosulfuron + Metsulfuron); T₂: Ready-mix formulation (Mesosulfuron + Idosulfuron); T₃: Pinoxaden; T₄: Ready-mix formulation (Carfentrazone + Isoproturon); T₅:

Pinoxaden + Metsulfuron; T₆: Pinoxaden + Carfentrazone; T₇: Halosulfuron; T₈: Halosulfuron + Pinoxaden; T₉: Weedy Check and T₁₀: Weed free. Treatments detailed are also available in Table 1. All treatments were arranged in a randomized complete block design with three replications. The unit plot size was 5 m length $\times$ 3 m wide. The replication-wise field arrangement of all treatments is presented in Figure 1.

Table 1. Different post-emergence herbicides used in different weed control treatments

Treat.	Herbicides	Dose (g a.i. ha⁻¹)	Product dose (g/ml ha⁻¹), dilution procedure and application time
T1	Ready-mix formulation (Sulfosulfuron + Metsulfuron)	30+2g	40g (300-350 litres of water with 1250 ml surfactant), applied at 30 DAS or 2-4 weed leaf stage)
T2	Ready-mix formulation Mesosulfuron + Idosulfuron	12+2.4g	400g (dilution with 300-350 litres water with 500 ml activator), applied at 30 DAS)
T3	Pinoxaden	50g	950 ml (dilution with 300-350 litres water), applied at 30 DAS
T4	Ready-mix formulation (Carfentrazone + Isoproturon)	50+0.75g	1.5 kg (dilution with 300-350 litres water), applied at 30 DAS
T5	Pinoxaden + Metsulfuron	50+4g	950 ml Axial +20g Convo (dilution with 300-350 litres water with 500 ml surfactant), applied at 30 DAS
T6	Pinoxaden + Carfentrazone	50+20g	950 ml Axial + 50g Affinity (dilution with 300-350 litres water), applied at 30 DAS
T7	Halosulfuron	67g	90g (dilution with 300-350 litres water), applied at 30 DAS
T8	Halosulfuron + Pinoxaden	67+50g	90g Sempra + 850 ml Axial (dilution with 300-350 litres water), applied at 30 DAS
T9	Weedy Check	-	No weeding was done
T10	Weed-free	Hand-weeding	First-hand weeding was done at 30 DAS and followed need-based weeding to keep the plot weed-free

Note: All herbicides were used as post-emergence applied at 30 DAS. In the ZT field, Roundup (Glyphosate @ 1000 g a.i. ha⁻¹) was applied as pre-sowing to kill existing weeds in all treatments



3.3.3 Experimental procedures

3.3.3.1 Collection of wheat seeds

Wheat variety BARI Gom 32 was used as experimental material which was collected from Bangladesh Wheat and Maize Research Institute (BWMRI), Nashipur, Dinajpur, Bangladesh.

3.3.3.2 Characteristics of wheat variety BARI Gom 32

The variety was released in the year 2017 (<http://www.bwmri.gov.bd/site/page/2e1b836b-8bd5-480b-b82c-dd9e70cb4867/->). It is high-yielding, early in maturity and tolerant to terminal heat stress. The variety is resistant to leaf rust and tolerant to BpLB disease. The variety also shows a medium level of tolerance against wheat blast disease. Grains are white amber in colour and have larger seed sizes (50-58g). Spikes are long with 42-47 average grains spike⁻¹. The average yield in the research field is about 4.6-5.0 t ha⁻¹ (<http://www.bwmri.gov.bd/site/page/2e1b836b-8bd5-480b-b82c-dd9e70cb4867/->; accessed on 15 July 2022).

3.3.3.3 Land preparation

This is a CA-based ZT-wheat and no-tillage was done for the experiment. Just weeds and stubbles were removed from the experimental field. Before sowing the seeds, the soil was treated with Furadan 5G, which was used at 8 kg ha⁻¹ to protect young plants from the attack of the mole cricket, ants, and cutworms (containing Carbofuran, marketed by FMC International S.A. Bangladesh Ltd.).

3.3.3.4 Application of fertilizers

Fertilizer was applied at recommended doses of 120-27-40-20-1 kg ha⁻¹ of N, P, K, S, and B in the form of urea, TSP, MoP, gypsum and boric acid (BWMRI, 2022). Two-thirds of N and a

full amount of the other fertilizers were applied as a basal amount during the sowing of seeds by a ZT machine. The remaining N fertilizer was applied immediately after the first irrigation at 21 DAS.

3.3.3.5 Seed treatment

Before sowing, seeds were treated with Provax-200 WP (marketed by Hossain Enterprise CC Bangladesh Ltd., an agrochemical company, in association with Chemtura Corp., USA) containing Carboxin and Thiram. Provax-200 WP is a perfect fungicide to control fungi in the soil at the seedling stage (Hossain and Teixeira da Silva, 2012).

3.3.3.6 Sowing of wheat seeds in research plots

Seeds were sown at 120 kg ha⁻¹ at specified depths (4-5 cm depth) by a ZT machine. Seeds were sown continuously by maintaining a 20 cm row-to-row distance. Special care was taken to protect against bird attacks upto 12 days after sowing.

3.3.3.7 Intercultural operations

The following intercultural operations were done to ensure the normal growth of the crop:

3.3.3.7.1 Thinning and Weeding

The emergence of seedlings was completed within 4-9 DAS. Overcrowded seedlings were thinned out two times. The first thinning was done at 15 DAS which was done to remove unhealthy and lineless seedlings. The second thinning was done 10 days after the first thinning. The weeds in the experimental plots were controlled as per treatments.

3.3.3.7.2 Irrigation

Wheat is quite sensitive to water stress. Therefore, proper irrigation is necessary for the proper growth and development of wheat plants (Mustafa *et al.*, 2017). In the current study, the first irrigation was done at 21 DAS (at the crown root initiation stage). The second irrigation was provided at 55 DAS (the panicle initiation stage of wheat), and the last irrigation was done at 75 DAS (the grain-filling stage). The proper drainage system was also made for draining out excess water, particularly at the time of irrigation.

3.3.3.7.3 Insect and pest control

Two guards were appointed to protect the wheat seeds and seedlings from birds. No infestation of disease and insects were found as such no control measure was taken for it.

3.3.3.8 General observation of the experimental field

The plots under experiment were frequently observed to notice any change in plant growth, other parameters were noted down immediately to take necessary measures.

3.3.3.9 Harvest and post-harvest operation

The crop was harvested when it reached maturity. One square meter area from the central position of each plot was harvested for yield data, and it was converted to t ha^{-1} . The harvested plants were tied into bundles and carried to the threshing floor. The crops were sun-dried by spreading on the threshing floor. The seeds were separated from the plants by pedal thresher, and thereafter cleaned, dried and weighed. The weights of the dry straw were also taken from the same demarcated area and were converted to t ha^{-1} .

3.3.4 Data and their collection procedures

The following data were recorded in both years:

3.3.4.1 Weed data

For weed data, four permanent 0.20 m² (40 cm x 50cm) quadrats were established in each plot after wheat seedling emergence (7 DAS), and then weed data were taken from these four permanent quadrats on different DAS (as mentioned below). The following weed data were taken during the observation:

- ❖ First weed data on the number and dry biomass of grass, broadleaved and sedge weeds were recorded from a permanent quadrat immediately (at 30 DAS) before post-emergence herbicides were applied.
- ❖ Second weed data on the number and dry biomass of grass, broadleaved and sedge weeds were recorded from a permanent quadrat at 15 days after the application of post-emergence herbicides (45 DAS).
- ❖ Species-wise weed density and dry biomass weight were recorded at 60 DAS from the two remaining permanent quadrats.
- ❖ Local, common and Latin names of weed species were noted from weedy check treatment at 60 DAS in both years
- ❖ Weed dry biomass was also recorded at harvest.
- ❖ The visual rating was also noted due to the application of different herbicides.
- ❖ Weed mortality (WM %) and weed control efficiency (WCE %) were also estimated for all weed control treatments as compared with the weedy check.

$$\text{Mortality\%} = \frac{W_t - W_s}{W_t} \times 100$$

Where; W_t = Total number of weeds m^{-2} in weedy check; W_s = Number of surviving weeds m^{-2} after spray multiplied by 100.

$$WCE = \frac{W_c - W_t}{W_c} \times 100$$

Where; W_c = Average dry weed biomass m^{-2} in the weedy check plot; W_t = Average dry weed biomass m^{-2} in the plot after spray multiplied by 100.

3.3.4.2 Crop data:

The following crop data were taken at the time of field research in both years:

- ❖ Crop emergence at 12 DAS (80% germination) and spikes m^{-2} (at physiological maturity stage) were counted from 1m long 5 rows ($1 m^{-2}$)
- ❖ Plant height at harvesting
- ❖ Yield attributes like spike length, spikelets $spike^{-1}$, grains $spike^{-1}$, and 1000-grain weight were taken at harvest.
- ❖ Straw yield, grain yield and harvest index were also recorded.

3.3.5 Economic analysis

To find out the cost-effective herbicides for weed control in CA-based ZT-wheat, the economic analysis such as variable cost (i.e., labour/nonmaterial cost and material cost), fixed cost (land rent, interest on input cost and miscellaneous cost), and the gross and net return were estimated by using the data on labour costs and management practices were noted for each treatment. The labour cost for hand weeding in weed-free treatment was estimated for comparison with herbicide treatments.

3.3.6 Statistical analysis

Recorded data were processed and analyzed separately by using STAR 3.0 V (IRRI, 2016). Treatment means were separated using the least significant difference (LSD) at the 5% level of significance. Square-root transformation [$\sqrt{(x + 0.5)}$] for weed density and dry biomass data was done before analyses of all data.

3.4 Results and Discussion

3.4.1 Infesting weed species in a zero-till wheat field

The wheat field was infested by 13 types of weed species in both years. In the year 2017-18, three were grasses (i.e., *Digitaria sanguinalis*, *Elusina indica* and *Cynodon dactylon*) under the family Poaceae, one was sedge (*Cyperus rotundus*) under the family Cyperaceae, and nine were broadleaved weeds (i.e., *Chenopodium album*, *Hedyotis diffusa*, *Stellaria media*, *Nicotiana plumbaginifolia*, *Rumex maritimus*, *Lens orientalis*, *Scroperia dulcis*, *Euphorbia parviflora* and *Oxalis corniculata*) under the family Amaranthaceae, Rubiaceae, Caryophyllaceae, Solanaceae, Polygonaceae, Fabaceae, Plantaginaceae, Euphorbiaceae and Oxalidaceae (Table 2).

Considering the type and species-wise infestation, the density of grass, sedge and broadleaved species were found at 51.7 (no. m⁻²) (15.5%), 3.3 (no. m⁻²) (1%) and 278.3 (no. m⁻²) (83.5%), respectively indicating that broadleaved weeds were dominant followed by grasses and sedges in the experimental field. Among these grasses (15.5%), the maximum number of weeds and dry matter were recorded in *Digitaria sanguinalis* followed by the next two types of grass (Table 2).

However, *H. diffusa* (85.0 (no. m⁻²); 25.5%) under the family Rubiaceae was found the most dominant weed, the 2nd was the *Chenopodium album* (76.7 (no. m⁻²); 23%) under the family Amaranthaceae, the 3rd was *Digitaria sanguinalis* (41.7 (no. m⁻²); 12.5%) under the family Poaceae, and the 4th was *Stellaria media* (16.7 (no. m⁻²); 5%) under the family Caryophyllaceae. In the case of biomass (oven dry) production, *H. diffusa* (10.0 (no. m⁻²); 44.5%) was also found the top producer, followed by *Chenopodium album* (6.7 (no. m⁻²); 29.3%) and *Stellaria media* (3.5 (no. m⁻²); 15.2%) indicating that *H. diffusa* was the most infesting weed species based on both density and dry matter production (Table 2; Figure 2).

Table 2. Infesting weed species with their family in wheat fields were recorded at 60 DAS in weedy check plots in both years

Sl no.	Common name	English name	Latin name	Family	Morphological type	Life cycle	Density (no. m ⁻²)	Importance value %	Dry weight (g m ⁻²)	Importance value %
During 2017-2018										
1	Anguli Grass	Finger-grass	<i>Digitaria sanguinalis</i>	Poaceae	Grass	Annual	41.7	12.5	1.3	5.5
2	Chapra	Goosegrass	<i>Eleusine indica</i>	Poaceae	Grass	Annual	5.0	1.5	0.1	0.4
3	Durba	Bermuda grass	<i>Cynodon dactylon</i>	Poaceae	Grass	Annual	5.0	1.5	0.1	0.4
4	Mutha	Purple nutsedge	<i>Cyperus rotundus</i>	Cyperaceae	Sedge	Annual	3.3	1.0	0.1	0.2
5	Bothua	Lamb's quarters	<i>Chenopodium album</i>	Amaranthaceae	Broadleaved	Annual	76.7	23.0	6.7	29.3
6	lalkagri	Snake-needle grass	<i>Hedyotis diffusa</i>	Rubiaceae	Broadleaved	Annual	85.0	25.5	10.1	44.5
7	sada kagri	Common chickweed	<i>Stellaria media</i>	Caryophyllaceae	Broadleaved	Annual	16.7	5.0	3.5	15.2
8	Bon Tamak	Tex-Mex tobacco	<i>Nicotiana plumbaginifolia</i>	Solanaceae	Broadleaved	Annual	75.0	22.5	0.7	3.1
9	Bon palong	Golden dock	<i>Rumex maritimus</i>	Polygonaceae	Broadleaved	Annual	5.0	1.5	0.1	0.4
10	Bon mosur	Wild lentil	<i>Lens orientalis</i>	Fabaceae	Broadleaved	Annual	5.0	1.5	0.1	0.2
11	Bon dhonia	Sweet-broom	<i>Scropania dulcis</i>	Plantaginaceae	Broadleaved	Annual	5.0	1.5	0.1	0.2
12	Dudia	Prostrate spurge	<i>Euphorbia parviflora</i>	Euphorbiaceae	Broadleaved	Annual	5.0	1.5	0.1	0.2
13	Amrul	Creeping woodsorrel	<i>Oxalis corniculata</i>	Oxalidaceae	Broadleaved	Annual	5.0	1.5	0.1	0.2
Total							333.3	100.0	22.7	99.8
During 2018-2019										
1	Anguli Grass	Finger-grass	<i>Digitaria sanguinalis</i>	Poaceae	Grass	Annual	76.65	14.8	17.8	43.88
2	Chapra	Goosegrass	<i>Eleusine indica</i>	Poaceae	Grass	Annual	11.65	2.2	0.4	0.99
3	Khuda Shama	Jungle rice	<i>Echinochloa colona</i>	Poaceae	Grass	Annual	6.65	1.3	0.2	0.49
4	Durba	Bermuda grass	<i>Cynodon dactylon</i>	Poaceae	Grass	Annual	11.65	2.2	1.3	3.21
5	Mutha	Purple nutsedge	<i>Cyperus rotundus</i>	Cyperaceae	Sedge	Annual	5.00	1.0	0.3	0.74
6	Bothua	Lamb's quarters	<i>Chenopodium album</i>	Amaranthaceae	Broadleaved	Annual	100.00	19.3	5.2	12.73
7	lalkagri	Snake-needle grass	<i>Hedyotis diffusa</i>	Rubiaceae	Broadleaved	Annual	245.00	47.3	11.2	27.56
8	sada kagri	Common chickweed	<i>Stellaria media</i>	Caryophyllaceae	Broadleaved	Annual	50.00	9.6	2.7	6.55
9	Bon Tamak	Tex-Mex tobacco	<i>Nicotiana plumbaginifolia</i>	Solanaceae	Broadleaved	Annual	1.65	0.3	0.1	0.25
10	Bon palong	Golden dock	<i>Rumex maritimus</i>	Polygonaceae	Broadleaved	Annual	1.65	0.3	0.3	0.74
11	Bon mosur	Wild lentil	<i>Lens orientalis</i>	Fabaceae	Broadleaved	Annual	5.00	1.0	0.7	1.73
12	Bon dhonia	Sweet-broom	<i>Scropania dulcis</i>	Plantaginaceae	Broadleaved	Annual	1.65	0.3	0.1	0.12
13	Helancha	Buffalo Spinach	<i>Enhydra fluctuan</i>	Asteraceae	Broadleaved	Annual	1.65	0.3	0.4	0.99
Total							518.20	100	40.45	100

The importance value of all weed species was calculated by dividing the density and dry weight of the individual weed species by the total density and dry weight of all weed species and multiplying by 100.

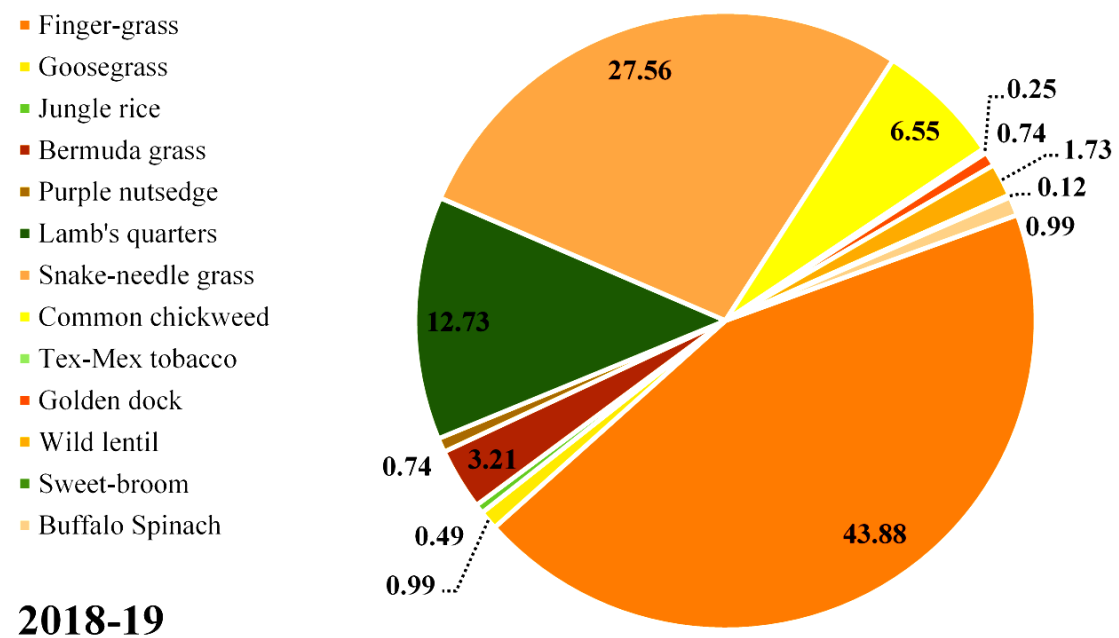
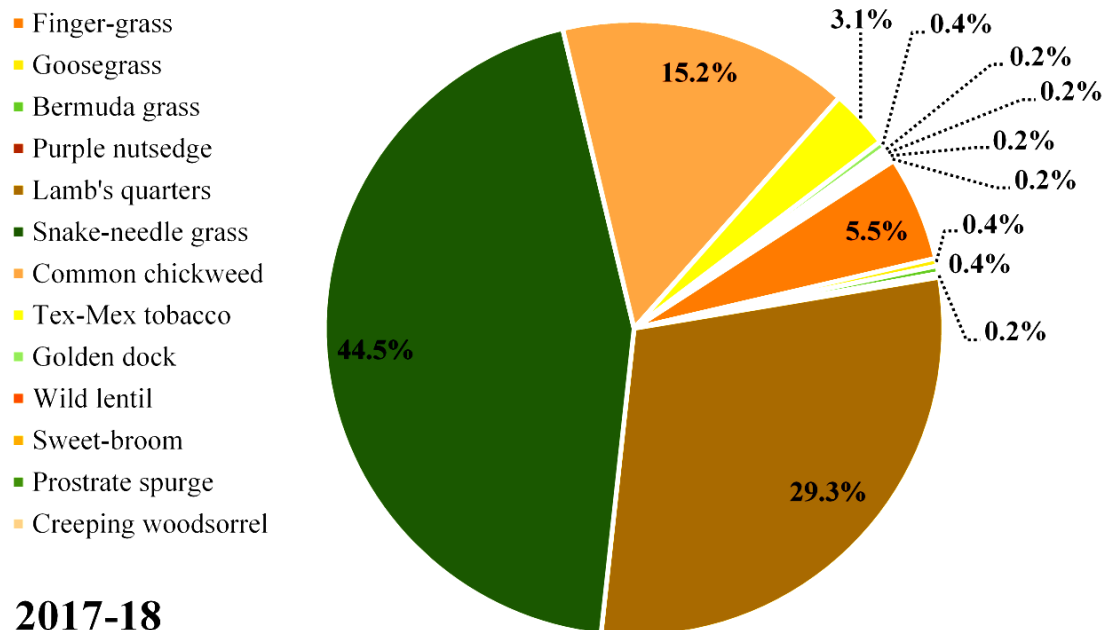


Figure 2. Infesting weed species and their importance value (based on the dry matter) in CA-based ZT-wheat in both years.

In the year 2018-19 season, four types of grass (i.e., *Digitaria sanguinalis*, *Elusina indica*, *Echinochloa colona* and *Cynodon dactylon*) were found under the family Poaceae, one was sedge (*Cyperus rotundus*) under the family Cyperaceae, and eight was noted as broadleaved weeds (i.e., *Chenopodium album*, *Hedyotis diffusa*, *Stellaria media*, *Nicotiana plumbaginifolia*, *Rumex maritimus*, *Lens orientalis*, *Scroperia dulcis* and *Enhydra fluctuan*) under the family Amaranthaceae, Rubiaceae, Caryophyllaceae, Solanaceae, Polygonaceae, Fabaceae, Plantaginaceae and Asteraceae (Table 2).

Considering the type and species-wise infestation, 106.6 (no. m⁻²) (20.5%) weeds were under the species grass, 5.0 (1%) weeds were under the sedges species, and the rest 406.6 (no. m⁻²) (78.5%) weeds were found under the broadleaved species. The results indicated that broadleaved weeds were the most dominant in the second season, followed by grasses and sedges. Similar to the first season, the weed species *H. diffusa* (245 (no. m⁻²); 47.3%) under the family, Rubiaceae was found the most dominant weed, the 2nd was the *Chenopodium album* (100 (no. m⁻²); 19.3%) under the family Amaranthaceae, the 3rd was *Digitaria sanguinalis* (76.7 (no. m⁻²); 14.8%) under the family Poaceae, and the 4th was *Stellaria media* (50.0 (no. m⁻²); 9.6%) under the family Caryophyllaceae. In the case of biomass (oven dry) production, *Digitaria sanguinalis* (17.8 (no. m⁻²); 43.9%) was found the top producer, followed by *H. diffusa* (11.2 (no. m⁻²); 27.6%), *Chenopodium album* (5.2 (no. m⁻²); 12.7%) and *Stellaria media* (2.7 (no. m⁻²); 6.6%); indicating that *Digitaria sanguinalis* was the most infesting weed species based on dry matter production, and *H. diffusa* was dominated based on density in both years (Table 2; Figure 2).

The results of the current study related to the variation of weed flora were also confirmed by several earlier studies, for example, Kumar *et al.* (2013) reported that the predominant weeds associated with wheat are little seed canary grass (*Phalaris canariensis* L.), annual bluegrass (*Poa*

annua L.), foxtail grass (*Polypogon monspeliensis* Desf.), wild oat (*Avena ludoviciana* Durieu), Indian sorrel or toothed dock (*Rumex dentatus* L.), pimpernel (*Anagallis arvensis* L.), field bindweed (*Convolvulus arvensis* L.), little mallow (*Malva parviflora* L.), bur clover (*Medicago denticulata* Willd), common lambsquarters (*Chenopodium album* L.), common vetch (*Vicia sativa* L.), meadow pea (*Lathyrus aphaca* L.), Canada thistle (*Cirsium arvense* L.), white sweet clover (*Melilotus alba* Lamk), swine grass (*Coronopus didymus* L.), alpine knotweed (*Polygonum plebejum* R. Br.), purple nutsedge (*Cyperus rotundus* L.), bermudagrass (*Cynodon dactylon* L. Pers.), and corn spurry (*Spergula arvensis* L.).

Another observation conducted by Chhokar *et al.* (2006) reported that weed flora in wheat differs from field to field, depending on environmental conditions, irrigation, fertilizer use, soil type, weed control practices and cropping sequences. They found that the predominant weeds associated with wheat are *Phalaris minor*, *Poa annua*, *Polypogon monspeliensis*, *Avena ludoviciana*, *Rumex dentatus*, *R. spinosus*, *Anagallis arvensis*, *Convolvulus arvensis*, *Malva parviflora*, *Medicago denticulata*, *Chenopodium album*, *Vicia sativa*, *Lathyrus aphaca*, *Cirsium arvense*, *Melilotus alba*, *Coronopus didymus*, *Polygonum plebejum* and *Spergula arvensis*. Similarly, Monsefi *et al.* (2016) reported that the major weed flora in the wheat field is *Chenopodium album* (12%), *Melilotus indica* (11.5%), *Anagallis arvensis* (10%), *Cirsium arvensis* (15%) and *Rumex dentatus* (9%) among broad-leaved species, and *Phalaris minor* (20%) and *Avena fatua* (17%) among grassy species. Chhokar and Malik (2002, 2008), and Franke *et al.* (2003) stated that among noxious weeds in wheat fields, little seed canary grass is the single most important grassy weed since it has a highly competitive ability leads to a significant yield loss ranging from 25 to 80% depending on the severity of infestation.

3.4.2 Effect of different post-emergence herbicides on controlling weeds

3.4.2.1 Density and dry weight of weed species

All types of weed species (such as grass, broadleaved and sedge weeds) recorded immediately before the application of all herbicides (30 DAS) did not differ significantly (Table 3). However, numerically the maximum density and dry weight were found in broadleaved among all treatments, followed by grasses and then sedges. Similarly, weed density and dry weight of all weed species recorded immediately before herbicides were applied (30 DAS), did not differ significantly in all treatments in both years (Table 3).

3.4.2.2 Weed density, dry weight, mortality (%) and WCE (%) of grass weeds

At 45 DAS

The density and dry weight of grasses in both years varied significantly ($p \leq 0.01$) in all treatments recorded at 45 DAS (recorded 15 days after application of post-emergence herbicides), indicating that all post-emergence herbicides control weeds effectively (Table 4). To know the effective weed control ability of all herbicides, the mortality (% mortality) from weed density, and the per cent weed control efficiency from weed dry biomass (%WCE) were calculated. Among these herbicides, the collective application of Halosulfuron + Pinoxaden (72% mortality in both years) controlled the maximum number of grasses, followed by the combination of Pinoxaden + Metsulfuron (68% mortality in both years), Ready-mix formulation (Carfentrazone + Isoproturon) (68% mortality in both years), and weed free (67% mortality in both years) treatments.

Table 3. Density and dry weight of different weed species in CA-based ZT-wheat recorded immediately before (30 DAS) spraying of all post-emergence herbicides in both years

Treatments	Recorded at 30 days after sowing (DAS)												The density of all species (no. m ⁻²)		The dry weight of all species (g m ⁻²)	
	Grass weeds (no. m ⁻²)				Broadleaved weeds (no. m ⁻²)				Sedge weeds (no. m ⁻²)							
	Density (no. m ⁻²)		Dry weight (g m ⁻²)		Density (no. m ⁻²)		Dry weight (g m ⁻²)		Density (no. m ⁻²)		Dry weight (g m ⁻²)					
	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019				
T1	11.00	10.83	3.02	2.42	13.17	12.57	1.94	2.14	5.89	6.10	2.07	2.17	30.06	29.5	7.03	6.9
T2	11.03	10.73	3.04	2.44	12.15	11.75	1.98	2.08	5.14	4.84	1.39	1.19	28.32	27.3	6.41	6.1
T3	10.55	9.90	3.00	2.49	12.96	13.36	1.96	2.06	3.98	4.00	1.39	1.29	24.99	25.3	6.35	5.8
T4	10.99	10.10	2.89	2.22	12.26	11.66	1.93	2.03	5.39	5.29	2.14	1.64	31.64	31.1	6.96	6.7
T5	11.20	10.80	3.04	2.84	13.10	12.90	2.96	3.10	5.11	4.61	1.16	1.36	29.61	28.3	7.16	7.3
T6	10.97	9.87	2.91	2.21	10.47	10.37	1.97	2.13	4.00	3.70	1.18	1.28	23.44	23.2	5.06	5.6
T7	10.83	10.03	2.87	2.17	12.08	12.38	3.98	4.21	4.17	3.97	2.14	1.64	25.78	26.4	7.99	8.0
T8	11.03	10.83	2.93	2.16	14.93	15.23	2.99	3.02	5.05	4.95	2.08	1.48	31.01	31.0	7.00	6.7
T9	11.80	10.40	2.87	2.31	12.98	13.18	3.19	2.69	4.39	4.19	1.01	1.31	29.17	29.8	7.07	7.0
T10	10.50	10.80	2.04	2.24	10.10	9.70	2.19	1.89	6.00	5.50	2.13	1.73	25.2	24.0	6.36	5.4
F-Test (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	25.81	27.11	27.18	26.98	13.56	14.06	24.13	25.13	33.13	37.13	29.83	32.83	35.00	32.60	34.23	33.5

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. NS indicates non-significant

Table 4. Effect of different post-emergence herbicides on controlling grass weeds recorded at 45 and 60 DAS in both years

Treatment	Grass weeds (45 DAS)						Grass weeds (60 DAS)					
	Density (no. m ⁻²)		Mortality (%)	Dry weight (g m ⁻²)		WCE (%)	Density (no. m ⁻²)		Mortality (%)	Dry weight (g m ⁻²)		WCE (%)
	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019		
T1	240.0 b	33.3 b	23	6.4 c	2.55 a	29	95.0 b	25.0 ef	48	9.2ab	2.6 c	28
T2	151.7 c	35.0 b	47	8.7 b	0.55 c	26	27.7 e	36.0 d	73	3.6c	1.6 de	69
T3	119.3 e	15.3 cde	62	4.8 d	1.15 bc	52	51.7 d	16.6 f	71	4.5c	1.1 ef	66
T4	93.0 g	21.0 cde	68	2.5 f	0.70 bc	74	81.7 c	23.0 f	55	9.3abc	2.7 c	26
T5	101.0 f	12.7 e	68	8.7 b	0.58 c	27	32.7 e	55.0 c	62	4.7c	2.1 cd	58
T6	104.7 f	23.0 cd	64	4.9 d	0.97 bc	53	28.3 e	22.7 f	78	4.4c	1.3 e	65
T7	143.3 d	14.7 de	55	6.7 c	1.37 b	36	130.0 a	65.0 b	16	10.6ab	2.4 c	21
T8	74.3 h	23.3 c	72	3.4 ef	1.43 b	62	91.7 bc	33.7 de	46	8.3b	3.5 b	28
T9	268.0 a	85.0 a	0	9.9 a	2.75 a	0	140.0 a	92.7 a	0	11.2a	5.2 a	0
T10	113.3 e	4.0 f	67	3.6 e	0.40 c	68	13.3 f	23.3 bf	84	1.2d	0.5 f	90
F-test (0.05)	**	**	-	**	**	-	**	**	-	**	**	-
CV (%)	1.74	10.74	-	6.22	20.77	-	5.98	7.90	-	14.13	10.89	-

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. **, significant at 1% level of probability. Different letter(s) in a column for treatments indicate significantly different, while the same letter(s) indicate non-significant.

Although, the density of grasses in the herbicide Pinoxaden treated plot and weed-free plot were statistically similar in the first season, but in both years the mortality was 62% where Pinoxaden was applied and weed-free treatment (67%). In the case of WCE (%) in both years, the ready-mix formulation (Carfentrazone + Isoproturon) performed the best result (74%), followed by weed-free treatment (68%) and the combination of Halosulfuron + Pinoxaden (62%). However, WCE (%) of ready-mix formulation (Sulfosulfuron + Metsulfuron) (29%), ready-mix formulation (Mesosulfuron + Idosulfuron) (26%) and Pinoxaden + Metsulfuron (27%) showed the lower WCE (%) (Table 4).

At 60 DAS

Similarly, the density and dry weight of grasses varied significantly ($p \leq 0.01$) in all treatments when recorded at 60 DAS in both years, also indicating that all post-emergence herbicides can control weeds effectively upto 60 DAS (Table 4), though % mortality was different than data recorded at 45 DAS. The mortality (%) of grasses at 60 DAS was found to be the maximum in weed-free treatment (84% mortality in both years), followed by the combination of Pinoxaden + Carfentrazone (78% mortality in both years), ready-mix formulation (Mesosulfuron + Idosulfuron) (73%), Pinoxaden (71% mortality in both years), and Pinoxaden + Metsulfuron (62% mortality in both years) (Table 4). In the case of WCE (%) in both years, all herbicides controlled the dry matter effectively which led to showing a positive effect on the WCE (%). Same as the percentage of grasses mortality, the WCE (%) was also the maximum at the weed-free treatment, followed by ready-mix formulation (Mesosulfuron + Idosulfuron) (69%), Pinoxaden (66%), and Pinoxaden + Carfentrazone (65%); indicated that herbicides specific control efficiency depended on the duration of application (Table 4).

3.4.2.3 Density, dry weight, mortality (%) and WCE (%) of broadleaved weeds

At 45 DAS

At 45 DAS (recorded at 15 days after application of post-emergence herbicides), the density and dry weight of broadleaved weeds in both years varied significantly ($p \leq 0.01$) in all treatments recorded, indicating that all post-emergence herbicides effectively control the weeds (Table 5).

To know the effective weed control ability of all herbicides, the mortality percentage from weed density and WCE (%) from dry biomass for all treatments was calculated. Among these treatments, the weed-free treatment showed the maximum mortality (94% mortality) of broadleaved in both years, followed by the collective application of Pinoxaden + Carfentrazone (40%), a single application of Halosulfuron (37%) and ready-mix formulation (Carfentrazone + Isoproturon) (36%) in both years. The lowest mortality (%) of broadleaved was recorded in the plot where ready-mix formulation (Mesosulfuron + Idosulfuron) was applied (Table 5). In the case of WCE (%), particularly for broadleaved in both years, the weed-free treatment also showed the maximum WCE (87%) in both years, followed by Pinoxaden + Carfentrazone (65%), Halosulfuron (65%), ready-mix formulation (Carfentrazone+Isoproturon) (54%) and Halosulfuron + Pinoxaden (50%) applied plots. The lowest WCE (%) was recorded in the plots where ready-mix formulation (Sulfosulfuron + Metsulfuron) was applied (24%) (Table 5).

Table 5. Effect of different post-emergence herbicides for controlling broadleaved weeds recorded at 45 and 60 DAS in both years

Treatment	Broadleaved weeds (45 DAS)						Broadleaved weeds (60 DAS)					
	Density (no. m ⁻²)		Mortality (%)	Dry weight (no. m ⁻²)		WCE (%)	Density (no. m ⁻²)		Mortality (%)	Dry weight (no. m ⁻²)		WCE (%)
	2017-2018	2018-2019		2017-2018	2018-2019		2017-2018	2018-2019		2017-2018	2018-2019	
T1	495.0 cd	99.7 c	28	17.95 b	3.7 b	24	165.0 e	18.3 gh	75	7.55 d	2.35 de	87
T2	588.3 b	120.0 b	15	12.87 d	2.67 c	46	353.0 b	32.7 ef	48	19.75 c	3.73 d	69
T3	523.3 bc	135.0 b	21	16.18 bc	2.82 c	34	83.0 g	322.3 b	46	4.39 ef	27.42 b	58
T4	446.7 de	86.3 cd	36	10.7 de	2.55 c	54	122.7 f	4.9 i	83	4.6 de	0.6 e	93
T5	456.7cde	158.3 a	26	13.25 cd	4.23 b	39	61.0 h	24.0 fg	89	1.47 fg	2.73 de	94
T6	418.3 e	79.3 d	40	8.62 e	1.42 d	65	116.7 f	116.7 c	69	5.13 de	4.73 d	87
T7	403.3 e	120.0 b	37	9.02 e	1.15 d	65	325.0 c	43.3 e	51	17.48 c	2.62 de	73
T8	501.3 cd	125.0 b	25	10.52 de	3.88 b	50	225.0 d	84.0 d	59	24.43 b	8.5 c	56
T9	665.0 a	166.7 a	0	22.97 a	5.53 a	0	400.0 a	346.7 a	0	30.18 a	45.33 a	0
T10	45.0 f	9.0 e	94	2.65 f	1.32 d	87	22.7 i	11.7 hi	95	0.37 g	2.2 de	97
F-test (0.05)	**	**	-	**	**	-	**	**	-	**	**	-
CV (%)	5.59	5.06	-	8.17	8.23	-	3.40	3.87	-	9.05	8.83	-

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. **, significant at 1% level of probability. Different letter(s) in a column for treatments indicate significantly different, while same letter(s) indicate non-significant.

At 60 DAS

Similarly to the grasses, the density and dry weight of broadleaved were also varied significantly ($p \leq 0.01$) in all treatments when recorded at 60 DAS in both years; indicating that all post-emergence herbicides controlled the broadleaved weeds effectively upto 60 DAS (Table 5), although the mortality percentage was different than data recorded at 45 DAS. The data in Table 5 showed that the mortality percentage and WCE (%) values of broadleaved at 60 DAS were found to the maximum than at 45 DAS, indicating that all herbicides were effective upto 60 DAS for controlling broadleaved weeds.

Except for weed-free treatment (95% mortality), the combined application of Pinoxaden + Metsulfuron (89%), and ready-mix formulation (Carfentrazone + Isoproturon) (83%) showed the maximum number of broadleaved weeds, followed by Ready-mix formulation (Sulfosulfuron + Metsulfuron) (75%) (Table 5). The lowest mortality (46%) was recorded in Pinoxaden (24%) applied plot.

In the case of WCE (%) in both years, all herbicides positively controlled the dry matter effectively which led to showing a positive effect of WCE. Same as the % grasses mortality, the WCE (%) was also found the maximum in weed-free treatment (97%). While the combined application of Pinoxaden + Metsulfuron (94%), and ready-mix formulation (Carfentrazone + Isoproturon) (93%) showed the maximum value of WCE (%), followed by ready-mix formulation (Sulfosulfuron + Metsulfuron) and Pinoxaden + Carfentrazone (87%) (Table 5). The lowest WCE was recorded in Halosulfuron + Pinoxaden treated plots (56%).

3.4.2.4 Weed density, dry weight, mortality (%) and WCE (%) of sedge weeds

At 45 DAS

At 45 DAS (recorded at 15 days after application of post-emergence herbicides), the density and dry weight of sedges in both years varied significantly ($p \leq 0.01$) in all treatments recorded, signifying that all post-emergence herbicides can control sedges effectively (Table 6). Among these treatments, both weed-free and Pinoxaden + Metsulfuron treatments showed the maximum mortality (76% mortality) of sedges in both years, followed by ready-mix formulation (Mesosulfuron + Idosulfuron) (50%), Pinoxaden (49%), Pinoxaden + Carfentrazone (49%) and the single application of Halosulfuron (49%). The lowest mortality (%) of sedges was recorded in the plot where ready-mix formulation (Carfentrazone+Isoproturon) (36%) was applied (Table 6).

In the case of WCE (%), particularly for sedges in all herbicides applied treatments, both weed-free and Pinoxaden + Metsulfuron treatments showed the maximum WCE value (49%) of sedges in both years, followed by ready-mix formulation (Sulfosulfuron + Metsulfuron) (44) and Halosulfuron + Pinoxaden (43%) plots. The lowest WCE (%) was recorded in the plots where ready-mix formulation Pinoxaden was applied (24%) (Table 6).

At 60 DAS

Similarly to the grasses and broadleaved at 45 and 60 DAS, the density and dry weight of sedges also varied significantly ($p \leq 0.01$) in all treatments when recorded at 60 DAS in both years, indicating that all post-emergence herbicides controlled the sedges effectively up to 60 DAS (Table 6).

Table 6. Effect of different post-emergence herbicides on controlling sedge weeds recorded at 45 and 60 DAS in both years

Treatment	Sedge weeds (45 DAS)						Sedge weeds (60 DAS)					
	Density (no. m ⁻²)		Mortality (%)	Dry weight (g m ⁻²)		WCE (%)	Density (no. m ⁻²)		Mortality (%)	Dry weight (g m ⁻²)		WCE (%)
	2017-2018	2018-2019		2017-2018	2018-2019		2017-2018	2018-2019		2017-2018	2018-2019	
T1	2.42 c	0.71 b	48	0.85 cd	0.71 b	44	9.3 d	10.5 d	50	1.02 bc	0.71 c	62
T2	2.31 c	0.71 b	50	0.98 c	0.71 b	40	2.3 e	5.5 e	80	1.22 bc	0.71 c	57
T3	2.35 c	0.71 b	49	1.43 ab	0.71 b	24	11.7 bcd	14.9 bcd	33	3.2 a	0.74 c	13
T4	3.13 b	0.71 b	36	1.28 b	0.71 b	29	13.7 bc	16.9 bc	23	3.23 a	0.71 c	13
T5	0.71 d	0.71 b	76	0.71 d	0.71 b	49	14.7 b	18.8 b	15	1.61 b	0.71 c	49
T6	2.35 c	0.71 b	49	1.3 b	0.71 b	28	5.0 e	6.0 e	72	0.77 cd	0.95 b	62
T7	2.35 c	0.71 b	49	1.38 ab	0.71 b	26	10.7 cd	15.7 cd	33	0.63 cd	0.71 c	70
T8	3.02 b	0.71 b	38	0.89 c	0.71 b	43	10.0 d	12.0 d	44	1.28 bc	0.71 c	56
T9	3.48 a	1.86 a	0	1.48 a	1.33 a	0	18.3 a	21.3 a	0	3.27 a	1.25 a	0
T10	0.71 d	0.71 b	76	0.71 d	0.71 b	49	2.3 e	5.5 e	80	0.13 d	0.71 c	81
F-test	**	**	-	**	**	-	**	**	-	**	**	-
CV (%)	5.21	10.36	-	4.99	2.50	-	10.52	9.50	-	14.89	2.62	-

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. **, significant at 1% level of probability. Different letter(s) in the column for treatments indicate significantly different, while the same letter(s) indicate non-significant.

The data in Table 6 showed that the mortality (%) and WCE (%) values of sedges recorded at 60 DAS were different in different herbicides applied treatments. Similar to the mortality of sedges at 45 DAS, the maximum mortality (80%) of sedges in both years was also recorded in both weed-free and ready-mix formulations (Mesosulfuron + Idosulfuron) treatments followed by Pinoxaden + Carfentazone applied plot (72%), ready-mix formulation Sulfosulfuron + Metsulfuron (50%) and Halosulfuron + Pinoxaden (44%) plots. The lowest mortality (%) of sedges was recorded in the plot, where the treatment Pinoxaden + Metsulfuron treatments (15%) were applied (Table 6). In the case of WCE (%) in both years, all herbicides positively limit the dry biomass of sedges effectively which leads to an increase in the value of WCE (%). Similar to the percentage mortality and WCE (%) of grasses and broadleaved, the weed-free treatment also showed the maximum value of WCE (81%), followed by Halosulfuron (70%), ready-mix formulation Sulfosulfuron + Metsulfuron, and Pinoxaden + Carfentrazone (62%). The lowest WCE (46%) was recorded in both Pinoxaden, ready-mix formulation (Carfentrazone + Isoproturon) treated plots (13%) (Table 6).

The findings of the current observation related to the weed-controlling ability of post-emergence herbicides were also confirmed by several earlier studies conducted in several countries. Although controlling the ability of herbicides generally depends on the system of cultivation, weed species, weed resistance ability as well as locations. For example, a study conducted in Punjab-India observed that *P. minor* has not evolved resistance to isoproturon, and application of isoproturon at 600-1000 g ha⁻¹ before or after first irrigation provided effective control of *P. minor*, *A. ludoviciana* and *Poa annua*, and many broad-leaved weeds in CA-based ZT-wheat (Singh *et al.* 2015). They also observed that in areas, where *P. minor* has evolved resistance to isoproturon, application of Pinoxaden 50g, Sulfosulfuron 25 g, Clodinafop 60 g, fenoxaprop 100 g ha⁻¹ at 30-35

DAS of wheat provided effective control of *P. minor* and *A. ludoviciana* in ZT wheat. In the case of broad-leaved weeds like *C. album*, *Anagallis arvensis*, *Medicago denticulata*, *Coronopus didymus*, *R. dentatus* etc., 2,4-D sodium salt or 2,4-D ethyl ester at 400-500 g ha⁻¹ at 35-45 DAS when wheat is sown at the normal time, and at 45-55 DAS in late sown crop (December) are effective. Another study was conducted by Naseer-ud-Din *et al.* (2011) in Pakistan to know the efficacy of various pre- and post-emergence herbicides. The results of the study revealed that the density of *Fumaria indica*, *Melilotus indica* and *Rumex dentatus* were decreased significantly by all types of herbicides. Among these applied herbicides, Bromoxynil + MCPA @ 0.49 kg a.i. ha⁻¹ as the post-emergence was found the most effective in controlling *F. indica*, *M. indica* and *R. dentatus* with the maximum mortality at both (30 & 60 DAS) without showing any phytotoxic in wheat. Zahan *et al.* (2021) conducted a two-year study in Bangladesh and found that the herbicide Pendimethalin applied as pre-emergence and Carfentrazone-ethyl + Isoproturon applied as post-emergence effectively controlled all types of weed species. The study revealed that the sequential application of Pendimethalin as pre-emergence treatment followed by Carfentrazone-ethyl + Isoproturon as post-emergence treatment was most effective and economically viable for weed control in strip-till wheat because they achieved the highest grain and straw yields. Another observation of the same group of researchers (Zahan *et al.*, 2020) revealed that three post-emergence herbicides (Ethoxysulfuron, Carfentrazone-ethyl + Isoproturon and Carfentrazone-ethyl) controlled all types of weed species effectively in CA-based ZT-wheat. Among these tested herbicides, the application of Ethoxysulfuron at the label rate and double the label rate was effective for controlling grass weeds, but not for broadleaf weeds. In the case of Carfentrazone-ethyl plus Isoproturon, the application of both herbicides at the label rate and double the label rate was effective in controlling all types of weeds. However, considering the undetermined herbicide

residual issue, and having the phytotoxic effect on wheat leaves and finally, on yield, the study discourages double the label rate application of Carfentrazone-ethyl plus Isoproturon for managing weeds in wheat under strip tillage system (Zahan *et al.*, 2020).

3.4.3 Effect of post-emergence herbicides on the yield attributes and yield of ZT-wheat

The plant height spikes m^{-2} , spike length and spikelets spike $^{-1}$ at harvest of CA-based ZT wheat varied significantly ($p \leq 0.01$) by different weed management treatments (Table 7). The tallest plant was recorded in weed-free treatment in both years, which was statistically similar with the Pinoxaden + Carfentrazone and Halosulfuron in the first year, and the Pinoxaden, Ready-mix formulation (Carfentrazone + Isoproturon), Pinoxaden + Metsulfuron, Pinoxaden + Carfentrazone and Halosulfuron in the second year. While the shortest plant was recorded in the Ready-mix formulation (Mesosulfuron + Idosulfuron) treatment in both years (Table 7). Similarly, the spikes m^{-2} also differed significantly ($p \leq 0.01$) due to the different post-emergence herbicides. In the first year, the maximum spikes m^{-2} were recorded in Ready-mix formulation (Mesosulfuron + Idosulfuron) (293), which was statistically similar to Weed free and Ready-mix formulation (Sulfosulfuron + Metsulfuron) treatments. Whereas, the minimum spikes m^{-2} were recorded in the weedy check plot (177), followed by Pinoxaden + Metsulfuron (206), and Pinoxaden + Carfentrazone (219) applied treatment. In the second season, the maximum number of spikes m^{-2} was found in Halosulfuron + Pinoxaden (346) treatment, followed by the Pinoxaden + Carfentrazone (330) and weed-free (323) treatments. The minimum number of spikes m^{-2} was noted in the weedy check plot (Table 7).

Table 7. Effect of post-emergence herbicides on the plant height at harvest, spikes m⁻², spike length and spikelets spike⁻¹ of wheat

Treatments	Plant height at harvest (cm)		Spikes (no. m ⁻²)		Spike length (cm)		Spikelets spike ⁻¹ (no.)	
	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019
T1	96.25 cd	94.07 cd	283.67 a	293.67 ef	12.59 bc	11.39 ab	19.07 abcd	16.93 c
T2	84.51 g	92.33 d	293.33 a	305.00 de	11.69 c	11.56 a	18.30 cd	18.87 ab
T3	96.65 bcd	96.90 ab	233.67 c	290.67 f	12.00 c	11.38 ab	17.93 d	19.40 a
T4	95.50 de	97.67 a	238.00 bc	311.67 cd	13.45 ab	12.22 a	19.80 ab	18.70 ab
T5	93.45 ef	97.43 ab	206.00 e	310.33 cd	12.57 bc	12.20 a	19.03 abcd	17.60 bc
T6	98.67 ab	97.33 ab	219.33 d	330.00 b	12.52 bc	11.63 a	19.57 abc	17.63 bc
T7	99.23 a	98.35 a	227.00 cd	299.00 def	12.57 bc	11.48 ab	19.53 abc	18.37 abc
T8	98.05 abc	93.43 cd	246.00 b	346.33 a	12.30 c	12.40 a	18.50 bcd	17.53 bc
T9	92.48 f	95.43 bc	177.00 f	217.33 g	10.35 d	10.35 b	14.80 e	14.47 d
T10	99.12 a	98.43 a	291.00 a	323.00 bc	13.89 a	11.53 a	19.87 a	18.27 abc
F-test (0.05)	**	**	**	**	**	**	**	**
CV (%)	0.78	0.76	1.69	1.53	2.77	3.37	2.48	3.22

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. **, significant at 1% level of probability. Different letter(s) in the column for treatments indicate significantly different, while the same letter(s) indicate non-significant.

Considering the spike length, the tallest spike (13.89 and 11.53 cm) was recorded in weed-free treatment in both years, respectively, which was statistically similar to the treatment where ready-mix formulation (Carfentrazone + Isoproturon) (T4) was applied in the first year. In the second year, except for the weedy check, the spike length was statistically similar to all other treatments (Table 7). Similarly, spikelets spike⁻¹ of wheat in all treatments also varied significantly ($p \leq 0.01$) in both years. However, spikelets spike⁻¹ in other treatments were found statistically similar except for weedy check in both years (Table 7), the maximum spikelets/spike were recorded in weed-free treatment (19.87) in the first season and T3 treatment in the second year. The minimum spikelets spike⁻¹ were found in weedy check plots in both years (Table 7).

3.4.4 Effect of post-emergence herbicides on the yield components and yield of ZT-wheat

The grains spike⁻¹ in CA-based ZT-wheat varied significantly ($p \leq 0.01$) due to the application of different post-emergence herbicides (Table 8). Among these treatments, the maximum grains spike⁻¹ was recorded in the T6 treatment (Pinoxaden + Carfentrazone) in the first year, and the weed-free treatment in the second year (53.63), which was statistically similar to T10, T4, T5 and T8 (65.47, 64.80, 62.73 and 64.93, respectively) in the first year and T3, T4, T5, T7 and T8 (52.10, 52.54, 52.63, 53.43 and 53.23, respectively) in the second year. While the minimum no. of grains spike⁻¹ was recorded in T10 treatments in both years (Table 8).

Table 8. Grains spike⁻¹, 1000-grain weight and grain yield of wheat as influenced by different post-emergence herbicides

Treatment	Grains spike ⁻¹ (no.)		1000-grain weight (g)		Grain yield (kg ha ⁻¹)	
	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019
T1	61.27 c	45.73 d	45.00 a	49.67 c	3851.67 e	4168.33 d
T2	53.60 d	50.00 bc	41.67 b	50.67 bc	3431.67 f	4433.33 c
T3	50.50 de	52.10 ab	45.00 a	51.00 bc	3428.33 f	4251.67cd
T4	64.80 abc	52.54 ab	45.00 a	51.00 bc	4246.67 d	4148.33 d
T5	62.73 abc	52.63 ab	45.00 a	50.67 bc	4643.33 ab	5683.33 a
T6	66.17 a	48.50 cd	45.00 a	53.00 a	4353.33 cd	4433.33 c
T7	61.40 bc	53.43 a	45.00 a	52.67 a	4505.00 bc	4933.33 b
T8	64.93 ab	53.23 a	45.00 a	51.67 ab	4410.00 bcd	4925.00 b
T9	49.67 e	41.40 e	40.00 b	41.67 d	2595.00 g	3880.00 e
T10	65.47 a	53.63 a	45.00 a	51.00 bc	4860.00 a	4815.00 b
F-test (0.05)	**	**	**	**	**	**
CV (%)	2.08	2.19	2.07	1.13	2.16	1.94

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. **, significant at 1% level of probability. Different letter(s) in a column for treatments indicate significantly different, while the same letter(s) indicate non-significant.

The 1000-grain weight in all treatments also differed significantly ($p \leq 0.01$) due to the different post-emergence herbicides. In the first year, except for T9 and T2 treatments, the maximum and statistically similar 1000-grain weight (45.0g) was recorded in all other treatments. In the second year, the maximum and statistically similar 1000-grain weight was found in T6, T7 and T8 treatments. The minimum 1000-grain weight was noted in the T9 (Weedy check) treatment (Table 8). Considering the grain yield, all treatments also differed due to different post-emergence herbicides applied to CA-based ZT-wheat. Among these weed control treatments, the highest yield was recorded in weed-free treatment (4860.0 kg ha⁻¹) in the first season, which was statistically similar to the T5 treatment (4643.33 kg ha⁻¹), and the lowest grain yield was recorded in the T9 (weedy check) plot (2595 kg ha⁻¹). In the second season, the maximum grain yield was recorded at the T5 treatment (5683.33 kg ha⁻¹), followed by T7 (4933.33 kg ha⁻¹), T8 (4925.00 kg ha⁻¹) and T10 (4815.00 kg ha⁻¹), and the lowest grain yield was produced in weedy check (T9) plot (3880.0 kg ha⁻¹) (Table 8).

3.4.5 Effect of post-emergence herbicides on the biomass, straw yield and harvest index of ZT-wheat

The total biomass at harvest, straw yield and harvest index of CA-based ZT-wheat also varied significantly ($p \leq 0.01$) in both years alike to grains spike⁻¹, 1000-grain weight and grain yield. In the first year, the maximum biomass (11900 kg ha⁻¹) was produced by the treatment where weeds were cleaned upto harvest (T10), which was statistically similar to the treatment T5 (11178.33 kg ha⁻¹), and the lowest biomass was produced in weedy check (T9) (7533.33 kg ha⁻¹) plot. In the second year, the maximum and statistically similar biomass were produced by treatments T8, T4 and T7 (14036.67, 13803.33 and 13398.33 kg ha⁻¹, respectively), while the lowest biomass was produced in the T9 (weedy check) (9448.33 kg ha⁻¹) treatment (Table 9).

Table 9. Effect of post-emergence herbicides on the total biomass, straw yield and harvest index of CA-based ZT-wheat

Treatment	Biomass at harvest (kg ha ⁻¹)		Straw yield (kg ha ⁻¹)		Harvest Index (%)	
	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019
T1	10523.33 bc	11605.00 f	6671.67 ab	7436.67d	36.61 cd	35.93 bc
T2	9280.00 d	12408.33 e	5848.33 b	7975.00cd	37.00 bcd	35.73 bc
T3	10328.33 c	12910.00 cde	6900.00 a	8658.33bc	33.19 d	32.94 cd
T4	10861.67 bc	13803.33 ab	6615.00 ab	9655.00a	39.16 abc	30.06 d
T5	11178.33 ab	13113.33 b-e	6535.00 ab	7430.00d	41.55 a	43.34 a
T6	10725.00 bc	12500.00 de	6371.67 ab	8066.67cd	40.61 ab	35.48 bc
T7	10713.33 bc	13398.33 abc	6208.33 ab	8465.00bc	42.08 a	36.83 b
T8	10310.00 c	14036.67 a	5900.00 b	9111.67ab	42.78 a	35.08 bc
T9	7533.33 e	9448.33 g	4938.33 c	5568.33e	34.50 d	41.13 a
T10	11900.00 a	13203.33 bcd	7040.00 a	8388.33bc	40.84 ab	36.47 b
F-test (0.05)	**	**	**	**	**	**
CV (%)	2.80	1.91	4.53	3.14	3.42	3.16

T1: Ready-mix formulation (Sulfosulfuron + Metsulfuron); **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron); **T3:** Pinoxaden; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon); **T5:** Pinoxaden + Metsulfuron; **T6:** Pinoxaden + Carfentrazone; **T7:** Halosulfuron; **T8:** Halosulfuron + Pinoxaden; **T9:** Weedy Check and **T10:** Weed free. **, significant at 1% level of probability. Different letter(s) in a column for treatments indicate significantly different, while the same letter(s) indicate non-significant.

The straw yield (kg ha^{-1}) in both years also varied significantly in the application of different post-emergence herbicidal treatments. However, in the first year except for T9, other treatments produced statistically similar straw yield, while the highest straw yield was recorded in T4 (9655 kg ha^{-1}) treatment in the second year, which was statistically similar to T8 ($9111.67 \text{ kg ha}^{-1}$) treatment, and the lowest straw was produced in weedy check (T9) plot in both years (Table 9).

The harvest index in both years also varied significantly in the application of different post-emergence herbicide treatments. However, in the first year, the maximum and statistically similar harvest index were recorded in T10, T4, T5, T6, T7 and T8 treatments, and the lowest harvest index was recorded in T3 and T9 (weedy check) treatments. In the second year, the maximum and statistically similar harvest index were recorded in the T5 treatment (Table 9).

The results related to the growth and yield of CA-based ZT-wheat under different post-emergence herbicidal treatments confirmed that all types of applied herbicides can control weeds and influence the growth and yield of wheat. However, the growth and yield of CA-based ZT-wheat varied as per treatments, which is confirmed by several earlier studies. For example, Zahan *et al.* (2020 a,b) observed that the application of Carfentrazone-ethyl plus Isoproturon both at the label rate and double the label rate as post-emergence was found effective in controlling all types of weeds, lead to influence the growth, ultimately increased the productivity of wheat. Although, the highest grain and straw yields were recorded from the label rate application of Carfentrazone-ethyl plus Isoproturon, and its double rate application also offered similar results in the case of grain and straw yields. However, considering undetermined herbicide residual issues, and having the phytotoxic effect on wheat leaves and finally, on yield, the study discourages double the label rate application of Carfentrazone-ethyl plus Isoproturon for managing weeds in wheat under strip tillage system (Zahan *et al.*, 2020,a,b; 2021).

Kamrozzaman *et al.* (2015) found that the WCE of Ronstar 25EC against broad leaf, sedge and grass were 92, 86 and 64 %, respectively over control leads to produce the highest grain (4.33 t ha^{-1}) and straw yields (4.38 t ha^{-1}) which were statistically identical to those of U46D fluid. Similarly, the highest harvest index (49.71%) was found in Ronstar 25EC, and the lowest (41.89%) was obtained in the control. The highest benefit-cost ratio (2.30) was obtained from Ronstar 25EC which was much higher than hand weeding (1.69). The lowest BCR (1.58) was recorded from the control. It was concluded that herbicide could be a viable alternative to manual weed control practices in wheat cultivation. Ahmed *et al.* (2019) evaluated four pre-emergence herbicides (i.e., Oxadiargyl 80, Pendimethalin 850g, Pyrazosulfuron 15 g, and Mefenacet + Bensulfuran methyl 550 g active ingredient/ha) applied at 2 DAS and four post-emergence herbicides (i.e., 2,4-D 1400g, Ethoxysulfuron 18g, Penoxsulam 22.5g, and Fenoxaprop 56 g active ingredient ha^{-1}) applied at 20 DAS on weed control efficacy. After two years of observation, they found that the best yield provided by pre-emergence (Pendimethalin and Oxadiargyl) and post-emergence (2,4-Dandethoxysulfuron) herbicide treatments were 13-15% and 12-17% lower than the yield (4.1 to 4.2 t ha^{-1}), respectively over the weed-free treatment. Among these herbicides, the post-emergence herbicides Fenoxaprop was the best in controlling weeds, however, due to phytotoxic effects on wheat plants, the plots applied with Fenoxaprop produced a very low yield (2.6 to 2.8 t ha^{-1}). Even after good weed control by the post-emergence application of Penoxsulam, phytotoxicity on wheat resulted in low yield. The study suggested that the best weed control option for wheat is to use a pre-emergence (Pendimethalin or Oxadiargyl) followed by a post-emergence (2,4-D or Ethoxysulfuron) herbicide depending upon weed species which would benefit the farmers by providing high weed control efficacy at a lower cost compared to manual weeding (Ahmed *et al.*, 2019).

3.4.6 Economic study on pre-and post-emergence herbicides for weed control in ZT-wheat

From the economic point of view, the maximum net benefit (Tk. ha⁻¹) in the first year was recorded in the T5 treatment (121386 Tk. ha⁻¹), followed by T10 (113747 Tk. ha⁻¹), T7 (113715 Tk. ha⁻¹) and T6 (112978 Tk. ha⁻¹) treatments, while the minimum net benefit was recorded in weedy check (T9) (61195 Tk. ha⁻¹) treatment. In the second year, the maximum benefit was recorded in T8 (212578 Tk. ha⁻¹) treatment, followed by T5 (153481 Tk. ha⁻¹), T7 (128822 Tk. ha⁻¹) and T10 (113747 Tk. ha⁻¹), and the minimum benefit was found in T9 (100375 Tk. ha⁻¹) treatment (Table 10).

The result of the current study revealed that weed control in wheat through herbicides is an economically viable and cost-effective method under CA-based ZT-wheat. The agreement of the results is also supported by various earlier studies, for example, Kamrozzaman *et al.* (2015) found that the highest benefit-cost ratio was obtained from Ronstar 25EC which was much higher than hand weeding. The lowest BCR was recorded from the control. A survey was carried out by Sayili *et al.* (2006) to analyse herbicide usage in wheat from an economic point of view. The survey included 78 farms, of which, 70 of them use herbicides and eight of them do not use herbicides in wheat growing. Herbicide usage resulted in a yield increased under irrigated conditions.

Table 10. Economic performance of pre-and post-emergence herbicides for controlling weeds in CA-based ZT-wheat in both years

Treatments	Cost for controlling weeds (Tk. ha ⁻¹)		Gross return after controlling weeds (Tk. ha ⁻¹)		Net benefit after controlling weeds (Tk. ha ⁻¹)	
	2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019
T1	23290	23290	122222	132487	98932	109197
T2	23884	23884	108798	140975	84914	117091
T3	24954	24954	109750	136208	84796	111254
T4	24838	24838	134015	134105	109177	109267
T5	24449	24449	145835	177930	121386	153481
T6	23994	23994	136972	141067	112978	117073
T7	27643	27643	141358	156465	113715	128822
T8	26284	26284	138200	238862	111916	212578
T9	21593	21593	82788	121968	61195	100375
T10	39093	39093	152840	152838	113747	113745

Cost for controlling weeds:

Market price (Tk. ha⁻¹) of commercial herbicides: **T1:** Ready-mix formulation (Sulfosulfuron + Metsulfuron) = (1347 + 350) Tk ha⁻¹; **T2:** Ready-mix formulation (Mesosulfuron + Idosulfuron) = (1941+ 350) Tk ha⁻¹; **T3:** Pinoxaden = (3011 + 350) Tk ha⁻¹; **T4:** Ready-mix formulation (Carfentrazone + Isoproturon) = (2895 + 350) Tk ha⁻¹; **T5:** Pinoxaden + Metsulfuron = (1506+ 1000+ 350) Tk ha⁻¹; **T6:** Pinoxaden + Carfentrazone = (2051+ 350) Tk ha⁻¹; **T7:** Halosulfuron = (5700 + 350) Tk ha⁻¹; **T8:** Halosulfuron + Pinoxaden; (4341+ 350) Tk ha⁻¹; **T9:** Weedy Check = 0; **T10:** Weed-free = 17500 Tk ha⁻¹.

Manual weeding cost (Tk.): 50 labours ha⁻¹ for 2 times weeding (in weed-free check) @ 350 labour⁻¹ day⁻¹, Herbicide application cost (Tk.): 1 labour ha⁻¹ round⁻¹ @ 350 labour⁻¹ day⁻¹, Irrigation cost (Tk.): 6 labours ha⁻¹ for 3 times irrigation in both years @ 350 labour⁻¹ day⁻¹, Harvest and post-harvest processing cost (Tk.): 45 labours ha⁻¹@ 350 labour⁻¹day⁻¹; Market price of grain (Tk. kg⁻¹): 30.0 and straw: 1.0.

Gross return = {grain yield (t ha⁻¹) × market price (Tk ha⁻¹)} + {straw yield (t ha⁻¹) × market price (Tk t ha⁻¹)}, Net benefit = Gross income – Total costs.

3.5 Conclusion

After two years of observation, the results of the study revealed that all herbicides applied as post-emergence can control all types of weeds effectively. Considering the grain yield, the highest yield was recorded in weed-free treatment ($4860.0 \text{ kg ha}^{-1}$) in the first year, which was statistically similar to T5 (Pinoxaden + Metsulfuron) in both years (4643.33 and $5683.33 \text{ kg ha}^{-1}$) and the lowest grain yield was recorded in the weedy check (2595 and 3880 kg ha^{-1}) in both years, respectively. From an economic point of view, the maximum net benefit (Tk. ha^{-1}) in the first year was recorded in the Pinoxaden + Metsulfuron (T5) treatment ($121386 \text{ Tk. ha}^{-1}$), but in the second year, the maximum benefit was recorded in Halosulfuron + Pinoxaden (T8) ($212578 \text{ Tk. ha}^{-1}$). Therefore, both combinations of these herbicides may be recommended for weed control in CA-based ZT-wheat under irrigated conditions.

CHAPTER 4

EXPERIMENT 2

Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in Zero-Till Maize

4.1 Abstract

The efficacy and economics of different pre-and post-emergence herbicides used alone or sequentially in the CA-based zero/zero-till maize production system are still sporadic under the condition of Bangladesh. In the context, an observation entitled ‘Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in Maize under Zero-Till Condition’ was undertaken in consecutive two years to know the efficacy and economics of different pre-and post-emergence herbicides used alone or sequentially for weed control in CA-based ZT maize. Treatments were two pre-emergence herbicides (i.e., Pendimethalin and Atrazine) and a control (i.e., No pre-emergence) and five post-emergence herbicides ((i.e., Atrazine; Tembotrione; Halosulfuron; Tembotrione + Atrazine and Halosulfuron + Atrazine) and a control (i.e., No post-emergence). After two years of observation, the findings of the study revealed that sequential use of pre- and post-emergence herbicides significantly influenced the grain yield of ZT-maize by effectively controlling all types of weeds. From the economic point of view, the maximum net benefit (two years’ average) was recorded from Pendimethalin & Atrazine (both as pre-emergence) and Atrazine (as post-emergence) (367807 & 362907 Tk. ha⁻¹) applied plots, followed by Pendimethalin & Atrazine (both as pre-emergence) and Tembotrione + Atrazine (as post-emergence) (362582 & 363832 Tk. ha⁻¹), while the minimum net benefit (258907 Tk. ha⁻¹) was recorded in weedy check treatment.

4.2 Introduction

Maize (*Zea mays* L.) is an important cereal crop in the world. It is a source of nutrition as well as phytochemical compounds (i.e., such as carotenoids, phenolic compounds, and phytosterols) which play an important role in preventing chronic diseases (Rouf Shah *et al.*, 2016). More than 3,500 uses of corn products are nominated for multiple uses (Huma *et al.*, 2019). It covers health-related issues such as analgesic, astringent, anti-allergic, emollient, skin rashes, and sore throat, anti-angina, anti-hypertensive, against biliousness, anti lithiasis, anti-diarrheal, urinary disorders including dysuria, cystitis, urethritis, nocturnal enuresis, etc. (Huma *et al.*, 2019). It is also a good source of vitamins A, B, and E and also many minerals, and it reduces hypertension and prevents neural tube defects at birth (Huma *et al.*, 2019). Besides these, it has a potential anti-HIV activity due to the presence of *Galanthus nivalis* agglutinin (GNA) lectin or GNA-maize. A tablespoon of maize oil satisfies the requirements for essential fatty acids for a healthy child or adult. Decoction of maize silk, roots, leaves, and cob are used for bladder problems, nausea, vomiting, and stomach complaints. Zein, an alcohol-soluble prolamine found in maize endosperm, has unique novel applications in pharmaceutical and nutraceutical areas. Resistant starch (RS) from maize reduces the risk of cecal cancer, atherosclerosis, and obesity-related complications (Rouf Shah *et al.*, 2016).

Due to its multipurpose uses, the demand for maize is increasing day by day, particularly in developing countries. Half of the world's maize is produced in developing countries where maize flour is used as a staple food for poor people, while the maize stalk provides feed to their animals (Ofori *et al.*, 2004). Recent projections by the International Food Policy Research Institute (IFPRI, 2020) indicated that the demand for maize will overtake the demand for wheat and rice by 2020, with Asia accounting for nearly 60% of the global demand for maize. The EGP (India, Bangladesh and Nepal) has a very high yield potential of Rabi and Kharif-1 (spring) maize including Bihar, West Bengal (India), Bangladesh and Nepal (Ali *et al.*, 2009).

Although maize is not a staple food cereal yet in Bangladesh, presently it is the third most important cereal after rice and wheat. During 2021-22, 5.63 million tons of maize was produced from 0.55 million ha of land, whereas the annual grain requirement is about 7.0 million tons. The current national average yield of maize is 10.2 t ha⁻¹ which is due to the introduction of hybrids, and the adoption of appropriate crop management practices (BWMRI, 2022). The demand for maize is increasing in Bangladesh day by day due to its increasing demand for livestock and fish feed, production of different types of processed foods, and also for exporting (BWMRI, 2022). However, in IGP like Bangladesh, the average yield of maize is not comparable with that of maize-growing countries for many reasons. Among them, cultivation methods and weed infestation are probably the most important. Presently, maize is grown more than 90% by manual dibbling after intensive 5-6 tillage operations leading to a delay in the maize sowing by at least 1-2 weeks (Islam *et al.*, 2013). On the other hand, the number of repetitive tillage operations increases the cost of cultivation, and fuel consumption and delays planting in two ways repetitive tillage operations followed by manual dibbling. Since, manual dibbling requires a large number of labourers which further reduces the net margins (Yadav *et al.*, 2016). Besides these, after post-seeding, maize growers face major challenges for weed management in both Rabi and spring maize due to the lack and availability of appropriate pre- and post-emergence herbicides in the region. The traditional weed management in maize during 30-40 DAS farmers generally used a spade to cut the weeds, and simultaneously earthing-up maize plants to make furrows and ridges which further consumed more labour but facilitated furrow irrigation (Hossain *et al.*, 2019).

The CA-based new agronomic management practices are advocating to overcome those above challenges. The direct seeded maize in no-till/strip-till/permanent beds or till the soil with fresh beds is an alternate option through mechanized precision planting in a single pass. In an increasingly competitive agricultural scenario, no-tillage farming systems are gaining growing

attention worldwide. These are farming systems where no soil tillage is practiced, not even superficially. There are many benefits associated with these no-tillage systems, particularly economic advantages. In addition, environmental benefits are also attributed to no-tillage farming regarding soil structure, aquatic resource variations and positive effects through the storage of organic carbon, as carbon dioxide, acts in the atmosphere as a greenhouse gas.

Soil tillage has been developed for several reasons, such as to facilitate the preparation of a seedbed for a more efficient seeding. However, weed control has always been attributed to soil tillage, and particularly, the development of the mouldboard plough is very effective for weed management. But, in the long term, the weed control effect of tillage has proven to be insufficient and herbicides have become the tool of choice in intensive farming. However, tillage creates a good seedbed for the seeds and while also creates the same conditions for the weeds. While weed seeds are buried deep with the mouldboard plough, the same plough brings the weed seeds to the surface that had been buried the season before. The seed bank in most agricultural soils is probably large enough that the plough does not have a long-lasting control effect on weeds which multiply by seeds. On the other side, weeds propagating through sprouts or roots can even be multiplied by tillage implements, which only cut and mix them with the soil, so that the number of potential weed plants is increased. Through soil carried with tillage implements from one field to another, the weed population is also spread throughout the entire farmland. Therefore, the use of tillage for weed control is not the ultimate answer, nor is the move to no-till the ultimate doom in terms of weed control.

Weeds are among the serious constraints that limit maize production. The competition between weed and maize is induced by reducing the quality and quantity of maize yield by over 30% (Mahmoodi *et al.*, 2009). In addition, weeds interfere with crop growth and yield through the acquisition of required resources of variations including light, water and nutrients, and are potentially a major constraint on crop production if not controlled (Kropff *et al.*, 1993; Zimdahl

et al., 2007; John *et al.*, 2010). To minimize weed losses, several methods are available such as mechanical, cultural, biological and chemical control methods. Exhausted by cultural methods, farmers are moving towards other alternative methods of weed control (Mahmoodi *et al.*, 2009 & Varga *et al.*, 2011). In this respect, chemical weed control may be considered the best option than other methods (Ahmed *et al.*, 2008). Mechanical methods including hand weeding are still useful but are getting expensive, laborious and time-consuming. In less developed countries, the situation still exists where the peak labour requirement is often for hand weeding (Chikoye *et al.*, 2007). Herbicide-based weed control is an important alternative to manual weeding because it is cheaper, faster and gives better weed control (Chikoye *et al.*, 2005). Chemical control is a better alternative to manual weeding because it is cheaper, faster, and gives better control (Chikoye *et al.*, 2004; Chikoye *et al.*, 2002). Weed control in maize with herbicides has been suggested by researchers (Correa *et al.*, 1990; Owen *et al.*, 1993). Ali *et al.* (2003) also reported that herbicides significantly decreased weed density and increased maize yield.

The CA-based crop management techniques are considered as major concerns in weed management initially. To address the weed management problems in CA-based maize production under no-till systems, different weed management options are designed to convince different stakeholders including farmers, input dealers, extension officers, private sectors, researchers and policymakers. In general, the evaluation of herbicide used in maize should depend not only on its efficiency in controlling the weeds but also include its effects on growing plants and maize grain yield as well as its residual effects on the succeeding winter crops. The use of pre-and post-emergence application of herbicides would make it more acceptable to farmers to control weeds which will not change the existing agronomic practices but will allow for complete control of weeds. The usage of pre-emergence herbicides assumes greater importance because of their effectiveness from the initial stages. Pre-emergence application of herbicides controls the weeds for up to 25 days, and after that post-emergent application is given

so that further growth of weeds can also be controlled. Pre-emergence and post-emergence herbicides will be an ideal means for controlling the weeds because of the economics and effectiveness of maize. Therefore, the present study was undertaken considering the following objectives:

- i) To know the efficacy and economics of different pre-and post-emergence herbicides used alone or sequentially for controlling weeds in CA-based ZT maize under a maize-mungbean-rice cropping system;
- iii) To quantify the effect of different herbicides on growth, yield attributes and yield of CA-based ZT maize a maize-mungbean-rice cropping system.

4.3 Materials and Methods

4.3.1. Location and characteristics of the experimental site

The experiment was conducted at BWMRI, Nashipur, Dinajpur for consecutive two years (from December 2017 to May 2018 and repeated from December 2018 to May 2019).

The AEZ of the area is the Old Himalayan Piedmont Plain (AEZ-1) (FAO and UNDP, 1988). The geographical position of the area is between 25°38'N, 88°41'E and 38.20 m above sea level. However, the soil was sandy-loam, and its reaction was strongly acidic (pH ranges from 4.9 to 5.7), organic matter content was below 1%, and the concentrations of N, K, S, B, Mg and Zn were below the critical level, but P was higher the critical level (Appendix 2).

The geographical location of the experimental site was under the subtropical climate. Weather data on weekly average temperature, humidity and rainfall during the experimental period were recorded regularly at the meteorological station of BWMRI, Nashipur, Dinajpur are presented in Appendix 3.

4.3.2 Experimental treatments and design

Treatments of the experiment were a control (without pre-emergence herbicide) and two pre-emergence herbicides (i.e., PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹) and six post-emergence herbicides (i.e., PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹). All treatments were arranged in a split-plot design and repeated all treatments in three times.

This was a factorial experiment, three pre-emergence herbicides were assigned in the main plots and six post-emergence herbicides were assigned in sub-plots.

Main plots: a control (without pre-emergence herbicide) and two pre-emergence herbicides (Applied within two days after seeding, at optimum moisture, preferably sprayed in evening hrs).

1. PH1: No herbicide (control)
2. PH2 : Pendimethalin (1000 g a.i. ha⁻¹) (Panida)
3. PH3 : Atrazine (1000 g a.i. ha⁻¹) (Foost)

Sub-plots: Post-emergence herbicides: five, and one as a control (without herbicide)

1. PO1: No herbicide (control)
2. PO2: Atrazine (Foost) (500 g a.i. ha⁻¹)
3. PO3: Tembotrione (Laudis) (120 g a.i. ha⁻¹)
4. PO4: Halosulfuron (Sempra) (90 g a.i. ha⁻¹)
5. PO5: Tembotrione (Laudis) (120 g a.i. ha⁻¹) + Atrazine (Foost) (500 g a.i. ha⁻¹)
6. PO6: Halosulfuron (Sempra) (90 g a.i. ha⁻¹) + Atrazine (Foost) (500 g a.i. ha⁻¹)

Details of all of the treatments are discussed in Table 11, and the field arrangement of all treatments is presented in Figure 3.

Table 11. Details of all herbicides used for controlling weeds in the zero-till maize

Treat.	Herbicide	Dose (g a.i. ha⁻¹)	Application time
Pre-emergence herbicides			
PH1	No herbicide (control)	-	Applied within two days after seeding
PH2	Pendimethalin	1000 g	(applied at optimum moisture, preferably
PH3	Atrazine	1000 g	spray in the evening time)
Post-emergence herbicides			
PO1	No herbicide (control)		
PO2	Atrazine	500g	Applied at 15 DAS or 3-5 leaf stage of weeds
PO3	Tembotrione	120g	Applied at 15 DAS or the 3-5 leaf stage of weeds
PO4	Halosulfuron	90g	Applied at 15 DAS or the 3-5 leaf stage of weeds
PO5	Tembotrione + Atrazine	120g + 500g (Tank mixture)	Applied at 15 DAS or 3-5 leaf stage of weeds (Both herbicides were tank-mixed together)
PO6	Halosulfuronl + Atrazine	90g + 500g (Tank mixture)	Applied at 15 DAS or at 3-5 leaf stage of weeds (both herbicides were tank-mixed together)

Note: In all ZT plots, existing weeds were killed with non-selective herbicide (glyphosate @ 1000 g a.i. ha⁻¹) 5-7 days before sowing of maize seeds; but if plots were dry tilled then no need to apply any pre-plant herbicides if minimum dry tillage before seeding then no needs to apply any pre-plant herbicide.

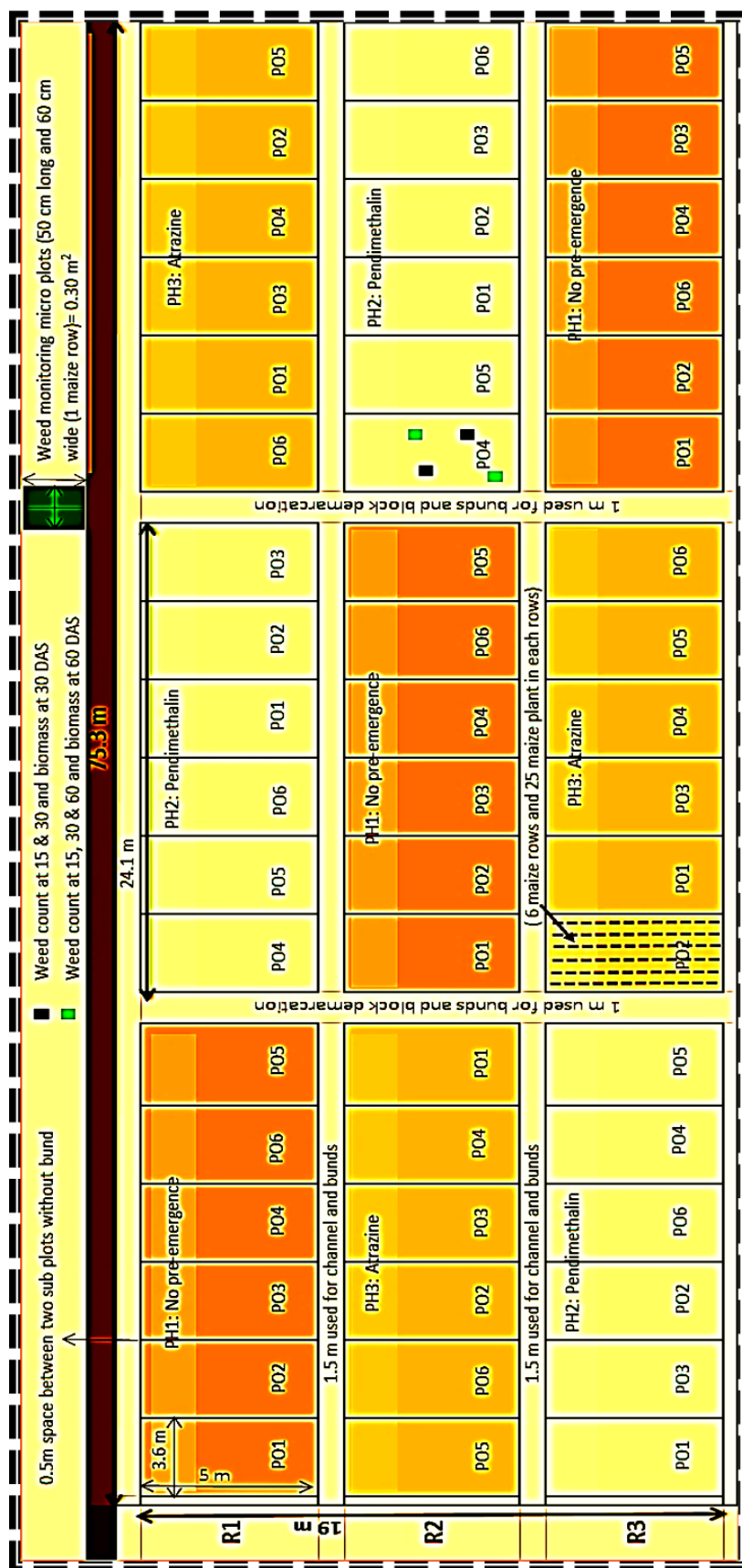


Figure 3. Experimental layout for ZT-maize weed management trial. Note: **PH1:** No pre-emergence; **PH2:** Pendimethalin (1000 g a.i. ha⁻¹) and **PH3:** Atrazine (1000 g a.i. ha⁻¹) and six post-emergence herbicides (i.e., **PO1:** No post-emergence; **PO2:** Atrazine (500 g a.i. ha⁻¹); **PO3:** Tembotrione (120 g a.i. ha⁻¹); **PO4:** Halosulfuron (90 g a.i. ha⁻¹); **PO5:** Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and **PO6:** Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹)

Total plots: 3 main plots x 6 subplots x 3 rep = 54 plots. All treatments were randomly allocated in experimental plots. Total experimental area required: 75.3m x 19m = 1430.7 m². The size of the unit's main plot size was 24.1m x 5m = 120.5 m² and the subplot size was 5m x 3.6m = 18 m². The distance between each of the main plots was 1 m and that of the unit plots was 0.5m and block to block was 1.5m.

4.3.3 Zero-till maize production and its management for experimental purpose

4.3.3.1. Land preparation

Good land levelling helps ensure high yield and reliable production of CA-based ZT-maize. A level field allows planters/drills to place seeds more precisely, and enables more uniform irrigation and water depth, leading to a uniform crop stand, and improved weed control and nutrient use efficiency. Levelling also helps to reduce irrigation water application by eliminating high spots. Before the start of the experiment, the field was levelled by hand hoe.

4.3.3.2 Application of Roundup (glyphosate) @ 1000 g a.i. ha⁻¹

Before sowing, the ZT field was applied Roundup (glyphosate) @ 1000 g a.i. ha⁻¹ at 5-7 days before the sowing of crops to kill existing weeds as a blanket application to the entire field for all treatments.

4.3.3.3 Maize Variety

The maize variety Dekalb 9120 was used in the present research. The maize hybrid is developed by Bayer Crop Science Ltd. for the farmers of Bihar, Eastern Uttar Pradesh, West

Bengal, Chhattisgarh, Bangladesh, Andhra Pradesh, Telangana, and Karnataka, particularly for the Rabi or dry season.

4.3.3.4 Sowing time, seed rate and planting system

The best date for the sowing of maize Dekalb 9120 is 15th November to 15th December. In the present research, in both years, maize seeds were sown on 12 December 2017 and 2018. Maize seeds were sown at the rate of 30 kg ha⁻¹ with a row spacing of 60 cm, using a power tiller-operated ZT machine with a fluted-type seed-metering device.

4.3.3.5 Fertilizers management

Fertilizer requirement varies depending on many factors including variety, soil type, residue and fertilizer management of prior crops, the number and nature of crops grown in the field each year and the desired yield level. Fertilizers were applied in our research at the rate of 220-180-50-120-10-4 kg ha⁻¹ of urea, triple super phosphate, muriate of potash, gypsum, zinc sulphate and boric acid, respectively. All P, K, S, B and Zn and one-third of urea were applied at the time of final land preparation. Fertilizer N was applied at two equal splits of 1/3 at 24 DAS, and 1/3 at 54 DAS.

4.3.3.6 Irrigation management

Maize is very susceptible both to excess moisture and deficit moisture stress. Never allow water to stand in the maize field at any stage of its growth. In the case of the Rabi season, 2-3 irrigations may be required depending on the kind of land and soil. In the research, two times irrigations were done.

4.3.3.7 Pest management

The plants were infected by cutworm at the seedling stage, and it was successfully controlled by applying Malathion (Sumady 57 EC) at the rate of 2.25 litre ha⁻¹ (Marketing by McDonald Bangladesh (Pvt) Limited).

4.3.3.8 Harvesting

After full maturity, the crop was harvested plot-wise on May 27, 2017. For collecting necessary data the sample plants were harvested separately. The harvested crop of each plot was bundled separately, tagged and taken to the threshing floor, then were dried to bright sunshine shelled and the grains cleaned properly. Grain and stalk were thoroughly dried plot by plot individually before their weights were recorded.

4.3.4 Data collection and their procedures

4.3.4.1 Weed data

For weed data, four permanent 0.30 m² (60 cm x 50cm) quadrats were established in each plot at 12 DAS (as per Figure 3). All types of weed data were taken from these four permanent quadrats.

- ❖ Density (no. m⁻²) of grass, broadleaved and sedge weeds were recorded from four permanent quadrats immediately before the application of post-emergence herbicides (at 15 DAS)
- ❖ Weed density (no. m⁻²) was recorded from all four permanent quadrats at 30 DAS, and the weed dry weight (g m⁻²) was recorded from randomly selected two quadrats.
- ❖ Weed density (no. m⁻²) and dry weight (g m⁻²) species-wise were recorded at 60 DAS from the remaining two permanent quadrats.

- ❖ Weed dry weight (g m^{-2}) at harvest was recorded from the same area from which crop samples were taken.
- ❖ Visual ratings on weed control and crop injury at the following DAA (days after application) were also recorded: At 15 DAA for pre-emergence herbicides and at 30 and 60 DAS for post-emergence herbicides.
- ❖ Local, common and Latin names of weed species were noted from weedy check treatment at 45 DAS in both years
- ❖ Weed mortality (%) and weed control efficiency (%) were also estimated for all weed control treatments as compared with the weedy check.

$$\text{Mortality\%} = \frac{W_t - W_s}{W_t} \times 100$$

Where; W_t = Total number of weeds m^{-2} before spray; W_s = Number of surviving weeds m^{-2} after spray.

$$\text{WCE} = \frac{W_c - W_t}{W_c} \times 100$$

Where; W_c = Average dry weight m^{-2} in the weedy check plot; W_t = Average dry weight m^{-2} in the plot after spray.

4.3.4.2 Crop data

Crop emergence was recorded at 15 DAS from a 2 m long 2 rows in each plot to know the pre-emergence herbicides' negative impact on emergence. Crop height at 30 and 60 DAS, and at harvest were also recorded. For getting actual plant height, the height of the randomly selected 10 plants' was measured from each plot and then averaged. At harvest, plant height, and yield attributes (no. of plants, no. of cobs per plant, grains per cob, and 1000-grain weight were recorded.

The stover and grain yield were also calculated by harvesting and threshing the entire plot rather than a 1m² area.

4.3.5. Economic analysis

For economic analysis, variable cost (i.e., labour/nonmaterial cost and material cost), fixed cost (land rent, interest on input cost and miscellaneous cost), and gross and net return were estimated from the data such as labour costs for all management including hand weeding in weed free treatment as well as application time of herbicides were noted in each treatment. Besides these herbicide and other input costs were also considered.

4.3.6. Statistical analysis

Data were analyzed using analysis of variance (ANOVA). The ANOVA results showed an interaction between treatments; therefore, the data were analyzed separately using STAR 3.0 V (IRRI, 2016). Treatment means were separated using the least significant difference (LSD) at the 5% level of significance. Weed density and biomass data were subjected to square-root transformation [$\sqrt{x + 0.5}$] before analyses. The transformation, however, did not improve the results, so no transformed data were used. Differences were considered significant only at $P \leq 0.05$.

4.4 Results and Discussion

Results obtained from the present study regarding the performance of different pre- and post-emergence herbicides and their combined effect on weed control in ZT maize are presented in the chapter.

4.4.1 Composition of infesting weed flora in zero-till maize

Local name, scientific name, family, morphological types, life cycle, weed density, dry weight, and per cent weed species of infesting weed species in weedy check (no-pre and post-emergence) plot were recorded at 60 DAS and presented in Table 12. The experiment plots were infested with 19 weed species namely *Digitaria sanguinalis*, *Eleusine indica*, *Echinochloa colonum*, *Echinochloa crusgalli*, *Blumea lacera*, *Phyllanthus niruri*, *Spilanthe acmella*, *Amaranthus spinosus*, *Hedyotis brachypoda*, *Nicotiana plumbaginifolia*, *Chenopodium album*, *Enhydra fluctuans*, *Commelina benghalensis*, *Amaranthus viridis*, *Oxalis europea*, *Ranunculus fluitans*, *Physalis heterophylla*, *Ipomoea spp.*, *Cyperus rotundus*. Among these weed species (19), four species were of the family Poaceae, three of each in the family Asteraceae, two of each in the family Amaranthaceae and Solanaceae, and one of each in the family Oxaliaceae, Phyllanthaceae, Rubiaceae, Cyperaceae, Convolvulaceae, Chenopodiaceae, Commelinaceae and Euphorbiaceae (Table 12).

Table 12. Local name, scientific name, family, morphological type life cycle, weed density, dry weight and their importance value of infesting weed species in weedy check plot recorded at 60 DAS (average of two years data)

SL no.	Common name	English name	Scientific name	Family	Morphological types	Life cycle	Density (no. m ⁻²)	Relative density (%)	Dry weight (g m ⁻²)
1	Anguli gas	Crabgrass	<i>Digitaria sanguinalis</i>	Poaceae	Grass	Annual	430.55	55.72	53.87 (57.76%)
2	Chapra	Goose grass	<i>Eleusine indica</i>	Poaceae	Grass	Annual	23.33	3.02	3.8 (4.07%)
3	Boroshama	Barnyard grass	<i>Echinochloa crusgalli</i>	Poaceae	Grass	Annual	3.33	0.43	4.17 (4.47%)
4	Khudisema	Jungle rice	<i>Echinochloa colonum</i>	Poaceae	Grass	Annual	124.4	16.10	5.56 (5.96%)
5	Kukursunga	Lettuce-Leaf Blumea	<i>Blumea lacera</i>	Asteraceae	Broadleaved	Annual	3.90	0.50	0.36 (0.39%)
6	Hazardana	Seed-under-leaf	<i>Phyllanthus niruri</i>	Phyllanthaceae	Broadleaved	Annual	2.20	0.28	0.27 (0.29%)
7	Holud-nakful	Toothache Plant	<i>Spilanthes acmella</i>	Asteraceae	Broadleaved	Annual	46.67	6.04	3.27 (3.51%)
8	Halencha	Buffalo spinach	<i>Enhydra fluctuans</i>	Asteraceae	Broadleaved	perennial	13.9	1.80	2.8 (3.00%)
9	Kanaibasi	Benghal dayflower	<i>Cammelia benghalensis</i>	Commelinaceae	Broadleaved	perennial	0.55	0.07	0.11(0.12%)
10	Shaknote	Slender amaranth	<i>Amaranthus viridis</i>	Amaranthaceae	Broadleaved	Annual	1.10	0.14	0.17(0.18%)
11	Amrul	Wood sorrel	<i>Oxalis europea</i>	Oxaliaceae	Broadleaved	Annual	4.50	0.58	0.31 (0.33%)
12	Katanote	Spiny amaranth	<i>Amaranthus spinosus</i>	Amaranthaceae	Broadleaved	Annual	5.00	0.65	0.7 (0.75%)
13	Bathua	Lamb's quarters	<i>Chenopodium album</i>	Chenopodiaceae	Broadleaved	Annual	10.00	1.29	3.28 (3.52%)
14	Lalkakri	Snake-needle Grass	<i>Hedyotis brachypoda</i>	Rubiaceae	Broadleaved	Annual	87.78	11.36	12.5 (13.4%)
15	Bontamak	Tex-Mex tobacco	<i>Nicotiana plumbaginifolia</i>	Solanaceae	Broadleaved	Annual	10.00	1.29	0.8 (0.88%)
16	Phoskabegun	Clammy groundcherry	<i>Physalis heterophylla</i>	Solanaceae	Broadleaved	Annual	0.55	0.07	0.33 (0.35%)
17	Bandhania	River Water-crowfoot	<i>Ranunculus fluitans</i>	Euphorbiaceae	Broadleaved	Annual	1.66	0.21	0.3 (0.32%)
18	Ipomea	Water spinach	<i>Ipomoea aquatica</i>	Convolvulaceae	Broadleaved	Annual	0.55	0.07	0.17 (0.18%)
19	Mutha	Purple nutsedge	<i>Cyperus rotundas</i>	Cyperaceae	Sedge	perennial	2.77	0.36	0.49(0.53%)
Total							772.74	100	93.26 (100%)

*Figure in the parenthesis in the column of dry weight, indicates the importance value (%) of weed species.

The involvement of all weed species was calculated by dividing the density and dry weight of the individual weed species by the total density and dry weight of all weed species and multiplying by 100.

Among the family, Poaceae consisted of 581.61 (75.27%), Asteraceae 6.9%, Solanaceae 1.23%, Amaranthaceae 0.93% and other seven families (Oxaliaceae, Phyllanthaceae, Rubiaceae, Cyperaceae, Convolvulaceae, Chenopodiaceae, Commelinaceae and Euphorbiaceae) consisted 18.69% (Figure 4; Table 12). Considering the percentage density and importance value of weed species *Digitaria sanguinalis* was the most dominant weed containing a density of 430.55 (55.72%), an importance value of 53.87 (57.7%) followed by *Echinochloa colonum* (16.10 and 5.96%, respectively), *Hedyotis brachypoda* (11.4 and 13.4%, respectively), *Eleusine indica* (3%) (Figure 4; Table 12). Thus the species in the family Poaceae were dominant weeds in experimental plots. Several earlier studies also confirmed various weed species in the maize fields. For example, Hossain *et al.* (2019) stated that infesting weed species in crop fields generally depends on crop species, cropping systems and their management practices, environmental conditions, seasonal variation, soil properties, nutrients and moisture status as well as soil types. They also revealed that the EGP is known for high weed seed banks in soils especially lower EGP (Bangladesh and West Bengal) due to flash and steady floods bringing weed seeds from a distance in their catchment areas. The weed species in maize fields highly depend on seasons, since maize can be grown around the year i.e. Kharif-II (Monsoon; June–September), Rabi (winter; November–May) and Kharif-I (spring; February–June). The high weed seed pressure and diversity make it more difficult to manage weeds manually in CA as well as in conventional agriculture (Hossain *et al.*, 2019).

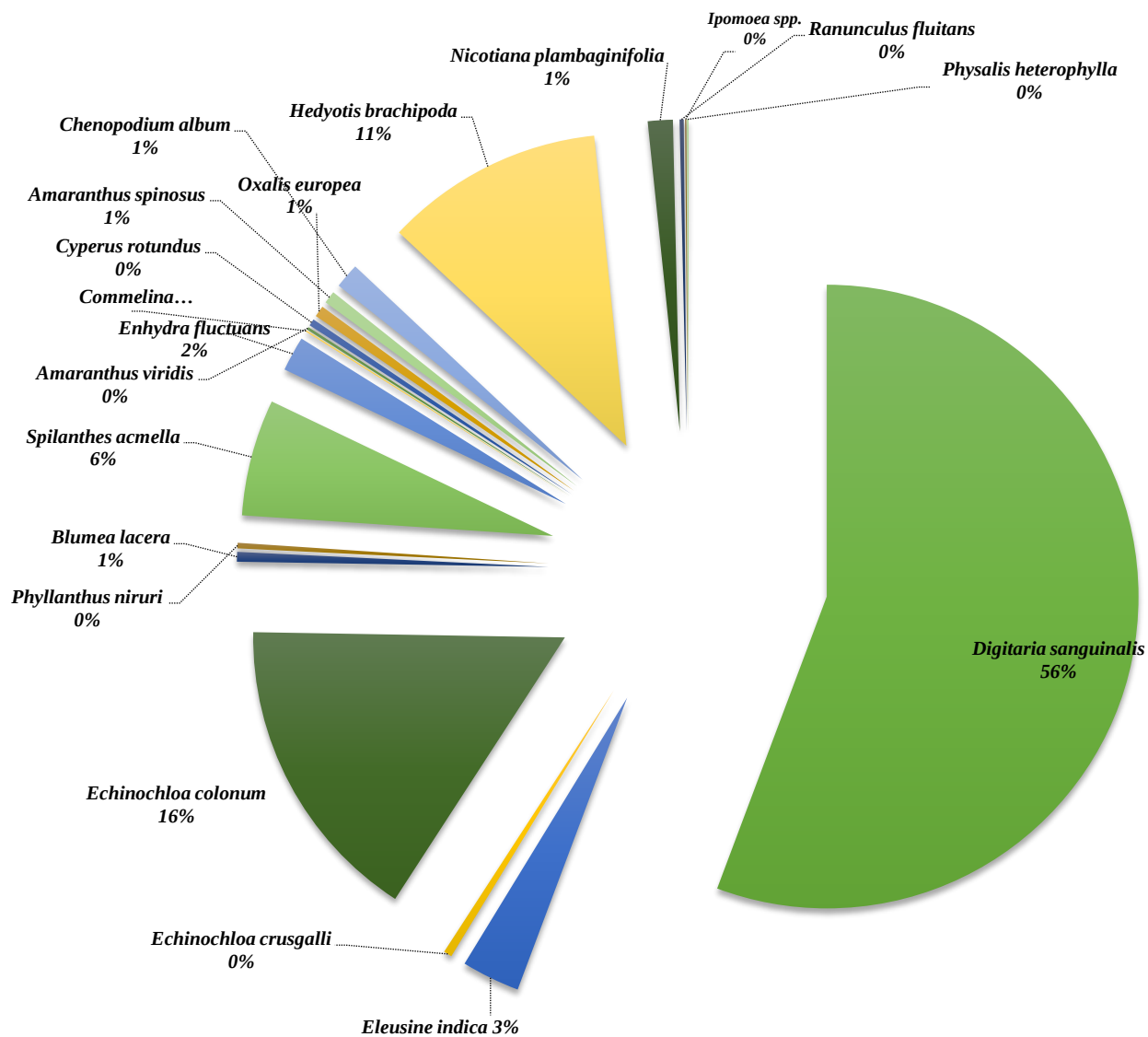


Figure 4. Infesting weed species (%) in weedy check plot of CA-based ZT-maize recorded at 60 DAS

Researchers reported that grasses weed species during Kharif season in the maize field in EGP are *Echinochloa colona* (L.), *Digitaria ciliaris* (L.), *Leptochloa chinensis* (L.), *Dactyloctenium aegyptium*, *Cynodon dactylon*, *Echinochloa crus-galli*, *Eleusine indica*, *Setaria viridis*, *Panicum javanicum*, *Paspalum commersonii*, etc., and the broadleaf weeds are *Marsilea minuta*, *Polygonum hydropiper*, *Galinsoga ciliata*, *Physalis heterophylla*, *Heliotropium indicum*, *Phyllanthus niruri*, *Euphorbia hirta*, *Jussiaea repens*, *Amaranthus spinosus*, *Amaranthus viridis*, *Spilanthes paniculata*, *Lindernia anagallis*, *Paspalum distichum*, etc. and the major sedges weeds are *Cyperus rotundus*, *Cyperus difformis*, *Cyperus iria*, *Eclipta prostrata*, *Ludwigia octovalvis*, *Portulaca oleracea*, *Fimbristylis miliacea*, *Scirpus* spp. etc. (Reddy *et al.*, 2012; Rao *et al.*, 2009; Gathala *et al.*, 2014). Hossain *et al.* (2019) also found that the perennial weeds species are dominant around the years but the seasonal weeds are different when maize is grown in dry season (winter maize), and the major dominant weeds are *Polygonum persicaria*, *Polygonum pensylvanicum*, *Polygonum orientale*, *Oldenlandia diffusa*, *Oldenlandia aquatic*, *Oxalis corniculata*, *Chenopodium arvensis*, *Physalis minima*, *Solanum nigrum*, *Hydrocotyle ranunculoides*, *Ageratum conyzoides*, *Medicago denticulate*, *Avena ludoviciana*, etc. (Singh *et al.*, 2015; Rai *et al.*, 2017). Rao *et al.* (2009) also reported the dominant weed flora in maize fields are *Echinochloa colona* (L.) Link (41%), *Dinebra retroflexa* (Vahl) Panzer (4%), *Panicum repens* L. (3%) and *Cynodon dactylon* (L.) Pers. (2%), *Leptochloa chinensis* (L.) Nees (5%) (Grasses), *Cyperus rotundus* L. (5%) (Sedges), *Chrozophorarottleri* (Geisel) A. Juss. Ex Spreng. (15%), *Trianthema portulacastrum* L. (13%), *Digeraarvensis* (4%), *Merremia emerginata* (Burm. f.) Hall. F. (3%), *Phyllanthus niruri* (3%) and *Euphorbiahirta* L. (2%) (Broad-leaved weeds). Mukundam *et al.* (2011) reported that *C. rotundus* and dicots *T. portulacastrum*, *D. arvensis*, *P. niruri* and *C. dactylon* among grasses were most dominant in maize fields. In clay loam soils of Warangal, India,

Reddy *et al.* (2012) reported that dominant weed species in maize field are grasses including *E. colona* (13%), *D. retroflexa* (11%), *P. repens* (8%) and *L. chinensis* (7%), sedges are *C. rotundus* L. (8%) and the broad-leaved weeds are *C. rotleri.* (11%), *T. portulacastrum* (9 %), *D. arvensis* (9%), *M. emerginata* (12%), *P. niruri* (3%) and *E. hirta* (9%). In another study, *E. colona*, *C. rotundus*, and *Ageratum conizoides* and *T. portulacastrum* were the most predominant weeds among the grasses, sedges, and broad-leaved weeds, respectively, observed in the sandy loam soils of Hyderabad, India (Parameshwari, 2013)

4.4.2 Effect of pre-and post-emergence herbicides on the weed density and dry weight at 15, 30 and 60 DAS, and harvest

At 15 DAS

In both years, weed density (m^{-2}) recorded at 15 DAS (immediately before application of post-emergence herbicides) was influenced significantly ($p \leq 0.001$) by the pre-emergence herbicides (Table 13), indicating that pre-emergence herbicides (applied immediately after sowing of maize) could control all types of weed up to 15 DAS. Considering the control of grasses in both years, the pre-emergence herbicide 'Atrazine' controlled the maximum number of grasses, followed by Pendimethalin. However, Pendimethalin more effectively controlled the broadleaved and sedges than Atrazine in both years (Table 13).

Table 13. Effect of pre-and post-emergence herbicides on the weed density (no. m⁻²) recorded immediately before the application of post-emergence herbicides (at 15 DAS) in both years

Treatments	2017-2018								2018-2019								
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	
Grass weeds (no. m ⁻²) recorded at 15 DAS									Grass weeds (no. m ⁻²) recorded at 15 DAS								
PH1	190.0 a	525.0 a	697.0 a	152.0 a	117.3 a	302.0 a	330.6	6.5	601.4 a	617.2 a	647.2 a	410.0 a	98.9 a	1040.0 a	569.1	11.0	
PH2	96.7 b	38.0 b	29.3 c	48.3 b	45.7 b	91.3 b	58.2		56.9 b	33.6 b	26.2 b	16.0 b	42.0 b	19.7 b	32.4		
PH3	59.3 c	51.3 b	57.3 b	40.3 b	60.0 b	36.7 c	50.8		27.0 b	17.3 b	0.7 b	24.6 b	3.0 c	0.7 b	12.2		
Mean	115.3	204.8	261.2	80.2	74.3	143.3			228.4	222.7	224.7	150.2	48.0	353.5			
CV (%)	5.84								10.61								
F-test	**								**								
Broadleaved weeds (no. m ⁻²) recorded at 15 DAS									Broadleaved weeds (no. m ⁻²) recorded at 15 DAS								
PH1	2.7 a	2.5 a	2.8 a	1.6 ab	3.2 a	1.8 b	2.4	27.6	5.2 a	2.8 b	2.7 b	5.8 a	5.3 a	4.1 b	4.3	20.9	
PH2	1.3 b	1.3 b	0.7 b	0.9 b	2.6 ab	1.6 b	1.4		3.3 b	1.3 c	1.8 b	3.4 b	2.6 c	2.3 c	2.4		
PH3	2.2 a	2.5 a	2.9 a	1.7 a	2.2 b	3.2 a	2.5		5.0 a	4.3 a	6.6 a	6.3 a	4.1 b	6.4 a	5.5		
Mean	2.1	2.1	2.1	1.4	2.7	2.2			4.5	2.8	3.7	5.2	4.0	4.3			
CV (%)	21.10								14.24								
F-test	**								**								
Sedge weeds (no. m ⁻²) recorded at 15 DAS									Sedge weeds (no. m ⁻²) recorded at 15 DAS								
PH1	0.9 b	3.7 a	0.7 b	0.7 a	0.7 a	0.7 b	1.2	50.0	1.9 b	2.7 a	0.7 a	0.7 a	0.7 b	0.71 a	1.2	1.3	
PH2	1.1 b	0.7 b	0.9 b	1.0 a	1.1 a	2.1 a	1.1		1.1 c	0.7 b	1.2 a	0.7 a	1.3 a	0.97 a	1.0		
PH3	2.2 a	1.4 b	1.9 a	0.7 a	0.7 a	0.9 b	1.3		3.4 a	2.7 a	0.7 a	0.9 a	1.1 ab	0.7 a	1.6		
Mean	1.4	1.9	1.2	0.8	0.8	1.2			2.1	2.0	0.9	0.8	1.1	0.8			
CV (%)	53.56								27.53								
F-test	**								**								

NS, non-significant; NS indicates non-significant and * & ** indicate significant at 5% and 1% levels of probability;

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹)

At 30 DAS

As compared with no pre-emergence herbicides plots, the density (no. m⁻²) and dry weight (g m⁻²) of all weed species (grasses, broadleaved and sedges) decreased significantly ($p \leq 0.001$) in all plots when two pre-emergence herbicides (Pendimethalin and Atrazine) applied at immediately after maize sowing. Among two pre-emergence herbicides, Pendimethalin performed better than Atrazine for controlling all types of weed species (grass, broadleaved and sedge) recorded at 30 DAS (Tables 14 & 15).

In the case of post-emergence herbicides, the density (no. m⁻²) and dry weight (g m⁻²) of all weed species (grass, broadleaved and sedge) were decreased significantly ($p \leq 0.001$) in all post-emergence herbicides applied plots recorded at 30 DAS. Among the herbicides, the controlling capacity of Halosulfuron + Atrazine, and Tembotrione + Atrazine was the highest level as compared to a single application of Atrazine, Tembotrione and Halosulfuron. However, the combination of Tembotrione + Atrazine controlled the maximum number of grasses and Halosulfuron + Atrazine controlled both broadleaved and sedges in both years (Tables 14 & 15).

The sequential application of both pre- and post-emergence herbicides has been found more effective than the single application (Tables 14 & 15). The highest control efficiency of grasses, broadleaved and sedges was observed in the plot where Atrazine was applied as pre-emergence, and Tembotrione and Halosulfuron + Atrazine were applied as post-emergence. Among these pre- and post-emergence herbicides, the sequential application of pre-emergence herbicide Atrazine in combination with other post-emergence herbicides performed the best for controlling all types of weeds over other combinations (Tables 14 & 15).

Table 14. Effect of pre-and post-emergence herbicides on the weed density (no. m⁻²) recorded at 30 DAS (15 days after application of post-emergence herbicides) in both years

Treatment	2017-2018							2018-2019								
	PO1	PO2	PO3	PO4	PO5	PO6	Mean CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean CV (%)		
Grass weeds (no. m ⁻²) recorded at 30 DAS								Grass weeds (no. m ⁻²) recorded at 30 DAS								
PH1	13.3 a	18.5 a	2.7 a	13.5 a	1.2 a	10.0 a	9.8	34.9	243.1 a	542.2 a	232.9 a	525.7 a	5.0 a	254.1 a	300.5	12.6
PH2	1.8 c	1.6 b	0.7 a	1.4 b	0.7 a	1.2 b	1.2		9.5 b	13.7 c	6.3 b	10.5 c	3.4 a	14.2 b	9.6	
PH3	8.1 b	3.1 b	0.7 a	3.5 b	0.9 a	1.0 b	2.9		24.0 b	36.7 b	14.4 b	32.2 c	0.9 a	3.8 b	18.7	
Mean	7.7	7.7	1.4	6.1	0.9	4.1			92.2	197.5	84.5	189.5	3.1	90.7		
CV (%)	37.88								9.68							
F-test	**								**							
Broadleaved weeds (no. m ⁻²) recorded at 30 DAS								Broadleaved weeds (no. m ⁻²) recorded at 30 DAS								
PH1	4.5 b	4.0 a	2.7 a	4.6 a	3.5 a	2.7 a	3.7	84.7	160.7 a	20.4 a	28.3 a	35.3 a	31.9 a	15.1 b	48.6	11.1
PH2	2.7 c	3.0 a	1.9 b	1.1 b	1.4 b	1.9 b	2.0		23.1 c	2.6 b	5.2 b	24.3 b	24.7 b	2.6 c	13.8	
PH3	9.1 a	2.8 b	2.7 a	1.8 b	1.8 b	3.0 a	3.5		35.3 b	18.5 a	26.4 a	23.7 b	21.9 b	27.5 a	25.5	
Mean	5.4	3.2	2.4	2.5	2.2	2.5			73.0	13.8	20.0	27.8	26.2	15.1		
CV (%)	87.37								10.76							
F-test	**								**							
Sedge weeds at (no. m ⁻²) recorded at 30 DAS								Sedge weeds at (no. m ⁻²) recorded at 30 DAS								
PH1	0.9 a	0.8 b	0.7 a	0.7 a	0.7 a	0.7 a	0.8	39.5	0.8 c	1.3 b	0.7 b	0.7 a	0.9 a	0.7 a	0.84	35.8
PH2	0.8 a	0.9 b	0.8 a	0.8 a	0.8 a	0.9 a	0.8		3.2 b	1.7 b	1.7 ab	1.0 a	1.9 a	0.8 a	1.71	
PH3	1.3 a	2.3 a	0.9 a	0.7 a	0.7 a	0.8 a	1.1		4.9 a	5.7 a	2.4 a	0.7 a	1.5 a	0.7 a	2.64	
Mean	1.0	1.3	0.8	0.7 a	0.8	0.8			3.0	2.9	1.6	0.8	1.4	0.7		
CV (%)	39.01								51.53							
F-test	**								**							

NS, non-significant; NS indicates non-significant and * & ** indicate significant at 5% and 1% levels of probability;

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹)

Table 15. Pre-and post-emergence herbicides effect on the weed dry weight (g m^{-2}) of zero-till maize, recorded at 30 DAS (15 days after application of post-emergence herbicides) in both years

Treatment	2017-2018								2018-2019								
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	
	Dry weight of grass weeds (g m ⁻²) at 30 DAS									Weight of grass weeds (g m ⁻²) at 30 DAS							
PH1	0.8 a	2.8 a	0.7 a	2.5 a	0.8 a	1.3 a	1.49	22.34	8.4 a	9.2 a	3.8 a	8.4 a	0.8 b	4.7 a	5.9	17.51	
PH2	0.7 a	0.8 b	0.7 a	1.1 b	0.7 a	0.8 b	0.81		0.9 b	1.4 b	0.9 b	3.8 b	1.7 a	1.8 b	1.8		
PH3	0.8 a	0.8 b	0.7 a	0.9 b	0.9 a	0.7 b	0.79		1.4 b	1.0 b	1.0 b	1.4 c	0.7 b	0.7 c	1.0		
Mean	0.8	1.4	0.7	1.5	0.8	0.9			3.6	3.9	1.9	4.5	1.1	2.4			
CV (%)	18.50									17.99							
F-test	**									**							
	Dry weight of Broadleaved (g m ⁻²) at 30 DAS									Dry weight of Broadleaved (g m ⁻²) at 30 DAS							
PH1	0.9	0.8	1.2	0.8	1.2	0.8	1.0	17.89	5.0 a	1.3 ab	4.7 a	6.5 a	7.2 a	3.5 a	4.7	13.55	
PH2	0.8	0.9	0.7	0.8	0.8	1.0	0.8		3.4 b	0.9 b	2.4 b	4.2 b	3.9 b	3.0 a	2.9		
PH3	1.0	0.8	0.9	0.8	1.1	1.0	0.9		4.5 ab	2.5 a	2.7 b	2.7 c	3.8 b	4.2 a	3.4		
Mean	0.9	0.9	1.0	0.8	1.0	0.9			4.3	1.5	3.3	4.5	5.0	3.6			
CV (%)	29.50									23.55							
F-test	NS									**							
	Dry weight of sedge weeds (g m ⁻²) at 30 DAS									Weight of sedge weeds (g m ⁻²) at 30 DAS							
PH1	1.1	1.3	1.1	1.1	1.3	1.1	1.2	12.27	0.5	1.9	0.4	0.5	0.5	0.5	0.7	27.84	
PH2	1.1	1.1	1.1	1.1	1.2	1.1	1.1		1.4	0.5	0.7	0.5	1.2	0.8	0.9		
PH3	1.2	1.3	1.2	1.1	1.1	1.1	1.2		1.5	0.5	1.2	0.5	0.6	0.5	0.8		
Mean	1.2	1.2	1.1	1.1	1.2	1.1			1.1	1.0	0.8	0.5	0.8	0.6			
CV (%)	9.49									32.75							
F-test	NS									NS							

NS, non-significant; NS indicates non-significant and * & ** indicate significant at 5% and 1% levels of probability;

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha^{-1}) and PH3: Atrazine (1000 g a.i. ha^{-1})

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha^{-1}); PO3: Tembotrione (120 g a.i. ha^{-1}); PO4: Halosulfuron (90 g a.i. ha^{-1}); PO5: Tembotrione (120 g a.i. ha^{-1}) + Atrazine (500 g a.i. ha^{-1}) and PO6: Halosulfuron (90 g a.i. ha^{-1}) + Atrazine (500 g a.i. ha^{-1})

The dry weight (g m^{-2}) decreased significantly in all pre- and post-emergence herbicides applied plots. Nonetheless, the highest weed dry weight was recorded in the plot where pre- and post-emergence herbicides were not applied. In other plots dry weight of grass was statistically similar, indicating that all types of herbicides (combined effect of pre-and post-emergence herbicides) can control the dry matter of grass (Tables 15).

At 60 DAS

Weed density (no. m^{-2}) and dry weight (g m^{-2}) recorded at 60 DAS noticed that both pre-emergence herbicides controlled significantly all types of weed. Among these two pre-emergence herbicides, the controlling ability of Pendimethalin was found superior to Atrazine up to 60 DAS for broadleaved; however, Pendimethalin controlled both grasses and sedge effectively in both years (Tables 16 & 17). Similar to 30 DAS, the density (no. m^{-2}) and dry weight (g m^{-2}) of all types of weed (grasses, broadleaved and sedges) were decreased significantly in the application of all post-emergence herbicides at 60 DAS in both years with a little exception. Among the herbicides, Tembotrione + Atrazine and Halosulfuron + Atrazine have statistically similar but higher weed control abilities (grasses, sedges and broadleaved) than the sole application of Atrazine, Tembotrione, and Halosulfuron. However, Tembotrione + Atrazine significantly controlled the maximum number of grasses than the combination of Halosulfuron + Atrazine and Tembotrione + Atrazine and also the sole application of Atrazine and Halosulfuron in both years. In the case of broadleaved, Atrazine in both years effectively controlled broadleaved which was statistically similar to Tembotrione + Atrazine. For controlling sedge, both Tembotrione + Atrazine and Halosulfuron + Atrazine were found effective.

Table 16. Pre-and post-emergence herbicides' effect on weed density (no. m⁻²) of zero-till maize recorded at 60 DAS in both years

Treatment	2017-18								2018-19							
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)
	Grasses (no. m⁻²) recorded at 60 DAS								Grasses (no. m⁻²) recorded at 60 DAS							
PH1	38.6 a	34.1 a	3.9 a	28.2 a	0.7 a	12.4 a	19.7		34.4 a	19.2 a	15.5 a	27.5 a	3.6 a	24.5 a	20.8	
PH2	7.4 c	6.5 b	0.9 a	3.9 c	0.7 a	4.7 b	4.0		6.5 c	5.2 b	5.5 b	2.6 c	2.7 a	2.6 b	4.2	
PH3	15.3 b	8.2 b	2.5 a	11.8 b	0.7 a	0.7 b	6.5	24.39	10.8 b	15.7 a	8.3 b	14.8 b	0.7 a	23.0 a	12.2	18.46
Mean	20.4	16.2	2.4	14.6	0.7	5.9			17.2	13.4	9.8	15.0	2.3	16.7		
CV (%)				19.73								18.17				
F-test				**								**				
	Broadleaved (no. m⁻²) recorded at 60 DAS								Broadleaved (no. m⁻²) recorded at 60 DAS							
PH1	261.6a	13.0a	50.0a	30.7a	23.3a	16.3a	65.8		224.0 a	7.7 b	50.7 a	16.0 a	20.7 a	10.3 b	54.9	
PH2	56.0b	26.3a	17.7a	19.0a	24.0a	79.3a	37.1		48.7 b	26.0 a	9.7 c	19.0 a	13.0 a	8.0 b	20.7	
PH3	21.6c	30.0a	25.7a	35.6a	28.6a	21.3a	27.1	38.0	20.0 c	20.0 ab	24.3 b	27.0 a	20.0 a	26.7 a	23.0	18.77
Mean	113.1	23.1	31.1	28.4	25.3	39.0			97.6	17.9	28.2	20.7	17.9	15.0		
CV (%)				40.0								18.77				
F-test				**								**				
	Sedges at (no. m⁻²) recorded at 60 DAS								Sedges at (no. m⁻²) recorded at 60 DAS							
PH1	17.1	10.6	4.5 a	13.6 a	4.3 a	4.6 a	9.1		12.4 a	4.9 b	1.0 a	0.7 a	0.7 a	0.8 a	3.4	
PH2	4.3	6.6	6.1 a	4.6 b	0.7 a	0.9 a	3.9		3.1 b	1.0 b	1.7 a	0.7 a	0.7 a	0.8 a	1.3	
PH3	9.1	15.7	3.9 a	0.7 b	5.4 a	0.7 a	5.9	48.61	7.2 b	10.0 a	4.8 a	0.7 a	0.8 a	0.7 a	4.0	20.99
Mean	10.2	11.0	4.8	6.3	3.5	2.1			7.6	5.3	2.5	0.7	0.7	0.8		
CV (%)				24.36								22.81				
F-test				**								**				

NS, non-significant; NS indicates non-significant and * & ** indicate significant at 5% and 1% levels of probability;

Pre-emergence herbicides: PH1: No pre-emergence; PH2: *Pendimethalin* (1000 g a.i. ha⁻¹) and PH3: *Atrazine* (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: *Atrazine* (500 g a.i. ha⁻¹); PO3: *Tembotrione* (120 g a.i. ha⁻¹); PO4: *Halosulfuron* (90 g a.i. ha⁻¹); PO5: *Tembotrione* (120 g a.i. ha⁻¹) + *Atrazine* (500 g a.i. ha⁻¹) and PO6: *Halosulfuron* (90 g a.i. ha⁻¹) + *Atrazine* (500 g a.i. ha⁻¹)

Table 17. Pre-and post-emergence herbicides' effect on weed dry weight (g m^{-2}) of zero-till maize was recorded at 60 DAS (After application of post-emergence herbicides) in both years

Treatment	2017-2018								2018-2019									
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)		
	Dry weight of grass weeds (g m ⁻²) at 60 DAS									Dry weight of grass weeds (g m ⁻²) at 60 DAS								
PH1	17.0 a	15.4 a	3.6 a	11.5 a	0.7 a	3.8 a	8.7	19.16	17.2 a	17.2 a	3.0 a	17.1 a	2.4 a	14.2 a	11.8	16.20		
PH2	1.3 c	2.9 b	0.9 b	1.9 b	0.7 a	1.3 b	1.5		2.3 c	2.3 b	2.9 a	3.0 b	0.8 a	3.4 b	2.5			
PH3	5.5 b	3.3 b	1.0 b	2.5 b	0.7 a	0.7 b	2.3		6.1 b	6.1 b	1.8 a	4.2 b	1.1 a	3.6 b	3.8			
Mean	7.9	7.2	1.8	5.3	0.7	1.9			8.5	8.5	2.6	8.1	1.5	7.0				
CV (%)	26.14									36.96								
F-test	**									**								
	Dry weight of broadleaved weeds (g m ⁻²) at 60 DAS									Dry weight of broadleaved weeds (g m ⁻²) at 60 DAS								
PH1	94.7a	10.7a	10.1a	13.7a	10.0a	19.7a	26.48	42.0	8.9a	7.5a	5.2 a	5.9 a	6.2 a	4.2 a	6.32	23.87		
PH2	13.3b	9.3b	4.7a	11.0a	10.0a	18.0a	11.05		5.2b	2.6c	2.3 b	4.3 a	4.8 b	3.1b	3.72			
PH3	12.0b	2.8c	9.0a	13.3a	5.0a	4.0b	7.68		3.8c	4.3b	4.5 a	3.0 b	3.1 c	2.1 c	3.47			
Mean	40.0	7.6	8.1	12.7	8.3	10.6			5.97	4.8	4.0	4.4	4.7	3.1				
CV (%)	44.0									35.76								
F-test	**									**								
	Dry weight of sedge weeds (g m ⁻²) at 60 DAS									Dry weight of sedge weeds (g m ⁻²) at 60 DAS								
PH1	6.9 a	4.3 a	2.9 a	3.5 a	2.6 a	1.1 a	3.5	42.45	5.7 a	4.9 a	2.7 a	3.7 a	2.7 a	3.7 a	3.9	34.09		
PH2	1.6 c	1.2 b	2.1 a	1.2 b	1.0 b	0.9 a	1.3		0.8 c	0.7 c	1.0 b	0.7 b	0.7 b	0.8 b	0.78			
PH3	3.2 b	2.1 b	2.4 a	1.1 b	2.4 a	0.7 a	2.0		2.8 b	2.4 b	0.7 c	0.7 b	0.8 b	0.7 b	1.35			
Mean	3.9	2.5	2.5	1.9	2.0	0.9			3.1	2.7	1.47	1.7	1.4	1.73				
CV (%)	38.69									39.85								
F-test	**									**								

NS, non-significant; NS indicates non-significant and * & ** indicate significant at 5% and 1% levels of probability;

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin ($1000 \text{ g a.i. ha}^{-1}$) and PH3: Atrazine ($1000 \text{ g a.i. ha}^{-1}$)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine ($500 \text{ g a.i. ha}^{-1}$); PO3: Tembotrione ($120 \text{ g a.i. ha}^{-1}$); PO4: Halosulfuron ($90 \text{ g a.i. ha}^{-1}$); PO5: Tembotrione ($120 \text{ g a.i. ha}^{-1}$) + Atrazine ($500 \text{ g a.i. ha}^{-1}$) and PO6: Halosulfuron ($90 \text{ g a.i. ha}^{-1}$) + Atrazine ($500 \text{ g a.i. ha}^{-1}$)

On the other hand, the sequential application of both pre-emergence herbicides (i.e., Pendimethalin and Atrazine) in combination with Tembotrione + Atrazine as post-emergence controlled the maximum number of grasses in both years as compared to their application separately. However, no sequence was observed for controlling broadleaved and sedges (density and dry weight), for example, in the first season Atrazine as pre-emergence, and Halosulfuron + Atrazine applied as post-emergence controlled the maximum number of broadleaved and sedges, while in the second season, Pendimethalin applied as pre-emergence and Halosulfuron + Atrazine applied as post-emergence controlled then the maximum number of weeds in broadleaved and sedges (Tables 15 & 16).

At harvest

To observe the effectiveness of all herbicides up to harvest, the dry weight of all weed species was recorded at harvest as per treatments in both years. The dry weight (g m^{-2}) of all weed species (grasses, broadleaved and sedges) varied significantly ($p \leq 0.001$) at harvest in all plots due to different pre-and post-emergence herbicides. The performance of herbicides was found effective up to harvest when herbicides were applied sequentially in combination with several herbicides as post-emergence (Table 18). Among these herbicides, both Pendimethalin and Atrazine applied as pre-emergence, and Tembotrione + Atrazine applied as post-emergence performed the best, followed by Halosulfuron + Atrazine, and sole application of Tembotrione in both years (Table 18).

Table 18. Pre-and post-emergence herbicides' effect on weed dry weight (g m⁻²) recorded at harvest in both years

Treatment	2017-2018								2018-2019									
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)		
	Total weed dry weight (g m ⁻²) at harvest								Total weed dry weight (g m ⁻²) at harvest									
PH1	13.6 a	16.4 a	3.8 a	12.9 a	2.4 a	5.5 a	9.1	16.16	308.3 a	306.3 a	109.3 a	245.3a	17.7 b	130.7 a	186.3	16.17		
PH2	5.4 b	5.4 b	2.3 b	1.6 b	1.0 b	3.0 b	3.1		56.0 b	32.7 c	17.0 b	31.0 b	44.7 a	23.7 b	34.2			
PH3	6.5 b	2.4 c	2.2 b	2.3 b	3.6 a	0.7 c	2.9		61.0 b	64.0 b	25.7 b	42.0 b	11.7 b	23.0 b	37.9			
Mean	8.5	8.1	2.7	5.6	2.3	3.1			141.8	134.3	50.7	106.1	24.7	59.1				
CV (%)	15.33								17.34									
F-test	**								**									

NS, non-significant; NS indicates non-significant and * & ** indicate significant at 5% and 1% levels of probability;

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹)

Herbicides that have been found effective for post-emergence weed control in the ZT maize and ZT-DSR rice system are Atrazine, Tembotrione (Laudis), Halosulfuron methyl (Sempra), Tembotrione (Laudis) + Atrazine, Halosulfuron methyl (Sempra) + Atrazine, Pyrazosulfuron, Bispyribac-sodium, Fenoxaprop-ethyl, Penoxsulam, Fenoxaprop-ethyl+safner, Cyhalofop-butyl, Propanil, Azimsulfuron, Ethoxysulfuron, Triclopyr, 2,4-D ethyl ester, Carfentrazone, Chlorimuron+metsulfuron, Bispyribac+azimsulfuron (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). Continuous use of a single herbicide on a long-term basis should be avoided, rather, it should be rotated with another herbicide with a different mode of action to avoid or delay resistance development. Tank mixtures of herbicides can be used when two or more herbicides are compatible to broaden the spectrum of weed control in such a way that each herbicide controls the weeds missed by the other one. The herbicide mixtures listed above are effective in better controlling a combination of weeds, including grasses, broadleaved, and sedges (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). The results of the present study are also similar to the following earlier studies. Weed control in maize is the most important treatment. Management of weeds is considered to be an important factor in achieving higher productivity. To minimize weed losses, several methods are available such as mechanical, cultural, biological and chemical control methods. Exhausted by cultural methods, farmers are moving towards other alternative methods of weed control (Mahmoodi *et al.*, 2009; Varga *et al.*, 2011). Again, due to increased cost and unavailability of manual labour in the required quantity timely for hand weeding, the role of herbicide is significant preposition herbicides not only control the weeds timely and effectively but also offer great scope for minimizing the cost of weed control irrespective of the situation (Mahmoodi *et al.*, 2009; Varga *et al.*, 2011). In this respect, chemical weed control may be considered the best option. The chemical control method is a quick, more

effective, time and labour-saving method than others (Ahmed *et al.*, 2008). Increasing maize cultivation area causes plantation infestation to increase. This tendency results mostly from the appearance of species resistant to the application of the same herbicides, which took place in the case of triazine herbicides (Rubin, 1996; Paradowski, 2008; Green and Owen, 2011). Traditionally, manual hand weeding has been the predominant method of weed control used by maize farmers in Asia (Shad *et al.*, 1993). If performed with enough frequency and at the right times, hand weeding results in maize yields that are equivalent to yields with herbicides (Prasad *et al.*, 2008). However, because of the shortage of labour and frequent monsoon rains during the early growth period of maize, hand weeding is often delayed or neglected altogether (Prasad *et al.*, 2008). As a result, severe uncontrolled weed infestations have been identified as one of the major reasons for low maize yields in Asia (Hussain *et al.*, 2010). Among the herbicides, sequential application of either Atrazine as pre-emergence 1.25 kg ha⁻¹ fb paraquat 0.6 kg ha⁻¹ at 3WAS or Pendimethalin as pre-emergence 1.5 kg ha⁻¹ fb paraquat 0.6 kg ha⁻¹ at 3 WAS (Srividya *et al.*, 2011). Khan *et al.* (1991) and Fazal *et al.* (2009) reported that Pendimethalin at pre-emergence decreased weed population, and increased grain yield over weedy control. Thus, Khan *et al.* (1993) and Mekky *et al.* (2002) reported that the application of herbicides in maize fields significantly controlled the weeds and increased crop yield. Wilson and Sbatella (2014) showed that Pendimethalin can be utilized pre-to provide acceptable weed control and crop selectivity. Khan *et al.* (1991) and Fazal *et al.* (2009) reported that Pendimethalin as pre-emergence considerably decreased weed population and increased grain yield over weedy control.

4.4.3 Effect of pre-and post-emergence herbicides on growth, yield attributes and yield of maize

4.4.3.1 Number of plant population m⁻² at 15 DAS

Plant population (m⁻²) were recorded to know any contaminated effect on the germination of seeds of maize. Data on the plants (m⁻²) recorded at 15 DAS did not differ significantly due to the application of different pre-emergence herbicides in both years, indicating that the application of pre-emergence herbicides (Pendimethalin and Atrazine) at the early stage did not influence the germinating maize seedlings (Table 19).

4.4.3.2 Plant height (cm)

At 30 DAS

The plant height recorded at 30 DAS was influenced significantly ($p \leq 0.001$) by the pre-emergence herbicides in both years. In the first season, the tallest plant (32.7 cm) was recorded in the plots that did not receive any pre-emergence herbicides, but in the second season, the tallest plant (36.9 cm) was found in the Atrazine applied plot, and the shortest plant was recorded in Pendimethalin applied plot, indicating that Pendimethalin has a toxic effect on the plant height in both years (Table 19).

In both years, the plant height recorded at 30 DAS was influenced significantly ($p \leq 0.001$) by the application of different post-emergence herbicides. In the first season, the tallest plant (36.0 cm) was observed in the plots where herbicide Atrazine was applied plot, followed by no post-emergence herbicide applied plot (33.0 cm) and Tembotrione (32.9 cm) applied plot, which was statistically similar (31.9 cm) to Tembotrione + Atrazine (Table 19).

Table 19. Effect of pre-and post-emergence herbicides on the plant population and plant height of ZT maize recorded at different DAS during the Rabi season of 2017-2018 and 2018-2019

Treatment	During 2017-2018 Rabi season							During 2018-2019 Rabi season										
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)		
	Plants (no. m ⁻²)									Plant (no. m ⁻²)								
PH1	19.0	18.5	18.6	18.3	19.0	19.0	17.98	1.5	18.7	18.0	19.7	18.3	19.0	19.3	18.8	3.2		
PH2	19.0	19.0	19.0	18.3	19.0	18.6	18.36		19.0	18.0	19.3	19.0	18.0	19.0	18.7			
PH3	19.0	19.0	18.7	19.0	18.5	18.7	18.66		19.3	18.7	19.7	18.7	19.3	19.0	19.1			
Mean	19.0	18.3	18.8	17.6	18.3	18.8			19.0	18.2	19.6	18.7	18.8	19.1				
CV (%)	2.48								3.76									
	Plant height (cm) at 30 DAS								Plant height (cm) at 30 DAS									
PH1	34.0	36.7	35.0	29.3	32.0	29.3	32.7A	4.5	36.7 a	34.7 b	37.3 a	36.7 a	40.3 a	33.7 a	36.6A	4.3		
PH2	30.7	35.3	32.7	25.0	31.7	28.0	30.6B		33.3 b	32.0 b	33.3 b	31.0 b	30.7 c	30.7 b	31.8B			
PH3	34.3	36.0	31.0	30.7	32.0	27.3	31.9A		37.7 a	38.7 a	35.7 ab	37.0 a	35.3 b	34.0 a	36.9A			
Mean	33.0B	36.0A	32.9B	28.3C	31.9B	28.2C			35.9A	35.1AB	35.4AB	34.9AB	35.4AB	32.2B				
CV (%)	5.69								5.23									
	Plant height (cm) at 60 DAS								Plant height (cm) at 60 DAS									
PH1	93.3 a	100.0 a	97.0 a	82.7 a	89.0 a	81.3 a	90.6A	4.6	110.7 b	117.3 a	127.0 a	107.0 a	114.3 a	111.3a	114.6A	4.1		
PH2	90.3 a	87.7 b	97.0 a	76.7 b	87.0 a	83.0 a	86.9B		101.7 c	94.3 b	95.7 b	95.7 b	91.3 b	100.3 b	96.5B			
PH3	95.0 a	96.7 b	90.3 b	75.0 b	79.3 b	79.0 a	85.9B		119.7 a	119.0 a	119.7 a	114.3 a	116.0 a	104.0 ab	115.4A			
Mean	92.9A	94.8A	94.8A	78.1C	85.1B	81.1C			110.7	110.2	114.1	105.7	107.2	105.2				
CV (%)	3.95								4.49									
	Plant height (m) at harvest								Plant height (m) at harvest									
PH1	2.9	2.9	2.9	2.8	2.8	2.7	2.8	5.2	2.7 b	2.8 b	3.1 a	2.8 a	3.0 a	2.8 a	2.9A	3.4		
PH2	2.9	2.9	2.9	2.8	2.8	2.7	2.8		2.6 b	2.7 c	2.8 b	2.8 a	2.7 b	2.8 a	2.7B			
PH3	2.9	2.9	2.9	2.7	2.8	2.8	2.8		2.9 a	3.1 a	3.0 a	2.9 a	3.0 a	2.9 a	3.0A			
Mean	2.89AB	2.91A	2.89AB	2.77B	2.89AB	2.77B			2.7B	2.9A	3.0A	2.8A	2.9A	2.8A				
CV (%)	3.4								2.2									

CV (%) indicates, the coefficient of variation

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹)

However, in the second season, the tallest plant (35.9 cm) was observed in no post-emergence herbicides applied plot, followed by Tembotrione (35.4 cm), Tembotrione + Atrazine (35.4 cm) and Atrazine (35.1 cm) applied plots (Table 19). Although, the sequential application of pre-and post-emergence herbicides did not influence the plant height in the first season at 30 DAS, and in the second season, the plant height was motivated significantly ($p \leq 0.001$) due to the application of different post-emergence herbicides (Table 19). The tallest plant was recorded in combination with two pre-emergence herbicides (Atrazine and Pendimethalin) applied immediately after maize seeding with post-emergence herbicides Tembotrione, and Tembotrione + Atrazine applied as post-emergence at 30 DAS (Table 19).

At 60 DAS

The plant height at 60 DAS was also influenced significantly ($p \leq 0.001$) by the pre-emergence herbicides in both years as like to the plant height at 30 DAS. In the first season, the tallest plant (90.6 cm) was recorded in the no pre-emergence herbicide applied plot, followed by Pendimethalin (86.9 cm) and Atrazine (85.9 cm) applied plot. The result indicated that weed species without pre-emergence herbicide plots did not affect the plant height of maize (Table 19).

Similar to the pre-emergence herbicides, the post-emergence herbicides also influenced significantly ($p \leq 0.001$) the plant height recorded at 60 DAS in both years. With little exception, the tallest plant in both years was recorded in the plot where Tembotrione and Atrazine were applied as post-emergence, followed by no post-emergence and Tembotrione + Atrazine. In both years, the results indicated that post-emergence herbicides especially Tembotrione and Atrazine found better than Halosulfuron and Halosulfuron + Atrazine. The decreasing trend of plant height

in Halosulfuron, and Halosulfuron + Atrazine was their phototoxic effect, which ultimately decreased the plant height (Table 19).

The sequential use of pre-and post-emergence herbicides influenced significantly ($p \leq 0.001$) on the plant height at 60 DAS of ZT maize. The sequential application of pre-emergence herbicide Atrazine in combination with other post-emergence herbicides showed the tallest plant in both years with a little exception, followed by no pre-emergence herbicide with the combination of all post-emergence herbicides applied plots. The decreasing trend of plant height in the sequential application of Pendimethalin as pre-emergence in combination with post-emergence herbicides was their phototoxic effect, which ultimately decreased the plant height (Table 19).

At harvest

In the first season, the plant height of CA-based ZT-maize at harvest was not influenced significantly by different pre-emergence herbicides, but in the second year, the plant height varied significantly. The tallest and statistically similar plant height was found in both Atrazine and no pre-emergence herbicide applied plots. Pendimethalin applied as pre-emergence had a phototoxic effect, which ultimately decreased the plant height (Table 19).

Plant height at harvest was influenced significantly by all post-emergence herbicides in both growing years. In the first season, the tallest plant was recorded in Atrazine, no-post-emergence, Tembotrione, and Tembotrione + Atrazine applied plots, while the shortest plants were observed in Halosulfuron, and Halosulfuron + Atrazine applied plots. In the second year, all post-emergence herbicides produced the tallest and statistically similar results (Table 19).

The sequential use of pre-and post-emergence herbicides on the plant height varied significantly in the second season, but in the first season, the combination of pre-and post-

emergence herbicides did not differ significantly. Numerically, both pre-emergence herbicides in combination with all post-emergence herbicides produced the same type of plant. However, Tembotrione + Atrazine, Halosulfuron and Halosulfuron + Atrazine in combination with both pre-emergence herbicides produced a similar and shortest plant in the first season. In the second season, the highest and the statistically similar plant height was found in the sequential application of Atrazine as pre-emergence in combination with other post-emergence herbicides applied plots, followed by no pre-emergence herbicide in combination with other post-emergence herbicides applied plots (Table 19).

4.4.3.3 Number of cobs plant⁻¹

The number of cobs plant⁻¹ did not differ significantly for pre-emergence, post-emergence herbicides and their interaction. In both years, each plant had a single cob in all treatments (Table 20).

4.4.3.4 Number of grains cob⁻¹

The number of grains cob⁻¹ of ZT maize was influenced significantly by the pre-emergence herbicides. The maximum number of grains cob⁻¹ were recorded in the plot where Atrazine was applied in both years (617.8 and 586.0), followed by Pendimethalin in 2nd and first year (585.8 and 580.8) (Table 20).

Similar to pre-emergence herbicides, post-emergence herbicides also influenced the grains cob⁻¹ significantly in both years. In the first year, the maximum number of grains cob⁻¹ were recorded in the plots where Atrazine (595.2) was applied combinedly, followed by the application of both Tembotrione + Atrazine (593.4) and Tembotrione (579.3), and the minimum number of

grains cob⁻¹ was observed in no post-emergence applied plots (558.2). In the second year, the sole application of both Atrazine (598.4) and Tembotrione (586.4) performed the best followed by Halosulfuron + Atrazine (578.3), and the minimum number of grains cob⁻¹ was recorded in no post-emergence applied plots (542.2) (Table 20). The decreasing trend of grains cob⁻¹ was recorded in the plots where Halosulfuron and Tembotrione + Atrazine were applied; this could be due to their phototoxic effect, which ultimately decreased the number of grains cob⁻¹ (Table 20).

The sequential use of pre-and post-emergence herbicides significantly influenced the grains cob⁻¹ of CA-based ZT maize in both years. However, the maximum grains cob⁻¹ were found in the plots where two pre-emergence herbicides (Pendimethalin and Atrazine) were applied as pre-emergence in combination with four post-emergence herbicides. In combination with pre-emergence Atrazine with post-emergence herbicide Tembotrione, Atrazine, Tembotrione + Atrazine gave higher and significantly similar grains cob⁻¹ in both years. The lowest number of grains cob⁻¹ was recorded in the weedy check plot (Table 20).

Table 20. Pre-and post-emergence herbicides affect the yield and yield attributes of zero-till maize in both years

Treatment	During 2017-2018 Rabi season							During 2018-2019 Rabi season								
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)
	Cob plant ⁻¹ (no.)								Cob plant ⁻¹ (no.)							
PH1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	NS	1.0	1.0	1.0	1.0	1.0	1.0	1.0	NS
PH2	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	
PH3	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	
Mean	1.0	1.0	1.0	1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0	1.0	1.0	
CV (%)	NS								NS							
	Grains cob ⁻¹ (no.)								Grains cob ⁻¹ (no.)							
PH1	542.1b	517.8a	513.2a	531.9a	549.3a	522.6a	529.5	1.3	532.3a	555.3a	548.3a	544.3a	546.7 a	539.3a	544.4	1.4
PH2	549.7bc	629.6a	583.5abc	568.1bc	598.8ab	555.1c	580.8		558.0b	635.3a	560.7b	561.0b	562.7b	625.0 a	583.8	
PH3	582.9b	638.3a	641.1a	599.3ab	632.1ab	613.1 ab	617.8		536.3c	604.7ab	650.3a	597.0ab	556.7bc	570.7bc	586.0	
Mean	558.2	595.2	579.3	566.4	593.4	563.6			542.2	598.4	586.4	567.4	555.4	578.3		
CV (%)	3.3								3.91							
	1000-grain weight (g)								1000-grain weight (g)							
PH1	226.5b	320.4a	322.9a	318.7a	327.2a	330.8a	307.8	1.84	231.7b	340a	341.3a	339.3a	341.0a	334.3a	321.3	1.89
PH2	314.5bc	338.7ab	335.5c	333.1ab	343.1a	334.1ab	333.2		345.7a	352a	345.0a	340.3a	352.0a	351.3a	347.7	
PH3	326.9a	335.9a	334.5a	328.6a	327.8a	331.8a	330.9		347.7ab	356ab	361.0a	355.7ab	357.0ab	351.3b	354.8	
Mean	289.3	331.7	331.0	326.8	332.7	332.2			308.4	349.3	349.1	345.1	350.0	345.6		
CV (%)	2.10								1.53							
	Grain yield (t ha ⁻¹)								Grain yield (t ha ⁻¹)							
PH1	10.8b	12.9a	12.2a	12.6ab	12.3a	12.5ab	12.2	6.72	10.9c	14.4ab	14.3ab	13.8b	15.9a	14.2ab	13.9	7.28
PH2	12.5a	13.5a	13.1a	13.4a	13.9a	13.2a	13.3		15.2a	16.9a	15.6a	15.4a	16.1a	15.3a	15.8	
PH3	11.6a	13.7a	12.7ab	13.6a	13.6a	12.1ab	12.9		15.1b	16.3ab	17.2a	15.7ab	16.6ab	15.4ab	16.1	
Mean	11.6	13.4	12.7	13.2	13.3	12.6			13.7	15.9	15.7	15.0	16.2	15.0		
CV (%)	5.79								4.77							

CV (%) indicates, the coefficient of variation

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹).

4.4.3.5 1000-grain weight (g)

In both the growing years, 1000-grain weight differed significantly by two pre-emergence herbicides. In the first year, the highest 1000-grain weight (333.2 g) was recorded in the plots where pre-emergence herbicides Pendimethalin was applied immediately after maize sowing, followed by the application of Atrazine (330.2 g), and the lowest highest 1000-grain weight (307.8 g) was recorded in weedy check plot. In the second season, the highest 1000-grain weight (354.8 g) was recorded in the plots where pre-emergence herbicides Atrazine was applied immediately after maize sowing, followed by the application of Pendimethalin (347.7 g), and the lowest highest 1000-grain weight (321.7g) was recorded in weedy check plot (Table 20). Post-emergence herbicides also influenced the 1000-grain weight of ZT-maize in both years. In both years, the statistically similar and the maximum 1000-grain weight was observed in all post-emergence herbicides applied plots; however, the minimum 1000-grain weight was recorded in the control plot (Table 20).

The sequential use of pre-and post-emergence herbicides also significantly influenced the 1000-grain weight of ZT-maize in both years. Nonetheless, the highest 1000-grain weight was recorded in sequential use of both pre-emergence herbicides Atrazine and Pendimethalin applied immediately after maize seeding with all post-emergence herbicides. Comparing years, the maximum 1000-grain weight was found in all treatments in the second growing season than in the first season (Table 20).

4.4.3.6 Grain yield (t ha⁻¹)

The grain yield of ZT maize differed significantly by two pre-emergence herbicides in both growing years. In the first year, the highest grain yield was recorded in the plot where Pendimethalin (13.3 t ha⁻¹) was applied immediately after sowing of maize seeds, which was

statistically similar to Atrazine (12.9 t ha^{-1}), and the lowest yield was recorded in the control plot (12.2 t ha^{-1}). In the second year, the highest grain yield was recorded in the plot where Atrazine (16.1 t ha^{-1}) was applied immediately after sowing of maize seeds, which was statistically similar to Pendimethalin (15.8 t ha^{-1}), and the lowest yield was recorded in control plot (13.9 t ha^{-1}) (Table 20).

Similar to pre-emergence herbicides, post-emergence herbicides also influenced the grain yield of ZT maize. In both years, all post-emergence herbicides showed the maximum grain yield than control plots. In the first year, the maximum grain yield was recorded in the plot where Atrazine (13.4 t ha^{-1}) was applied as post-emergence, which was statistically similar to Tembotrione (12.7 t ha^{-1}), Halosulfuron (13.2 t ha^{-1}) and Tembotrione + Atrazine (13.3 t ha^{-1}). The lowest was recorded in the control plot (11.6 t ha^{-1}). In the second year, the maximum grain yield was recorded in the plot where Tembotrione + Atrazine (16.2) was applied as post-emergence, which was statistically similar to Atrazine (15.9 t ha^{-1}) and Tembotrione (15.7 t ha^{-1}). The lowest was recorded in the control plot (13.7 t ha^{-1}) (Table 20).

Similar to the sole application of pre-and post-emergence herbicides, the sequential use of pre-and post-emergence herbicides also significantly influenced the grain yield of ZT maize. The highest grain yield was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with post-emergence herbicides Tembotrione + Atrazine (13.9 t ha^{-1}) applied at 15 DAS in the first season, which was statistically similar to the application of Atrazine applied just after maize seeding with the post-emergence herbicides Tembotrione + Atrazine (13.6 t ha^{-1}) and Halosulfuron (13.6 t ha^{-1}), while the lowest was recorded in the control plot (10.8 t ha^{-1}). In the second season, the highest grain yield (17.2 t ha^{-1}) was recorded in the sequential application of Atrazine applied just after sowing of maize with post-emergence

herbicides Tembotrione applied at 15 DAS, which was statistically similar to the application of Tembotrione + Atrazine (16.6 t ha^{-1}) applied as post-emergence, and the lowest was recorded in the control plot (10.9 t ha^{-1}) (Table 20).

4.4.3.7 Straw weight (t ha^{-1})

The straw yield of ZT maize differed significantly by two pre-emergence herbicides in both growing years. In the first year, the highest grain yield was recorded in the plot where Pendimethalin (12.9 t ha^{-1}) was applied immediately after sowing of maize seeds, which was statistically similar to Atrazine (12.5 t ha^{-1}), and the lowest yield was recorded in the control plot (11.5 t ha^{-1}). On the other hand, the highest straw yield was recorded in the plot where Atrazine (11.5 t ha^{-1}) was applied immediately after sowing of maize seeds in the second year, which was statistically similar to Pendimethalin (11.2 t ha^{-1}), and the lowest yield was recorded in control plot (10.0 t ha^{-1}). Similar to pre-emergence herbicides, post-emergence herbicides also influenced the straw yield of CA-based ZT-maize in both growing years. However, the maximum straw yield was recorded in the plots where post-emergence herbicides were applied and the lowest straw yield was recorded in control plots (Table 21).

Table 21. Pre-and post-emergence herbicides affect biomass and harvest index of zero-till maize during the Rabi season of 2017-2018 and 2018-2019

Treatment	During 2017-2018 Rabi season								During 2018-2019 Rabi season							
	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)	PO1	PO2	PO3	PO4	PO5	PO6	Mean	CV (%)
	Straw yield (t ha⁻¹)								Straw yield (t ha⁻¹)							
PH1	9.9 b	12.0a	12.3a	11.1ab	12.4a	11.4ab	11.5	10.78	9.3b	9.4b	11.5a	10.2ab	10.4ab	9.3b	10.0	12.74
PH2	10.0c	13.7ab	12.5abc	14.8a	14.4ab	12.0bc	12.9		9.9a	10.7a	12.8a	12.0a	11.5a	10.5a	11.2	
PH3	10.0b	12.9ab	12.7b	14.7a	12.9ab	11.7b	12.5		9.7b	12.7a	12.5ab	12.0ab	11.5ab	10.6ab	11.5	
Mean	10.0	12.9	12.5	13.5	13.2	11.7			9.6	10.9	12.3	11.4	11.1	10.1		
CV (%)				9.16												9.50
	Biomass at harvest (t ha⁻¹) (sun dry basis)								Biomass at harvest (t ha⁻¹) (sun dry basis)							
PH1	20.7b	24.9a	23.9a	21.7a	23.2a	23.9a	23.1	5.51	20.2b	23.8b	26.3a	24.1b	26.3a	23.5a	24.0	6.84
PH2	28.0a	27.3a	25.6a	23.4a	28.3a	24.5a	26.2		27.6a	25.4a	27.4a	27.1a	27.5a	25.8a	26.8	
PH3	28.2a	26.9a	26.3a	23.6a	27.0a	25.8a	26.3		28.4a	28.7a	28.7a	25.6ab	28.0a	25.1a	27.4	
Mean	25.6	26.4	25.3	22.9	26.2	24.7			25.4	26.0	27.5	25.6	27.3	24.8		
CV (%)				6.29												5.67
	HI (%)								HI (%)							
PH1	47.1a	50.2ab	50.7a	53.3b	49.8b	50.4a	50.3	6.71	53.9b	55.0a	55.9a	57.7a	58.4a	54.5a	55.9	5.94
PH2	52.3b	52.0b	51.3a	57.3a	52.0a	51.1a	52.7		55.9a	60.7a	59.2a	61.4a	60.8a	59.3a	59.6	
PH3	48.1b	54.7a	52.3a	53.8ab	52.3a	52.8a	52.3		55.4b	61.6a	59.8a	58.8a	59.2a	61.4a	59.4	
Mean	49.2	52.3	51.4	54.8	51.4	51.4			55.1	59.1	58.3	59.3	59.5	58.4		
CV (%)				3.95												3.98

CV (%) indicates, the coefficient of variation

Pre-emergence herbicides: PH1: No pre-emergence; PH2: Pendimethalin (1000 g a.i. ha⁻¹) and PH3: Atrazine (1000 g a.i. ha⁻¹)

Post-emergence herbicides: PO1: No post-emergence; PO2: Atrazine (500 g a.i. ha⁻¹); PO3: Tembotrione (120 g a.i. ha⁻¹); PO4: Halosulfuron (90 g a.i. ha⁻¹); PO5: Tembotrione (120 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹) and PO6: Halosulfuron (90 g a.i. ha⁻¹) + Atrazine (500 g a.i. ha⁻¹)

If we consider the year-specific variation of straw yield, the maximum straw yield (13.5 t ha⁻¹) in the first season was recorded in the plot where Halosulfuron was applied, which was statistically similar to the combined application of Tembotrione + Atrazine (13.2 t ha⁻¹) applied as post-emergence, followed by Atrazine (12.9) and Tembotrione (12.5) and the lowest straw yield was recorded in the control plot (10.0). In the second season, the maximum straw yield was recorded in the plot where Tembotrione (12.3) was applied as post-emergence, followed by Halosulfuron (11.4) and Tembotrione + Atrazine (11.1) and the lowest straw yield was recorded in the control plot (9.6) (Table 21).

Similar to the sole application of pre-and post-emergence herbicides, the sequential use of pre-and post-emergence herbicides also significantly influenced the straw yield of ZT maize. In the first season, the highest straw yield was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with post-emergence herbicides Halosulfuron (14.8 t ha⁻¹), which was statistically similar to Tembotrione + Atrazine (14.4 t ha⁻¹) applied at 15 DAS, and the lowest was recorded in the control plot (9.9 t ha⁻¹). In the second season, the highest straw yield was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with post-emergence herbicides Tembotrione (12.8 t ha⁻¹) applied at 15 DAS, which was statistically similar to the application of Atrazine (12.7 t ha⁻¹) applied as both pre-and-post-emergence, and the lowest was recorded in the control plot (10.9 t ha⁻¹) (Table 21).

4.4.3.8 Biomass yield at harvest (t ha⁻¹)

Similar to the grain and straw yield, the biomass yield at harvest also differed significantly due to the application of both pre-emergence herbicides in the second season. However, in the first season, the highest biomass yield (26.3 t ha⁻¹) was recorded in the plot where Atrazine was applied (as pre-emergence) immediately after sowing of maize seeds which was statistically

similar to Pendimethalin (26.2 t ha^{-1}) and the lowest biomass yield (23.1 t ha^{-1}) was recorded in the control plot. In the second season, the highest biomass yield (27.4 t ha^{-1}) was recorded in the plot where Atrazine was applied immediately after sowing of maize seeds, which was statistically similar to Pendimethalin (26.8 t ha^{-1}), and the lowest biomass yield was recorded in control plot (24.0) (Table 21). Similar to pre-emergence herbicides, post-emergence herbicides also influenced the biomass yield of ZT maize in both growing years. In both years, all post-emergence herbicides showed the maximum biomass yield than control plots. In the first year, the maximum biomass yield (26.4 t ha^{-1}) was recorded in the plot where Atrazine was applied as post-emergence, which was statistically similar to Tembotrione + Atrazine (26.2 t ha^{-1}), while the lowest biomass (22.9 t ha^{-1}) was recorded in Halosulfuron. In the second year, the maximum biomass yield (27.5 t ha^{-1}) was recorded in the plot where Tembotrione was applied as post-emergence, which was statistically similar to Tembotrione + Atrazine (27.3 t ha^{-1}). The lowest biomass yield (24.8 t ha^{-1}) was recorded in the plots treated with Halosulfuron + Atrazine (Table 21).

Similar to the sole application of pre-and post-emergence herbicides, the sequential use of both pre-and post-emergence herbicides also significantly influenced the biomass yield of ZT maize. In the first season, the highest biomass yield (28.3 t ha^{-1}) was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with the application of post-emergence herbicides Tembotrione + Atrazine at 15 DAS which was statistically similar to the application of Atrazine (28.2 t ha^{-1}) and Pendimethalin (28.0 t ha^{-1}) applied immediately after maize seeding with no post-emergence herbicides, and the lowest biomass was recorded in the control plot (20.7). In the second season, the highest biomass yield (28.7 t ha^{-1}) was recorded in the sequential application of Atrazine applied immediately after maize seeding with post-emergence herbicides Atrazine, Tembotrione + Atrazine, and

Tembotrione applied at 15 DAS, and the lowest (20.2 t ha⁻¹) was recorded in the control plot (Table 21).

4.4.3.9 Harvest Index (%)

The harvest index of ZT maize differed significantly by pre-emergence herbicides in both growing years. In the first season, the highest harvest index (52.7%) was recorded in the plot where Pendimethalin was applied immediately after sowing of maize seeds, which was statistically similar to Atrazine (52.3%), and the lowest harvest index was recorded in the control plot (50.3%). However, in the second season, the highest harvest index (59.6%) was recorded in the plot where Pendimethalin was applied immediately after sowing of maize seeds, which was statistically similar to Atrazine (59.4%), and the lowest harvest index was recorded in the control plot (55.9%) (Table 21). Similar to pre-emergence herbicides, post-emergence herbicides also influenced the harvest index of ZT maize in both growing years. In both years, all post-emergence herbicides showed the maximum harvest index than control plots. However, in the first year, the maximum harvest index (54.8%) was recorded in the plot where Halosulfuron was applied as post-emergence, which was statistically similar to the sole application of Atrazine (52.3%) and Tembotrione (51.4%). The lowest harvest index was recorded in the control plot (49.2%). In the second year, the maximum harvest index was recorded in the plot where Tembotrione + Atrazine (59.5%) was applied as post-emergence, which is statistically similar to Halosulfuron (59.3%), Atrazine (59.1%) and Tembotrione (58.3%). The lowest harvest index was recorded in the control plot (55.1%) (Table 21).

Similar to the sole application of pre-and post-emergence herbicides, the sequential use of pre-and post-emergence herbicides also significantly influenced the harvest index of ZT maize. In the first season, the highest harvest index (57.3 %) was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with post-emergence

herbicides Halosulfuron applied at 15 DAS, which was statistically similar to the application of Atrazine applied immediately after maize seeding with post-emergence herbicides Atrazine (54.7%) and Halosulfuron (53.8%), and the lowest harvest index (47.1%) was recorded in the control plot. In the second season, the highest and statistically similar harvest index was recorded in the sequential application of Atrazine applied immediately after maize seeding with post-emergence herbicides also Atrazine (61.6%) and Halosulfuron (61.4%) at 15 DAS, which was statistically similar to the application of Pendimethalin as pre-emergence and Halosulfuron + Atrazine (61.4%) applied as post-emergence. Whereas, the lowest harvest index was recorded in the control plot (53.9%) (Table 21).

Weeds are among the serious constraints that limit maize production. The competition between weeds and maize is induced by reducing the quality and quantity of maize yield by over 30% (Mahmoodi *et al.*, 2009). According to studies by Parameswari (2013), among different crop establishment methods significantly higher plant height, and dry matter production of maize was obtained when maize was grown after transplanted rice under zero-till conditions. Higher plant height and crop dry matter were observed with hand weeding (HW) twice at 20 and 40 DAS, and it was *fb* pre-emergence application of Atrazine 1.0 kg ha⁻¹ *fb* Topramezone 0.030 kg ha⁻¹ (Parameswari, 2013). Massinga *et al.* (2003) found that maize yield was reduced up to 91% by compaction with eight palmer amaranth (*Amaranthus palmeri* L.) plants m⁻², whereas maize grain yield was only reduced by 13 to 14% by 10 giant foxtails (*Setaria faberi* L.) plants m⁻² (Fausey *et al.*, 1997). The use of pre and post-emergence application of herbicides would make herbicidal weed control more acceptable to farmers which will not change the existing agronomic practices but will allow for complete control of weeds. Pre-emergence application of herbicides controls the weeds for up to 25 days, and after that post-emergent application is given so that further growth of weeds is controlled. Pre-emergence and post-emergence herbicides are ideal means for controlling weeds because of their

economics and effectiveness in maize (Singh *et al.*, 2008; Kumar and Ladha, 2011; Chauhan, 2012; Gathala *et al.*, 2015). Yield losses of 77.4, 44.2 and 38.4% were observed in maize due to grasses, non-grassy weeds and sedges, respectively (Pandey *et al.*, 2002). Losses due to weeds under zero-till sown conditions in Telangana state and Andhra Pradesh varied from 30 to 93%. In the clay loam soil of Guntur (India), unchecked weed growth caused a yield loss of 43% due to severe weed competition (Rao *et al.*, 2009). Reddy *et al.* (2012) conducted an experiment with herbicides alone and tank mix application of selective and non-selective herbicides showed that the grain yield obtained with tank mix application of Atrazine + glyphosate (5.25 t ha⁻¹) was 170 and 70% more than weedy check and sole Atrazine, respectively.

4.4.4 Economic study on pre-and post-emergence herbicides for controlling weeds in CA-based ZT-maize

From the economic point of view, the maximum net benefit (Tk. ha⁻¹) was recorded in the sequential application of Pendimethalin and Atrazine as pre-emergence, and Atrazine and Tembotrione + Atrazine were applied post-emergence, followed by no pre-emergence herbicide with both Atrazine and Tembotrione + Atrazine were applied as post-emergence, while the minimum net benefit was recorded in weedy check treatment (Table 22).

Table 22. Economic study on pre-and post-emergence herbicides for controlling weeds in CA-based ZT-maize in both years

Treatments		Cost of controlling weeds (Tk. ha ⁻¹)		Gross return after controlling weeds (Tk. ha ⁻¹)		Net benefit after controlling weeds (Tk. ha ⁻¹)		The average profit in both years after controlling weeds (Tk. ha ⁻¹)
		2017-2018	2018-2019	2017-2018	2018-2019	2017-2018	2018-2019	
PH1	PO1	21943	21943	279900	281800	257957	259857	258907.0
	PO2	23143	23143	334500	369400	311357	346257	328807.0
	PO3	25030	25030	317300	369000	292270	343970	318120.0
	PO4	27993	27993	326100	355200	298107	327207	312657.0
	PO5	24118	24118	319900	407900	295782	383782	339782.0
	PO6	26543	26543	323900	364300	297357	337757	317557.0
PH2	PO1	23543	23543	322500	389900	298957	366357	332657.0
	PO2	24393	24393	351200	433200	326807	408807	367807.0
	PO3	26280	26280	340000	402800	313720	376520	345120.0
	PO4	29243	29243	349800	397000	320557	367757	344157.0
	PO5	25368	25368	361900	414000	336532	388632	362582.0
	PO6	27793	27793	342000	393000	314207	365207	339707.0
PH3	PO1	24043	24043	300000	387200	275957	363157	319557.0
	PO2	24893	24893	355400	420200	330507	395307	362907.0
	PO3	26780	26780	330200	442500	303420	415720	359570.0
	PO4	29743	29743	354700	404500	324957	374757	349857.0
	PO5	25868	25868	352900	426500	327032	400632	363832.0
	PO6	28293	28293	314200	395600	285907	367307	326607.0

Economic study for controlling weeds in CA-Based ZT-Maize

Market price (Tk ha⁻¹) of commercial herbicides:

Pre-emergence herbicides: PH1: No pre-emergence; 2450 Tk; PH2: Pendimethalin; 1250+ 350 + 2450 Tk and PH3: Atrazine; 1750 + 350 + 2450 Tk

Post-emergence herbicides:

PO1: No post emergence; PO2: Atrazine; 850 + 350 + 2450 Tk; PO3: Tembotrione; 2737 + 350 + 2450 Tk; PO4: Halosulfuron; 5700 + 350 + 2450 Tk; PO5: Tembotrione + Atrazine; 425+1400 + 350 + 2450 Tk and PO6: Halosulfuron + Atrazine; 2850+1400 + 350 + 2450 Tk

Labour wage: 350 labour⁻¹day⁻¹, Herbicide application cost (Tk.): 1 labour ha⁻¹ round⁻¹ @ 350 Tk labour⁻¹ day⁻¹, Irrigation cost (Tk.): 8 labours ha⁻¹ for 4 times irrigation in both years @ 350 labour⁻¹ day⁻¹, Harvest and post-harvest processing cost (Tk.): 45 labours ha⁻¹@ 350 labour⁻¹day⁻¹; sowing cost (ZT machine): 3743

The market price of grain is 25 (Tk. kg⁻¹) and straw is 1 (Tk. kg⁻¹)

Gross return = {grain yield (t ha⁻¹) × market price (tk t ha⁻¹)} + {straw yield (t ha⁻¹) × market price (Tk t ha⁻¹)}, Net benefit = Gross income – Total costs.

4.5 Conclusion

Two years of observation revealed that all types of weeds (grass, sedge and broadleaved weeds) were effectively controlled by sequential use of pre-and post-emergence herbicides. The findings of the study revealed that the sequential use of pre-and-post-emergence herbicides significantly influenced the grain yield of CA-based ZT-maize. In the first year, the highest grain yield (13.9 t ha^{-1}) was recorded in the sequential application of Pendimethalin immediately after maize seeding with post-emergence herbicides Tembotrione + Atrazine applied at 15 DAS. In the second year, the sequential application of Atrazine immediately after maize seeding along with the application of post-emergence herbicides Tembotrione at 15 DAS showed the highest grain yield (17.2 t ha^{-1}), which was statistically similar to the application of Tembotrione + Atrazine (16.6 t ha^{-1}) applied as post-emergence. The lowest grain yield (10.9 t ha^{-1}) was recorded in the control plot. From the economic point of view, the maximum net benefit (two years' average) was recorded from Pendimethalin & Atrazine (both as pre-emergence) and Atrazine (as post-emergence) (367807 & $362907 \text{ Tk. ha}^{-1}$) applied plots, followed by Pendimethalin & Atrazine (both as pre-emergence) and Tembotrione + Atrazine (as post-emergence) (362582 & $363832 \text{ Tk. ha}^{-1}$), while the minimum net benefit ($258907 \text{ Tk. ha}^{-1}$) was recorded in weedy check treatment. Therefore, sequential use of pre-emergence herbicides Pendimethalin and Atrazine applied immediately after maize seeding with post-emergence herbicides Atrazine and Tembotrione solely and Atrazine + Tembotrione combinedly, applied at 15 DAS may be recommended for weed control as well as higher grain yield of zero-till maize.

CHAPTER 5

EXPERIMENT 3

Efficacy and Economics of Different Pre- and Post-Emergence Herbicides for Controlling Weeds in Zero-Till Direct Seeded Aman Rice

5.1 Abstract

The sequential application of pre-and post-emergence herbicides is effective for controlling weeds in diverse cropping systems, particularly in ZT-DSR rice. Considering the burning issue, an observation entitled ‘Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in zero-direct seeded *Aman* rice’ was conducted to find out the effective herbicides for weed control in ZT-DSR Aman rice. Treatments were two pre-emergence herbicides (i.e., Pendimethalin and Oxadiazon) and control (i.e., No pre-emergence) and five post-emergence herbicides (i.e., No-post-emergence; Bispyribac Sodium; Bispyribac Sodium + Pyrazosulfuron; Fenaxoprop + Ethoxysulfuron and Fenoxoprop *fb* Halosulfuron. Results of the two-year study showed that all types of weeds were effectively controlled by the sequential use of pre- and post-emergence herbicides. Among the herbicides, the highest grain yield in both years was found in the sequential use of pre-emergence herbicide Pendimethalin applied immediately after rice seeding followed by the application of post-emergence herbicides ‘Bispyribac Sodium + Pyrazosulfuron’ (5.3 t ha⁻¹ in the first year) and ‘Bispyribac-sodium’ (5.2 t ha⁻¹ in second year). Based on the two years of yield and the economic benefit, the sequential application of Pendimethalin and Oxadiazon as pre-emergence immediately after sowing of rice seeding in combination with Bispyribac + Pyrazosulfuron or Fenaxoprop + Ethoxysulfuron or sole application of Bispyribac Sodium as post-emergence may be recommended for weed control in ZT DSR Aman rice.

5.2 Introduction

Water and labour scarcity threaten the sustainability of traditional rice production in Asia. In South and Southeast Asia, the major rice establishment method is the manual transplanting of seedlings into flooded and puddled soil. Flooded transplanted rice has the advantage of controlling the first cohorts of weeds because of standing water, which is known to suppress the germination of weeds that need oxygen to germinate. Furthermore, transplanted rice seedlings are larger than newly emerged weed seedlings, thus increasing the degree of competitive size asymmetry in the crop-weed community and benefitting the crop at the expense of weeds (Weiner *et al.*, 2001).

The population in Asia is increasing at an alarming rate, and more water is required for urbanization, whereas water resources of variations are being depleted. Rice consumes about 50% of the total available irrigation water (Gianessi and Williams, 2011). The share of agricultural water is declining because of competition with increased domestic and industrial uses (Kumar and Ladha, 2011). In the future, a noteworthy rice area will face water shortage, and rice growers will not have enough water for rice cultivation on a large scale, particularly for puddling (land preparation in standing water is called puddling) and flood irrigation (Tuong and Bouman, 2003; Mahajan *et al.*, 2012).

In several Asian countries, increased economic growth has increased the labour demand for non-agricultural sectors, which has reduced the availability of labour in the agriculture sector. Because of the increasing labour scarcity, labour wages have gone up, for example, in 1960, the wage was less than US\$0.25 day⁻¹, but it has increased to \$0.75, \$1.25, \$1.50, and \$5.50 day⁻¹ in Bangladesh, India, Sri Lanka, and the Philippines, respectively, leading to make the traditional rice production system uneconomical in these countries (Gianessi and Sankula, 2003; Gianessi and Williams, 2011; Kumar and Ladha, 2011). Therefore, zero-till dry-direct seeded rice (ZT-DSR) is an emerging production system (Ahmed *et al.*, 2013); since this system

requires 35-57% less water, and 67% less labour than transplanted rice (Mazid *et al.*, 2003; Farooq *et al.*, 2011). Dry seeding reduces labour requirements by eliminating seedling rearing in nursery beds, seedling uprooting, repeated tillage under wet conditions to puddle the soil and manual transplanting (Farooq *et al.*, 2011; Chauhan *et al.*, 2012). Furthermore, accumulation of arsenic in the grain and straw is much less if the soil is allowed to dry between irrigations to let air (oxygen) into the soil (“aerobic” conditions) than in continuously flooded rice (Gathala *et al.*, 2014). Farmers in many Asian countries, including Bangladesh, are shifting their traditional rice cultivation method of puddled transplanted rice to ZT-DSR, due to scarcity of labour and water (Pandey and Velasco, 2005; Chauhan, 2012; Mahajan *et al.*, 2012; Gathala *et al.*, 2014). ZT-DSR can be established directly in the field with no prior tillage (zero tillage) or following dry tillage. ZT-DSR can be readily adopted by small farmers as well as large farmers, provided that the required machinery is locally available (e.g., through custom hire from agricultural service providers). Best practice involves using a 2- or 4-wheel tractor-drawn drill to seed in rows into non-tilled or dry-tilled soil, as for wheat (Riches *et al.*, 2008; Gathala *et al.*, 2014).

Although, ZT-DSR is an environmentally and economically viable approach, however, weeds are one of the most important biological constraints in ZT-DSR systems (Subhas and Jitendra, 2001; Chauhan *et al.*, 2012; Chauhan and Opena, 2012). ZT-DSR system is subject to much higher weed pressure than transplanted rice because of dry ploughing and aerobic soil conditions (Balasubramanian and Hill, 2002). High weed pressure in ZT-DSR rice lowers the economic returns, and in extreme cases, it causes complete failure of the rice crop (Jabran *et al.*, 2012). Yield loss in ZT-DSR due to weeds increased from 27 to 80% in Pakistan (Awan *et al.*, 2006; Khaliq *et al.*, 2012), and 40 to 70% in the Philippines (Phoung *et al.*, 2005; Chauhan and Opena, 2013).

Therefore, proper weed management is considered one of the most important prerequisites in the ZT-DSR system to ensure higher crop yield. Judicious weed management in ZT-DSR rice is a critical factor for securing and sustaining the food security of developing countries in Asia (Timsina and Connor, 2001). Chemical weed management is the most popular method of weed control in the ZT-DSR rice system because it is cheaper, more reliable, and more labour- and time-saving than other weed control measures (De Datta and Baltazar, 1996; Mazid *et al.*, 2003). The use of herbicides in rice for controlling weeds has increased significantly over the last several years (FAO, 2002). This is because of increased labour wages, labour shortages, and a shift in rice planting methods from transplanted to direct-seeded. For ecological weed management in the ZT-DSR rice system, the use of herbicides is not ruled out, but they are used in combination with other weed management strategies. In Australia and Europe, herbicide use began with the introduction of the ZT-DSR rice system (Bocchi *et al.*, 2005; Taylor, 2007). In Asian countries, where ZT-DSR rice is replacing transplanted rice, the use of herbicides has increased (Azmi *et al.*, 2005; Rao *et al.*, 2007; Weerakoon *et al.*, 2011). ZT-DSR rice system has complex and diverse weed species, therefore no single herbicide will control all types of weed species. Therefore, a combination or sequential or a mixture of two or more herbicides or a broad-spectrum herbicide along with other cultural practices is needed for effective control of sedges, grasses and broad-leaved weeds in ZT-DSR rice system (Sharma, 1997; Yaduraju and Mishra, 2004; Maity and Mukherjee, 2008).

Several herbicides, with pre-activity, such as Oxadiazon, Oxadiargyl, Butachlor, Pendimethalin, Thiobencarb, Oxyfluorfen, and Pyrazosulfuron, applied solely or with hand weeding, have been reported to provide effective control of weeds (Chauhan, 2012; Chauhan and Opena, 2012; Mahajan and Chauhan, 2013). However, some issues related to the use of pre-herbicides exist, such as their limited window of application timing and an adequate soil moisture requirement at the time of their application (Singh *et al.*, 2006). If optimum conditions

are not available, post-herbicides may be a better option to manage weeds in the ZT-DSR rice system (Singh *et al.*, 2006; Mahajan and Chauhan, 2013). Previous research suggested that a sequential application of pre-and post-emergence herbicides was very effective in controlling weeds in the ZT-DSR rice system, and they reduced weed density and biomass more than a single application of herbicides (Singh *et al.*, 2006; Chauhan *et al.*, 2013; Mahajan and Chauhan, 2013; Ahmed and Chauhan, 2014). In another study, Bispyribac-sodium was similar to manual weeding in controlling weeds and increasing rice yield (Khaliq *et al.*, 2012), whereas others reported that this herbicide had little to no activity on perennial sedges and grasses, such as *Digera arvensis* Forssk., *Leptochloa chinensis*, and *Eragrostis* spp. (Rao *et al.*, 2007; Mahajan *et al.*, 2009).

However, in some situations, a weed control treatment may produce the highest yield but decrease the net return (Suria *et al.*, 2011; Khaliq *et al.*, 2012), making such a treatment impractical. However, such information is not available for the use of different pre- and post-emergence herbicides in the ZT-DSR rice system in Bangladesh because mechanized dry-seeded rice is a newly emerging technology in this country. To provide wider options to farmers for economic weed control in the ZT-DSR rice system, it is necessary to evaluate the efficacy and economics of different pre- and post-emergence herbicides when used solely and sequentially. Considering these above aspects for controlling weeds in ZT-DSR rice, the current study was undertaken to fulfil the following objectives:

- i) To identify the efficacy and economics of different pre-and post-emergence herbicides used alone or sequentially in CA-based ZT-direct seeded Aman rice (ZT-DSR) under W-M-R and M-M-R cropping systems,
- ii) To know the effect of different herbicides on growth, yield attributes and yield of ZT-DSR Aman rice.

5.3 Materials and Methods

5.3.1 Location and Site Characteristics of the Research

The experiment was conducted at BWMRI, Nashipur, Dinajpur. The experiment was started in June 2018 for W-M-R and in August 2018 for the M-M-R cropping system after the incorporation of mungbean residues. It was repeated for consecutive two years (June 2019 for W-M-R and August 2019 for the M-M-R cropping system).

The site was located under AEZ-1 (FAO and UNDP, 1988). The geographical position of the area was between 25°38' N and 88°41' E, with an elevation of 38.20 m from sea level. However, the soil was sandy-loam and its reaction was strongly acidic (4.5-5.5); organic matter content was below 1%; N, K, S, B, Mg and Zn were below the critical level, but the concentration of P was higher than critical level (Hossain *et al.*, 2015; Appendix 2).

The geographical location of the experimental site was under the subtropical climate. Weather data on weekly average temperature, humidity and rainfall during the experimental period were recorded regularly at the meteorological station of BWMRI, Nashipur, Dinajpur are presented in Appendix 3.

5.3.2 Experimental Treatments and Design

5.3.2.1 Treatments

The treatments of pre-emergence herbicides like Pendimethalin (Panida) and Oxadiazon (Ronstar), and post-emergence herbicides like Bispyribac-sodium (Nominee Gold), Bispyribac-sodium + Pyrazosulfuron, Fenaxoprop (Whipsuper) + Ethoxysulfuron, Fenoxoprop (Whipsuper) *fb* Halosulfuron were used in both W-M-R and M-M-R systems. Herbicides with doses and methods of application are presented in Table 23.

Table 23. Herbicides detail used for controlling weeds in zero-till direct-seeded Aman rice

Treatments	Herbicides	Dose (g a.i. ha ⁻¹)	Time of application
Pre-emergence herbicides			
PH1	PH1: No pre-emergence	-	
PH2	PH2: Pendimethalin	1000g	Applied within two days after seeding at optimum moisture, preferably spray in the evening hrs
PH3	PH3 : Oxadiazon	500g	Applied within two days after seeding at optimum moisture
Post-emergence herbicides			
PO1	PO1: No post-emergence		
PO2	PO2: Bispyribac-sodium	25g	Applied at 15 DAS or 3-4 stages of leaf
PO3	PO3: Bispyribac-sodium + Pyrazosulfuron	25g + 20g	Apply at 15 DAS or 3-5 leaf stage of weeds
PO4	PO4: Fenaxoprop + Ethoxysulfuron	56g + 18g	Apply at 15 DAS or 3-5 leaf stage of weeds
PO5	PO5: Fenoxoprop <i>fb</i> Halosulfuron	56g <i>fb</i> 67g	Apply at 15 DAS or the 3-5 leaf stage of weeds

In the zero-till field apply Glyphosate (1000 g a.i. ha⁻¹) 5-7 days before sowing the crop to kill existing weeds as a blanket application to the entire field to all treatments.

5.3.2.2 Experimental Design and Layout

The experiment was laid out in a split-plot design with three replications. The pre-emergence herbicides were assigned to main plots, and the post-emergence herbicides were in sub-plots in both W-M-R and M-M-R systems, which are described as follows:

Main plot: Pre-emergence herbicides: 3

1. PH1: No pre-emergence
2. PH2: Pendimethalin (1000 g a.i. ha⁻¹)
3. PH3: Oxadiazon

Subplot: Post-emergence herbicide: 5

1. PO1: No post-emergence
2. PO2: Bispyribac-sodium
3. PO3: Bispyribac-sodium + Pyrazosulfuron
4. PO4: Fenaxoprop + Ethoxysulfuron
5. PO5: Fenoxoprop *fb* Halosulfuron

Total plots: 3 main plots x 5 sub-plots x 3 Rep. = 45 plots

All treatments were randomly allocated in experimental plots in both W-M-R and M-M-R systems. Total experimental area required: 54 m x 19 m = 1026 m². The size of the main plot was 17 m x 5 m = 85 m² and the subplot was 5 m x 3m = 15 m². Distance between each of the main plots was 1 m and that between the unit plots was 0.5 m and block to block was 1.5 m. The field arrangement of all treatments is available in Figure 5.

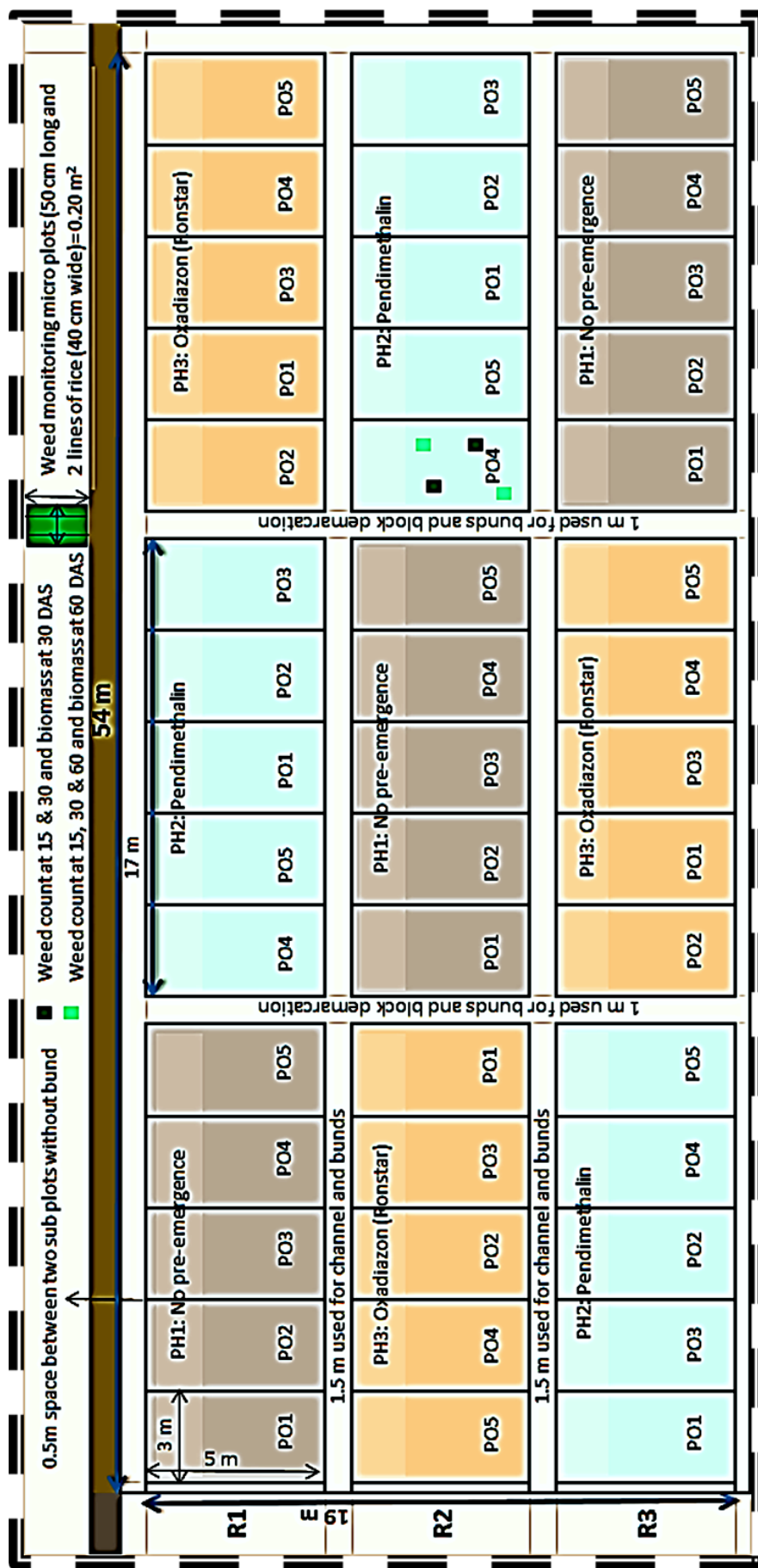


Figure 5. Experimental layout for zero-direct-seed rice trial. Note: **Pre-emergence herbicides:** PH1: No pre-emergence herbicides were applied; PH2: Pendimethalin applied at pre-emergence immediately after sowing; PH3: Oxadiazon applied at pre-emergence immediately after sowing; **Post-emergence herbicides:** PO1: No post-emergence was applied; PO2: Bispyribac-sodium was applied at 15 DAS or at 3-5 leaf stage of weeds; PO3: Bispyribac + Pyrazosulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; PO4: Fenaxoprop + Ethoxysulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; PO5: Fenoxoprop fb Halosulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds

5.3.3 Direct seeded rice production and its management for experimental purpose

5.3.3.1 Land preparation

Since rice seeds were sown in zero-direct seeded condition, we did not do any tillage for the experiment in both years. Just before the start of the experiment, we have done proper leveling manually with a hand hoe. Generally, levelling helps to reduce excessive irrigation water leads to a reduction in the cost of production.

5.3.3.2 Application of Roundup (glyphosate) @ 1000 g a.i. ha⁻¹

Before sowing, Roundup (glyphosate) @ 1000 g a.i. ha⁻¹ was applied 5-7 days before sowing rice seeds to kill existing weeds as a blanket application to the entire field for all treatments.

5.3.3.3 Rice Variety

The rice cultivar Arize Dhani Gold (BAYER HYBRID-4) was used in both W-M-R and M-M-R systems. It is the first hybrid to be registered in India for use under the direct-seeding method, due to its strong vigour and better resilience to general biotic stresses. The rice cultivar Arize Dhani Gold (BAYER HYBRID-4) has a clear advantage over inbred varieties when used with ZT-DSR. Most Arize hybrids have proven to be highly adaptive to direct-seeding techniques, whether in dry or wet conditions. Considering the above resistance quality of the new hybrid rice, we used the rice (BAYER HYBRID-4) in our experiment. In Bangladesh, it is marketed by Bayer Crop Science, Bangladesh.

5.3.3.4 Sowing time, seed rate and planting system

The best date for sowing ZT-DSR aman rice is 10-15 days before the onset of the northwest monsoon rains. The experiment was started in June 2018 for W-M-R and in August 2018 for the M-M-R cropping system after the incorporation of mungbean residues. It was

repeated for consecutive two years (June 2019 for W-M-R and August 2019 for the M-M-R cropping system). Dry rice seeds were sown at a rate of 40 kg ha⁻¹ with a row spacing of 20 cm, using a power tiller-operated seed drill fitted with a fluted-type seed-metering device.

5.3.3.5 Fertilizers management

Fertilizers were applied in our research at the rate of 120-15-48-12-2.2 kg ha⁻¹ of N, P, K, S, and Zn, respectively. All P, K, S, and Zn were applied immediately before sowing. Fertilizer N was applied in four equal splits (25% each) at 14 DAS, at the start of tillering, at maximum tillering, and at the booting stage.

5.3.3.6 Irrigation management

The goal of irrigation management is to minimize the use of irrigation water while maintaining yield because of increasing water scarcity and/or the high cost of pumping groundwater. ZT-DSR does not need to be continuously flooded for good growth and yield. It can be grown with periodic irrigation, allowing the soil surface to dry for a few days between irrigations. Light irrigation was supplied just after sowing. During the active tillering phase (30-45 DAS), and the heading to the grain-filling stage, the topsoil (0–15 cm) kept close to saturation with applying irrigation as needed. At other stages, the topsoil kept drier up to harvest.

5.3.3.7 Pest management

The rice plants were severely infested with leaf blasts and spots. Therefore, fungicide Tebuconazole + Trifloxystrobin 75WP (300 g a.i. ha⁻¹) was thus applied at 30 and 50 DAS. Fipronil 3G (10 kg a.i. ha⁻¹) was applied at 40 DAS to control stem borers.

5.3.3.8 Harvesting

After full maturity, the crop was harvested in both systems. At harvest, the rice grain yield was determined by harvesting the whole plot ($5\text{m} \times 3\text{m} = 15\text{ m}^2$) by hand.

5.3.4 Data and their collection procedures

5.3.4.1 Weed data

For weed count data in both (W-M-R and M-M-R) systems, four permanent 0.20 m^2 ($40\text{ cm} \times 50\text{ cm}$) quadrats were established in each plot after rice sowing and pre-emergence applications (3-5 DAS), and then weed data was taken from these four permanent quadrats. The following weed data were taken during both years of the experiment:

1. Weed density (no. m^{-2}) (number of grass, broadleaved and sedge weeds) was recorded from four permanent quadrats immediately before post-emergence herbicides were applied (at 15 DAS).
2. Weed density (no. m^{-2}) was recorded from all four permanent quadrats, and weed dry weight (g m^{-2}) was recorded from two randomly selected quadrats at 35 DAS (20 days after post-emergence herbicide application).
3. Both weed density (no. m^{-2}) and weed dry weight (g m^{-2}) by species-wise were taken from the two remaining permanent quadrats at 60 DAS.
4. Weed dry weight (g m^{-2}) at harvest was also recorded from the same area from which crop biomass was taken.
5. Visual ratings on weed and crop injury were recorded for the following stages of crop
 - a. At 12 DAA for pre-emergence herbicides
 - b. Just one day before weed dry weight collection (35 and 60 DAS)
6. Local, common and Latin names of weed species were noted from weedy check treatment at 60 DAS in both years

7. Weed mortality (%) and weed control efficiency (%) were also estimated for all weed control treatments as compared with the weedy check.

$$\text{Mortality\%} = \frac{W_t - W_s}{W_t} \times 100$$

Where; W_t = Total number of weeds m^{-2} before spray; W_s = Number of surviving weeds m^{-2} after spray.

$$\text{WCE} = \frac{W_c - W_t}{W_c} \times 100$$

Where; W_c = Average dry weed dry weight m^{-2} in the weedy check plot; W_t = Average dry weed dry weight m^{-2} in the plot after spray.

5.3.4.2 Crop data

1. Crop emergence m^{-2} at 12 DAS (80% germination), tillers m^{-2} at 45 DAS, and panicles m^{-2} at physiological maturity were recorded from 1m long 5 rows (1 m^{-2}).
2. Crop height at 30, and 60 DAS and at harvest was recorded.
3. At harvest, the plant height, and yield attributes (spikelets panicle⁻¹, grains panicle⁻¹, and 1000-grain weight were recorded.
4. Straw and grain yield were calculated by harvesting and threshing the entire plot rather from a 1m^2 area.

5.3.5 Economics analysis

Similar to wheat and maize trials, variable cost (i.e., labour/nonmaterial cost and material cost), fixed cost (land rent, interest on input cost and miscellaneous cost), and gross and net return were estimated to find out the cost-effective and environmentally friendly treatment. For estimation of net return, data such as labour costs for all management practices as well as the

application time of herbicides, and labour costs for hand weeding in weed-free treatments were also noted. Besides these, herbicide costs and other input costs.

5.3.6 Statistical analysis

Please note that the average data of weeds and crops in both W-M-R and M-M-R systems were rearranged and analysed separately by using STAR 3.0 V (IRRI, 2016). Treatment means were separated using the least significant difference (LSD) at the 5% level of significance. Square-root transformation [$\sqrt{(x + 0.5)}$] for weed density and dry biomass data was done before analysing all data in both W-M-R and M-M-R systems.

5.4 Results and Discussion

Results obtained from the present study regarding the performance of pre- and post-emergence herbicides and their combined effect on weed control in zero dry-till direct seeded (ZT-DSR rice) *Aman* rice is presented in the chapter.

5.4.1 Composition of infesting weed flora in direct-seeded rice

Local name, scientific name, family, morphological types life cycle, weed density, dry weight and their contribution in rice-based and % weed species of infesting weed species in no-pre and post-emergence plots recorded at 60 DAS are presented in Table 24 and Figure 6. The experimental plots were infested with seventeen weed species namely *Digitaria sanguinalis*, *Eleusine indica*, *Cynodon dactylon*, *Echinochloa crusgalli*, *Ludwigia hyssopifolia*, *Blumea lacera*, *Phyllanthus niruri*, *Murdania nudiflora*, *Spilanthes acmella*, *Alternanthera philoxeroides*, *Enhydra fluctuans*, *Commelina benghalensis*, *Celosia argentea*, *Amaranthus viridis*, *Mimosa pudica*, *Cyanotis axillaris*, *Cyperus rotundus* (Table 24). Four weed species in Poaceae, three of each in Amaranthaceae, Commelinaceae and Asteraceae, and one of each in the Onagraceae, Phyllanthaceae, Mimosaceae and Cyperaceae families were observed. Among the families of weeds, the family Poaceae, Onagraceae, Asteraceae, Commelinaceae, Amaranthaceae and other three families (Phyllanthaceae, Mimosaceae and Cyperaceae) consisted of 94.03, 2.7, 1.63, 0.57, 0.50 and 0.59%, respectively. Considering the total density of 136.5 and dry weight (440.7g) of weed species and their involvement, *Echinochloa crusgalli* was the most dominant weed (density 34.21%, involvement 78.42%) followed by *Digitaria sanguinalis* (18.46 and 13.84%), *Ludwigia hyssopifolia* (15.24 and 2.68%), *Eleusine indica* (8.1%), *Cynodon dactylon* (7.3%), *Mimosa pudica* and *Amaranthus viridis*. Thus the species in the family Poaceae were the most dominant weeds in experimental plots (Table 24 and Figure 6).

Table 24. Local name, scientific name, family, morphological type's life cycle, weed density, dry weight and their importance value of infesting weed species in no-pre and post-emergence plots recorded at 60 DAS

Sl no.	Common name	English name	Scientific name	Family	Morphological types	Life cycle	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Importance value %
1.	Anguli gas	Finger-grass	<i>Digitaria sanguinalis</i>	Poaceae	Grass	Annual	25.2	61	13.84
2.	Chapra	Goosegrass	<i>Eleusine indica</i>	Poaceae	Grass	Annual	11	2.8	0.64
3.	Durba	Bermuda grass	<i>Cynodon dactylon</i>	Poaceae	Grass	Perennial	10	5	1.13
4.	Boroshama	Barnyard grass	<i>Echinochloa crus-galli</i>	Poaceae	Grass	Annual	46.7	345.6	78.42
5.	Panilong	Water primrose	<i>Ludwigia hyssopifolia</i>	Onagraceae	Broadleaved	Annual	20.8	11.8	2.68
6.	Kukursunga	Kakronda	<i>Blumea lacera</i>	Asteraceae	Broadleaved	Annual	2.5	2.5	0.57
7.	Hazardana	Seed-under-leaf	<i>Phyllanthus niruri</i>	Phyllanthaceae	Broadleaved	Annual	0.8	0.1	0.02
8.	Kanainala	Doveweed	<i>Murdania nudiflora</i>	Commelinaceae	Broadleaved	Annual	2.5	0.4	0.09
9.	Halud-nakful	Toothache Plant	<i>Spilanthes acmella</i>	Asteraceae	Broadleaved	Annual	1.7	0.3	0.07
10.	Maloncho	Alligator weed	<i>Alternanthera philoxeroides</i>	Amaranthaceae	Broadleaved	Annual	2.5	1.5	0.34
11.	Halench	Buffalo Spinach	<i>Enhydra fluctuans</i>	Asteraceae	Broadleaved	Perennial	2.7	4.4	1.00
12.	Kanaibashi	Benghal dayflower	<i>Commelina benghalensis</i>	Commelinaceae	Broadleaved	Perennial	3.3	1.6	0.36
13.	Muragphul	Plumed Cockscomb	<i>Celosia argentea</i>	Amaranthaceae	Broadleaved	Annual	0.2	0.6	0.14
14.	Shaknote	Slender amaranth	<i>Amaranthus viridis</i>	Amaranthaceae	Broadleaved	Annual	0.1	0.1	0.02
15.	Lazzaboti	Sensitive plant	<i>Mimosa pudica</i>	Mimosaceae	Broadleaved	Perennial	1	0.2	0.05
16.	Gima	Creeping Cradle Plant	<i>Cyanotis axillaris</i>	Commelinaceae	Broadleaved	Annual	1	0.5	0.11
17.	Mutha	Purple nutsedge	<i>Cyperus rotundus</i>	Cyperaceae	Sedge	Annual	4.5	2.3	0.52
Total							136.5	440.7	100.00

Note: These are averaged data of both (W-M-R and M-M-R) systems and both years. *Figure in the parenthesis in the column of dry weight, indicates the importance value (%) of weed species.

The importance value of all weed species was calculated by dividing the density and dry weight of the individual weed species by the total density and dry weight of all weed species and multiplying by 100.

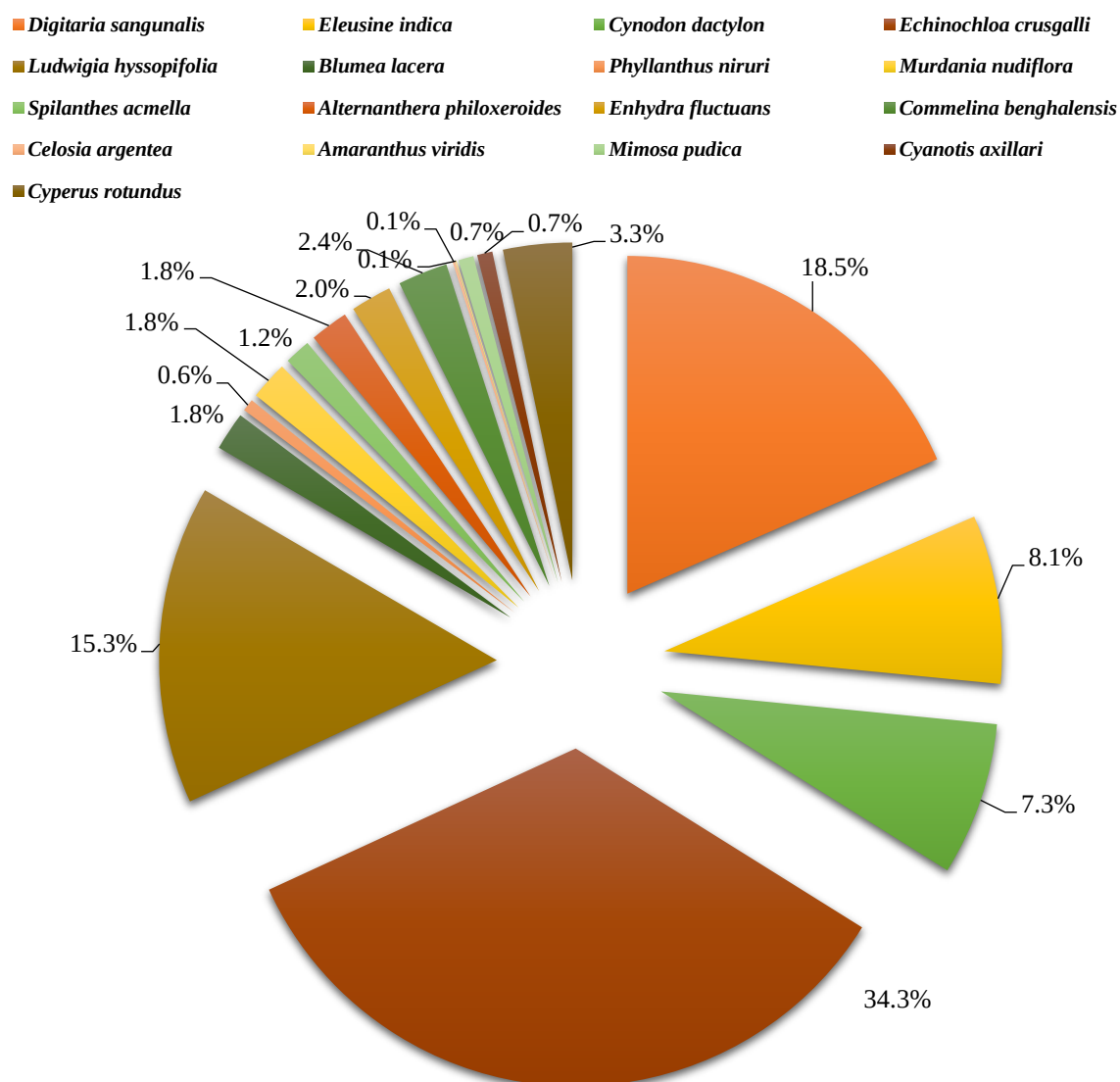


Figure 6. Infesting weed species (%) in no-weeding plots in ZT direct seeded Aman rice field recorded at 60 DAS (Note: These are averaged data of both (W-M-R and M-M-R) systems and both years)

In India, Singh *et al.* (2005) observed that *E. crus-galli*, *Commelina diffusa* Burm. f., *Cyperus rotundus* L., *Cyperus iria*, and *L. chinensis* were dominant in non-weeded dry-ZT-DSR plots in comparison with *C. iria*, *Echinochloa colona*, and *Caesulia axillaris* Roxb. in conventional rice transplanted plots after four years of rice cropping. Awan *et al.* (2015) found the dominant weeds of ZT-DSR in India are *Echinochloa colona* (L.) Link, *Leptochloa chinensis* (L.) Nees, and *Echinochloa crus-galli* (L.) Beauv, *Eclipta prostrata* (L.) L., *Ludwigia hyssopifolia* (G. Don) Exell, *Cyperus iria* L. and *Fimbristylis miliacea* (L.) Vahl. The common weed species of ZT-DSR in Bangladesh were *Ageratum conyzoides*, *Cleome rutidosperma*, *Celosia argentea*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Digitaria ciliaris*, *Echinochloa colona*, *Eleusine indica*, *Galinsoga ciliate*, *Murdannia nudiflora* and *Phyllanthus niruri* (Ahmed and Chauhan, 2015).

5.4.2 The sequential application of pre - and post-emergence herbicides effect on density and dry weight of grass, broadleaved and sedge weeds recorded at 15, 35 and 60 DAS

At 15 DAS

In both years, the density (no. m⁻²) of grass, broadleaved and sedge weeds in all proposed post-emergence herbicide plots (before application of post-emergence herbicides) was significantly controlled by the two pre-emergence herbicides (Pendimethalin and Oxadiazon) applied immediately after rice sowing (Tables 25 & 26). However, with a little exception, the control efficiency of Oxadiazon (PH3) was found better than Pendimethalin (PH2) in both years for all species (Tables 25 & 26).

Table 25. Pre- and post-emergence herbicides' effect on weed control in zero-till direct seeded rice was recorded at 15, 35 and 60 DAS in the year 2018

Treatments		Grass weeds					Broadleaved weeds					Sedge weeds				
		15 DAS		35 DAS		60 DAS	15 DAS		35 DAS		60 DAS	15 DAS		35 DAS		60 DAS
		Density (no. m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)
PH1	PO1	4.7a	10.7a	9.6a	7.8a	20.5a	87.4a	263.3a	8.4a	7.9b	16.3a	1.1ab	23.4a	5.5a	8.0a	1.2c
	PO2	5.7a	5.4b	1.4c	4.7b	7.5c	82.1a	9.8c	1.2c	2.5d	1.5d	1.3a	0.8c	1.3d	1.1e	1.1c
	PO3	7.7a	5.6b	4.1b	4.7b	3.2d	128.9a	9.3c	1.0c	3.1d	1.7d	0.7b	0.7c	2.7c	0.7e	0.7c
	PO4	9.3a	4.1c	1.2c	6.5ab	11.6b	62.2a	272.6a	6.3b	17.3a	13.1b	0.7b	2.7b	5.2a	5.4b	3.7b
	PO5	8.1a	0.7d	0.7c	1.7d	4.8d	127.6a	221.1ab	5.6b	12.3b	9.4c	0.7b	2.7b	3.9b	1.7d	0.9b
PH2	PO1	2.4b	6.1b	7.5a	6.1ab	4.5d	67.0a	344.7a	5.6a	8.0b	7.8c	0.8b	13.5a	5.0a	4.6b	5.0a
	PO2	2.5b	5.1b	1.1c	3.0c	11.0b	36.2c	7.3d	1.0c	5.0c	4.8d	0.7b	0.9c	1.0d	0.8e	0.8c
	PO3	3.4b	4.5b	1.2c	1.8d	7.9c	55.2b	7.1d	1.2b	4.5c	2.6d	0.9b	0.9c	1.0d	0.7e	0.7c
	PO4	2.4b	2.6c	0.9c	5.4ab	4.9d	60.2a	123.3b	5.7b	9.6b	12.7b	0.7b	3.2b	3.8b	3.1c	1.1c
	PO5	4.4b	1.8c	0.7c	2.9c	0.7e	57.5b	127.5b	5.7b	13.3b	13.2b	2.4a	1.7c	5.7a	2.6c	0.9c
PH3	PO1	2.9b	7.5b	2.4b	5.4ab	9.3b	63.4a	128.4a	7.4a	5.9c	15.8a	0.8b	6.3ab	5.9a	2.9c	2.8b
	PO2	1.8b	4.5b	1.0c	2.8c	3.8d	52.1b	9.3c	1.8c	5.9c	2.3d	1.8a	1.7c	1.6d	1.7d	1.0c
	PO3	1.7c	4.2b	1.9b	0.7d	6.5c	45.6c	4.4d	0.9d	2.8d	2.9d	0.7b	0.7c	0.8d	0.7e	0.7c
	PO4	1.7c	3.2c	1.1c	4.8b	0.8e	33.7d	85.0b	3.7bc	5.4c	8.7c	1.7a	1.9c	1.0d	0.7e	0.7c
	PO5	2.6b	2.2d	0.8c	4.4b	1.1e	29.8e	22.7cd	3.1bc	4.1c	6.2c	1.8a	0.9c	5.2a	1.1d	0.7c
CV (%)		11.10	11.89	16.67	21.51	15.8	2.70	3.46	12.83	11.06	14.52	25.79	15.02	15.33	41.24	33.84
F-test (0.05)		**	**	**	**	*	**	**	**	**	**	**	**	**	**	*

NS indicates non-significant; * & ** indicate significance at 5% and 1% levels of probability; CV (%) indicates the coefficient of variation. In a column, means with the similar letter(s) are significantly similar to each other. **Note:** These are averaged data of both (W-M-R and M-M-R) systems

Pre-emergence herbicides:

PH1: No pre-emergence herbicides were applied; **PH2:** Pendimethalin applied at pre-emergence immediately after sowing; **PH3:** Oxadiazon applied at pre-emergence immediately after sowing

Post-emergence herbicides:

PO1: No post-emergence was applied; **PO2:** Bispyribac-sodium was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO3:** Bispyribac + Pyrazosulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO4:** Fenaxoprop + Ethoxysulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO5:** Fenoxoprop *fb* Halosulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds.

At 35 DAS

The density (no. m^{-2}) and dry weight (g m^{-2}) of all types of weed species were influenced significantly by the sequential application of pre- and post-emergence herbicides recorded at 35 DAS. It was observed that sequential application of both pre-emergence herbicides in combination with all post-emergence herbicides controlled all types of weeds significantly. Among these pre-and post-emergence herbicides, Fenoxoprop *fb* Halosulfuron was applied as post-emergence, followed by Fenaxoprop + Ethoxysulfuron and sole application of Bispyribac-sodium in combination with all pre-emergence herbicides controlled all type of grass weeds effectively. In the case of broadleaved and sedge weeds, the sequential application of both pre-emergence herbicides in combination with Bispyribac-sodium + Pyrazosulfuron, and the sole application of Bispyribac-sodium showed the maximum control efficiency in both years (Tables 25 & 26).

The dry weight (g m^{-2}) of all weed species decreased significantly when applied both pre- and post-emergence herbicides sequentially. However, the highest dry weight (g m^{-2}) of grass weeds was recorded in the pre-emergence herbicides applied plots where no post-emergence herbicides were applied. With a little exception, the dry weight of grass was found statistically similar in all other plots, indicating that all types of herbicides (sequential application of both pre- and post-emergence herbicides) can control the dry matter of grass weeds effectively (Tables 25 & 26).

In the case of weeds under the classification of broadleaved and sedge, the dry weight of both broadleaved and sedge weeds is influenced by different pre-and post-emergence herbicides, when also applied sequentially. As compared with no pre- and post-emergence applied plot, the lowest dry weight of broadleaved and sedge were recorded in the plot where Pendimethalin and Oxadiazon were applied as pre-emergence and Bispyribac-sodium +

Pyrazosulfuron, followed by Bispyribac-sodium (post-emergence) in combination with Pendimethalin and Oxadiazon (pre-emergence) (Tables 25 & 26).

At 60 DAS

Similar to 35 DAS, the density and dry weight of grass species were influenced significantly by the sequential application of both pre- and post-emergence herbicides recorded at 60 DAS in both growing years (Tables 25 & 26). However, the highest grass was observed in the plot where no pre- and post-emergence herbicides were applied, and the lowest was in the plot where Pendimethalin and Oxadiazon were applied as pre- and Fenoxoprop *fb* Halosulfuron was applied as post-emergence, followed by Bispyribac-sodium + Pyrazosulfuron. The dry weight of grass species decreased significantly in all pre- and post-emergence herbicides applied plots, and all treatments were statistically similar to each other. The highest weed dry weight was recorded in the plot where no pre-and post-emergence herbicides were applied, and the lowest was recorded in the plot where Pendimethalin and Oxadiazon were applied as pre-emergence, and Fenoxoprop *fb* Halosulfuron was applied as post-emergence, followed by Fenaxoprop + Ethoxysulfuron (Tables 25 & 26).

Similar to grass weeds, the broadleaved species was influenced by the combination of different pre- and post-emergence herbicides. The lowest density and dry weight of broadleaved were found in the plot where Pendimethalin and Oxadiazon were applied as pre-and-post-emergence herbicides in combination with Bispyribac-sodium + Pyrazosulfuron was applied as post-emergence, followed by Bispyribac-sodium, Fenaxoprop + Ethoxysulfuron and Fenoxoprop *fb* Halosulfuron. A similar trend was also in the case of sedge (Table 25 & 26).

Table 26. Pre-and post-emergence herbicides' effect on controlling weeds in ZT DSR Aman rice recorded at 15, 35 and 60 DAS in the year 2019

Treatments		Grass weeds					Broadleaved weeds					Sedge weeds				
		15 DAS		35 DAS		60 DAS	15 DAS		35 DAS		60 DAS	15 DAS		35 DAS		60 DAS
		Density (no. m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)	Density (no. m ⁻²)	Dry weight (g m ⁻²)
PH1	PO1	23.6b	63.3a	106.7a	64.2a	417.3a	62.5a	728.3a	93.4a	372.7a	162.8c	26.6a	25.0a	33.8b	1.6bc	9.7a
	PO2	19.6c	22.7c	19.4c	47.0b	233.9b	36.2b	80.0c	14.1d	160.0b	137.3c	4.2c	16.2ab	24.4c	2.9b	1.3b
	PO3	17.5c	9.0d	73.1b	7.5d	3.5d	26.8c	18.3e	25.6b	54.2c	6.9e	2.0d	1.9d	5.3e	0.7c	0.7b
	PO4	5.8c	5.3e	12.1d	5.0d	9.1d	37.6b	48.5d	19.4c	44.3c	265.0b	0.9d	2.6d	14.8d	0.7c	0.7b
	PO5	7.5c	8.3d	3.2e	26.5c	108.1c	35.2b	182.6b	18.7c	54.0c	76.1d	6.1b	4.7c	28.3b	0.7c	0.7b
PH2	PO1	14.4c	74.7a	49.0b	45.0b	12.5e	73.7a	339.0b	34.4b	106.3c	77.4d	12.9ab	8.5b	54.2a	5.3a	4.0a
	PO2	49.3a	57.7a	7.3d	53.7ab	343.0b	46.3a	80.3c	17.1c	53.3c	49.7d	5.4b	6.8b	2.3f	0.8c	0.9b
	PO3	37.4a	36.7b	24.8c	46.0b	469.6a	30.3b	42.9de	12.1cd	47.7c	32.4e	4.6c	3.7d	6.4e	0.7c	0.7b
	PO4	67.5a	59.3a	29.2c	20.0c	122.7c	80.7a	385.0a	33.9c	258.3ab	304.5a	2.8d	5.4b	11.5d	1.9bc	1.3b
	PO5	107.2a	60.3a	24.5c	18.6c	78.6d	60.3a	238.3b	60.5b	257.0ab	318.8a	18.2ab	2.5d	31.7b	0.9c	0.9b
PH3	PO1	38.8a	40.3b	109.0a	56.7ab	415.6a	32.9b	536.3a	40.6b	50.0c	151.2c	7.4b	3.1d	23.7c	3.3b	4.9a
	PO2	28.0b	42.7b	59.9b	20.0c	262.4b	39.5b	91.8c	3.5d	27.7d	17.3e	4.3c	0.9e	4.5e	0.7c	0.7b
	PO3	26.9b	19.7b	88.6ab	39.2b	352.7b	48.1a	44.3de	1.5e	33.3d	50.0d	4.0c	1.2e	3.9e	0.7c	0.7b
	PO4	25.5b	43.0b	30.2c	31.7bc	32.0d	32.6b	157.0bc	30.9b	178.8b	263.1b	2.2d	2.7d	7.1e	0.7c	0.7b
	PO5	20.1b	17.7c	10.5d	2.7e	26.5d	28.4c	167.1bc	42.2b	164.0b	293.9a	4.1b	1.2e	11.4d	0.7c	0.7b
CV (%)		4.95	4.43	3.61	7.59	112.92	2.64	1.37	4.55	44.03	9.73	11.48	12.15	17.54	25.72	22.25
F-test		**	**	**	**	**	*	**	**	**	**	**	**	**	*	*

NS indicates non-significant; * & ** indicate significance at 5% and 1% levels of probability; CV (%) indicates the coefficient of variation. In a column, means with the similar letter(s) are significantly similar to each other. **Note:** These are averaged data of both (W-M-R and M-M-R) systems

Pre-emergence herbicides: **PH1:** No pre-emergence herbicides were applied; **PH2:** Pendimethalin applied at pre-emergence immediately after sowing; **PH3:** Oxadiazon applied at pre-emergence immediately after sowing

Post-emergence herbicides: **PO1:** No post-emergence was applied; **PO2:** Bispyribac-sodium was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO3:** Bispyribac + Pyrazosulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO4:** Fenaxoprop + Ethoxysulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO5:** Fenoxoprop *fb* Halosulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds

It has been already well-documented that continuous and long-term use of the same herbicide creates resistance to a specific weed. The use of herbicide mixtures is essential in response to changes in the weed community structure in dry-seeded rice (Yaduraju and Mishra, 2002; Maity and Mukherjee, 2008). The tank mixture of herbicides can be used and also found effective when two or more herbicides are compatible with a broad spectrum of weeds; in such a way that each herbicide controls the weeds missed by the other one (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). However, post-emergence herbicides in combination with pre-emergence herbicides may be a better option for managing weeds in dry-seeded rice systems (Singh *et al.*, 2006; Khaliq *et al.*, 2012; Mahajan and Chauhan, 2013). Mahajan and Chauhan (2013) found the sequential application of Pendimethalin as pre-*fb* post-application, such as a tank mixture of Bispyribac-sodium þ Azimsulfuron would be a potential herbicide combination if both grassy and broadleaved weeds. The inclusion of Azimsulfuron with Bispyribac-sodium as post-application was found an effective weed control measure because Azimsulfuron effectively controlled sedge and broadleaved weeds (Walia *et al.*, 2008). Another observation conducted by Mahajan and Chauhan (2013) found that the maximum weed dry weight reduction (82-91%) was observed in the plot where Pendimethalin was applied as pre-*fb* Bispyribac-sodium + Azimsulfuron applied as a post-emergence at 45 DAS.

5.4.3 Effect of pre-and post-emergence herbicides and their interaction effect on density, dry weight of all weed species and WCE (%) of ZT dry DSR Aman rice recorded at 15, 35, 60 DAS and at harvest

At 15 DAS

At 15 DAS, the density of all weed species was recorded immediately before the application of all post-emergence herbicides which was varied in all post-emergence herbicides plots; as a result of the effect of pre-emergence herbicides which were applied immediately after sowing of rice seeds, indicating that both pre-emergence herbicides can able to control all types of weeds (Table 27).

At 35 DAS

The total density and dry weight of all weed species recorded at 35 DAS significantly differed due to the sequential application of both pre- and post-emergence herbicides. Among these herbicides, sequential application of both pre-emergence herbicides Pendimethalin and Oxadiazon in combination with post-emergence herbicides Bispyribac-sodium + Pyrazosulfuron at 15 DAS decreased the maximum number of weeds and their dry weight in both years, followed by Bispyribac-sodium (Table 27).

WCE (%) at 35 DAS

Considering the WCE (%) at 35 DAS, all pre-emergence herbicides applied immediately after rice seeding in combination with Bispyribac-sodium applied as post-emergence at 15 DAS showed the maximum WCE (84 and 60%) in both years, followed by Pendimethalin as pre-emergence and Bispyribac-sodium + Pyrazosulfuron as post-emergence (WCE 61%) (Table 27).

Table 27. Effect of pre-and post-emergence herbicides on the weed density, dry weight and WCE of zero-till direct seeded rice at 15, 35 and 60 DAS, and at harvest in both years

Treatments		All types of weed species were recorded on different days after sowing (DAS)														
		Density		Density (no. m ⁻²)		Dry weight (g m ⁻²)		WCE (%)	Density (no. m ⁻²)		Dry weight		WCE (%)	Dry weight		WCE (%)
		(no. m ⁻²) at 15 DAS		at 35 DAS		at 35 DAS			at 60 DAS		(g m ⁻²) at 60 DAS			(g m ⁻²) at harvest		
		2018	2019	2018	2019	2018	2019	at 35 DAS	2018	2019	2018	2019	at 60 DAS	2018	2019	at harvest
PH1	PO1	93.1b	112.6a	297.4a	816.6a	23.5a	159.2a	0	23.7a	352.4a	38.0a	590.0a	0	119.7a	264.0a	0
	PO2	89.0c	60.0b	16.0d	118.7c	3.9e	57.8d	66	10.1c	210.0b	10.0d	372.0b	39	40.3c	104.3c	62
	PO3	137.3a	46.2cd	15.5d	28.9e	7.8d	104.0b	39	8.5c	62.4c	5.3e	11.3e	97	12.0d	207.3b	43
	PO4	72.2d	44.3d	279.6b	56.5d	12.8b	46.3e	68	27.4a	50.0c	28.7b	274.7c	52	91.3b	109.0c	48
	PO5	136.4a	48.8c	224.5c	195.5b	10.3c	65.7c	58	15.7b	80.9c	15.0c	185.0d	68	116.0a	260.0a	2
PH2	PO1	70.1a	100.9c	364.2a	449.4a	18.1a	176.9a	0	18.7a	156.3c	17.3a	502.7a	17	172.7a	325.3a	0
	PO2	39.3d	100.9c	13.2c	144.6d	3.1d	26.8d	84	11.2b	107.4c	16.3ab	94.0c	82	13.0d	180.3c	50
	PO3	59.4c	72.2d	12.5c	83.07e	3.4d	67.5c	61	8.2b	94.0c	11.0c	393.7c	36	8.3d	207.3c	43
	PO4	63.3b	150.9b	129.2b	422.2b	10.4c	70.2c	56	15.6a	280.2b	18.3a	428.7b	29	36.7b	192.3c	40
	PO5	64.3b	185.6a	131.0b	301.3c	12.1b	116.7b	30	17.7a	392.2a	14.7b	398.3b	34	136.3a	259.7b	0
PH3	PO1	67.0a	79.1a	142.2a	577.5a	15.7a	173.2a	0	13.6a	110.0bc	28.0a	571.7a	5	95.3a	258.0a	8
	PO2	55.7b	71.8b	15.6d	137.0d	4.5cd	67.9c	60	13.0a	48.4c	7.0c	280.3c	54	7.3c	134.0c	63
	PO3	48.0c	79.0a	9.3e	65.5e	3.6d	94.0b	47	7.9b	73.2bc	10.0b	403.3b	34	5.3c	252.0a	33
	PO4	37.1d	60.2c	90.0b	200.9b	6.0c	68.1c	59	6.8b	211.2a	10.3b	295.7c	51	10.0c	204.0b	44
	PO5	34.1d	52.5d	25.6c	187.6c	9.2b	64.1c	60	8.0b	167.4ab	7.7c	321.0c	48	62.0b	255.3a	17
CV (%)		2.49	2.52	3.03	1.14	9.86	3.55	-	16.23	35.45	7.69	11.45	-	10.34	10.76	-
F-test		**	**	**	**	**	**	-	**	**	**	**	-	**	**	-

WCE (%) indicates, % weed control efficiency; NS, indicates non-significant; **&***, indicates significance at 5% and 1% level of probability; CV (%), indicates the coefficient of variation. In a column, means with a similar letter(s) are significantly similar to each other. **Note:** These are averaged data of both (W-M-R and M-M-R) systems

Pre-emergence herbicides: **PH1:** No pre-emergence herbicides were applied; **PH2:** Pendimethalin applied at pre-emergence immediately after sowing; **PH3:** Oxadiazon applied at pre-emergence immediately after sowing

Post-emergence herbicides: **PO1:** No post-emergence was applied; **PO2:** Bispyribac-sodium was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO3:** Bispyribac + Pyrazosulfuron was applied at 15 DAS or 3-5 leaf stage of weeds; **PO4:** Fenaxoprop + Ethoxysulfuron was applied at 15 DAS or at 3-5 leaf stage of weeds; **PO5:** Fenoxoprop *fb* Halosulfuron was applied at 15 DAS or 3-5 leaf stage of weeds.

At 60 DAS

Similar to 35 DAS, the total density and dry weight of all weed species recorded at 60 DAS also significantly varied due to the sequential application of both pre- and post-emergence herbicides in both years. The results revealed that both pre- and post-emergence herbicides controlled all types of weeds. Although all herbicides showed their ability to control all types of weed in the first year, but less weed control ability was observed in the second year. However, with a little exception, the sequential application of pre-emergence herbicides in combination with post-emergence herbicides Bispyribac-sodium, Bispyribac + Pyrazosulfuron, Fenoxoprop + Ethoxysulfuron, and Fenoxoprop *fb* Halosulfuron controlled statistically similar and maximum weed density and dry weight as compared with control (no pre-emergence and no post-emergence) in first year. In the second year, Bispyribac + Pyrazosulfuron, Fenaxoprop + Ethoxysulfuron, and Fenoxoprop *fb* Halosulfuron controlled the maximum weed density and dry weight where no pre-emergence herbicide was applied, followed by Oxadiazon as pre-emergence in combination with the sole application of Bispyribac-sodium applied as post-emergence and Pendimethalin applied as pre-emergence in combination Bispyribac-sodium + Pyrazosulfuron applied as post-emergence (Table 27).

WCE (%) at 60 DAS

However, based on WCE (%), the maximum WCE (%) at 60 DAS was recorded with no pre-emergence herbicide in combination with Bispyribac-sodium + Pyrazosulfuron (WCE 97%) and Fenoxoprop *fb* Halosulfuron (WCE 68%) applied as post-emergence at 15 DAS. In the case of pre-emergence herbicides, Pendimethalin and Oxadiazon in combination with Bispyribac-sodium (WCE 82 and 54%), followed by pre-emergence herbicide Oxadiazon in combination with post-emergence herbicides Fenaxoprop + Ethoxysulfuron (WCE 51%) (Table 27).

At harvest

At harvest, only weed dry weight was recorded to know the effectiveness of all pre- and post-emergence herbicides up to harvesting. Although, all herbicides showed their ability to control all types of weed in the first season, but in the second season less activity was found. Both pre-emergence in combination with other post-emergence herbicides significantly reduced the maximum weed weight in the first season, but the minimum control efficiency was recorded in the second season. Among these herbicides, Pendimethalin and Oxadiazon in combination with Bispyribac-sodium applied as sole and in combination with Pyrazosulfuron reduced the maximum dry weight for all types of weed species (Table 27).

WCE (%) at harvest

The maximum WCE (%) at harvest was recorded in the sequential application of all pre-emergence herbicides in combination with Bispyribac-sodium as post-emergence controlled the maximum number of weeds in both years, followed by Fenoxoprop + Ethoxysulfuron and Bispyribac + Pyrazosulfuron (Table 27).

Kumar and Ladha (2011), Gathala *et al.* (2014), and Ahmed and Chauhan (2014 & 2015) noticed that the herbicides Pyrazosulfuron, Bispyribac-sodium, Fenoxaprop-ethyl, Penoxsulam, Fenoxaprop-ethyl+safner, Cyhalofop-butyl, Propanil, Azimsulfuron, Ethoxysulfuron, Triclopyr, 2,4-D ethyl ester, Carfentrazone, Chlorimuron+metsulfuron, Bispyribac + Azimsulfuron were found more effective to control all types of weeds when applied as post-emergence in ZT-DSR system. They also suggested that continuous use of a single herbicide on a long-term basis should be avoided; rather, it should be rotated with another herbicide with a different mode of action to avoid/delay resistance development. However, tank mixtures of herbicides have to be used when two or more herbicides are compatible to broaden the spectrum of weed control in such a way that each herbicide controls the weeds missed by

the other one. The herbicide mixtures listed above were found effective for better controlling a combination of weeds, including grasses, broadleaved, and sedges. Singh *et al.* (2006) and Mahajan and Chauhan (2013) suggested that if optimum conditions are not available for pre-emergence herbicides for controlling weeds in ZT-DSR, post-emergence herbicides may be a better option to manage weeds in DSR systems. Another study found that Bispyribac-sodium was similar to manual weeding in controlling weeds and increasing rice yield (Khaliq *et al.*, 2012).

While, many observations suggested that the use of herbicide mixtures is essential in response to changes in the structure of weed communities under dry-seeded rice (Maity and Mukherjee, 2008; Yaduraju and Mishra, 2012). Khaliq *et al.* (2012) conducted a field experiment in Pakistan, with three post-emergence herbicides (i.e., Bispyribac-sodium, Ethoxysulfuron ethyl and Penoxuslam) applied 15 DAS in dry direct-seeded rice, and reported that Bispyribac-sodium suppressed both the weed density (75%) and dry weight (80%) over control which was highest among all herbicides.

5.4.4 Effect of pre-and post-emergence herbicides and their interaction effect on the number of plants m⁻² and plant height of zero-till DSR Aman rice

5.4.4.1 Plants (no. m⁻²)

The number of plants m⁻² of ZT-DSR rice did not differ significantly in both years (Table 28). Numerically higher plant populations were recorded in the second year in most of the treatments and their combination with a little exception. In the case of pre-emergence herbicides, the highest number of plants were observed weedy check plot in the first year, however, in the second season, it was in the Oxadiazon applied plot, followed by the weedy check plot. In the case of post-emergence herbicides, a numerically higher plant was recorded

in the second year in all plots, while the highest plant population was recorded in Fenaxoprop + Ethoxysulfuron, followed by Bispyribac-sodium + Pyrazosulfuron, and no post-emergence applied plot (Table 28).

5.4.4.2 Plant height (cm)

At 30 DAS

The plant height of rice recorded at 30 DAS in both growing years was influenced significantly by all types of pre- and post-emergence herbicides. In the case of pre-emergence herbicides, Oxadiazon applied as pre-emergence produced the tallest plant in the first year; while in the second year, the tallest plant was recorded in the plot where no pre-emergence herbicides were applied. In the first season, the tallest and statistically similar plant height at 30 DAS was recorded in the plot where Fenaxoprop + Ethoxysulfuron was applied as post-emergence, which was statistically similar to Bispyribac-sodium and Bispyribac-sodium + Pyrazosulfuron and Fenoxoprop *fb* Halosulfuron. The tallest plant in the second rice season was recorded in the plot where Fenaxoprop + Ethoxysulfuron was applied as post-emergence, which was statistically similar to Fenoxoprop *fb* Halosulfuron, Bispyribac-sodium and Bispyribac-sodium + Pyrazosulfuron (Table 28).

At 60 DAS

The plant height of rice recorded at 60 DAS in both growing years was influenced significantly by all types of pre- and post-emergence herbicides. In the case of pre-emergence herbicides, Oxadiazon produced the tallest plant in the first year; while in the second year, the tallest plant was recorded in the plot where no pre-emergence herbicides were applied (Table 28).

Table 28. Plant population (no. m⁻²) and plant height at 30 DAS of ZT direct seeded rice are influenced by both pre-and post-emergence herbicides in both years

		Post-emergence herbicides						CV (%) (Pre-emergence herbicides)
Herbicides		No post-emergence	Bispyribac-sodium	Bispyribac-sodium + Pyrazosulfuron	Fenaxoprop + Ethoxysulfuron	Fenoxoprop fb Halosulfuron	Mean	
Plants (no. m ⁻²) in 2018								
Pre-emergence	No pre-emergence	323.7	324.0	325.7	327.3	326.7	325.5	6.49
	Pendimethalin	316.3	315.3	316.3	319.0	317.0	316.8	
	Oxadiazon	317.3	316.3	318.0	314.0	312.3	315.6	
	Mean	319.1	318.5	320.0	320.1	318.7		
	CV (%) (Interaction)	5.38						
F-test		NS						
Plants (no. m ⁻²) in 2019								
Pre-emergence	No pre-emergence	325.7	323.0	344.7	429.7	326.0	349.8	13.85
	Pendimethalin	339.7	240.3	306.7	381.3	306.7	314.9	
	Oxadiazon	363.3	335.3	366.0	437.7	302.0	360.9	
	Mean	342.9	299.6	339.1	416.2	311.6		
	CV (%) (Interaction)	14.99						
F-test		NS						
Plant height at 30 DAS (cm) in 2018								
Pre-emergence	No pre-emergence	34.3 b	38.3 b	40.3 a	38.3 c	37.0 b	37.7	2.42
	Pendimethalin	39.7 a	38.7 b	35.0 b	40.0 b	38.7 a	38.4	
	Oxadiazon	40.7 a	40.7 a	40.7 a	41.7 a	39.3 a	40.6	
	Mean	38.2	39.2	38.7	40.0	38.3		
	CV (%) (Interaction)	2.24						
F-test		**						
Plant height at 30 DAS (cm) in 2019								
Pre-emergence	No pre-emergence	41.3 a	42.7 a	39.7 ab	47.3 a	46.7 a	43.5	3.10
	Pendimethalin	37.7 b	36.7 b	37.7 b	43.7 b	43.0 b	39.7	
	Oxadiazon	37.0 b	41.7 a	41.0a	45.0ab	43.0 b	41.5	
	Mean	38.7	40.3	39.4	45.3	44.2		
	CV (%) (Interaction)	3.71						
F-test		**						

NS indicates non-significant; *&*** indicate significant at 5% and 1% levels of probability. In a column, means with the similar letter(s) are significantly similar with each other; *fb*; followed by. **Note:** These are averaged data of both (W-M-R and M-M-R) systems

Table 29. Plant height at 60 DAS and harvest of direct seeded rice are influenced by pre-and post-emergence herbicides in both years

Herbicides		Post-emergence herbicides				Mean	CV (%) (Pre-emergence herbicides)
		No post-emergence	Bispyribac-sodium	Bispyribac-sodium + Pyrazosulfuron	Fenaxoprop + Ethoxysulfuron		
Pre-emergence	Plant height at 60 DAS (cm) in 2018						
	No pre-emergence	97.0 b	98.0 b	101.0 a	102.3 a	96.0 b	98.9
	Pendimethalin	101.3 a	95.7 b	99.3 a	97.0 b	97.3 b	98.1
	Oxadiazon	99.0 ab	102.3 a	98.3 a	100.3 a	102.7 a	100.5
	Mean	99.1	98.7	99.6	99.9	98.7	
	CV (%) (Interaction)	1.57					
	F-test	**					
Pre-emergence	Plant height at 60 DAS (cm) in 2019						
	No pre-emergence	97.3 a	77.3 b	81.3 a	78.7 a	83.3 a	83.6
	Pendimethalin	78.3 b	85.7 a	85.7 a	78.7 a	81.3 a	81.9
	Oxadiazon	85.0 b	76.7 b	81.3 a	82.3 a	78.7 a	80.8
	Mean	86.9	79.9	82.8	79.9	81.1	
	CV (%) (Interaction)	5.44					
	F-test	**					
Pre-emergence	Plant height at harvest (cm) in 2018						
	No pre-emergence	109.3 b	128.0 a	131.7 a	121.3 b	128.3 a	123.7
	Pendimethalin	121.7 a	123.7 b	127.0 b	131.0 a	124.3 b	125.5
	Oxadiazon	119.0 a	127.3 a	131.0 a	123.0 b	125.3 ab	125.1
	Mean	116.7	126.3	129.9	125.1	126.0	
	CV (%) (Interaction)	1.45					
	F-test	**					
Pre-emergence	Plant height at harvest (cm) in 2019						
	No pre-emergence	97.0 b	107.8 a	109.0 a	106.3 a	103.3 ab	104.7
	Pendimethalin	100.2 a	87.6 c	99.3 b	105.4 a	103.1 b	99.1
	Oxadiazon	94.4 c	104.8 b	108.2 a	106.7 a	105.7 a	104.0
	Mean	97.2	100.1	105.5	106.2	104.0	
	CV (%) (Interaction)	1.18					
	F-test	**					

NS indicates non-significant; * & ** indicate significant at 5% and 1% levels of probability. In a column, means with the similar letter(s) are significantly similar with each other; fb; followed by. **Note:** These are averaged data of both (W-M-R and M-M-R) systems

In the first season, the tallest and statistically similar plant height at 60 DAS was recorded in the plot where Fenoxoprop + Ethoxysulfuron was applied as post-emergence, which was statistically similar with Bispyribac-sodium + Pyrazosulfuron, no post-emergence herbicides, Bispyribac-sodium and Fenoxoprop *fb* Halosulfuron. The tallest plant in the second year was recorded in no post-emergence applied plots, followed by Bispyribac-sodium + Pyrazosulfuron, Fenoxoprop + Ethoxysulfuron applied plots (Table 29).

At harvest

Plant height at harvest in both years differed significantly due to the application of pre-emergence herbicides applied immediately after sowing. In the first year, significantly similar and the tallest plant was recorded in both pre-emergence herbicides applied plots; while in the second year, the tallest plant was recorded in no pre-emergence herbicide applied plot, and the shortest plant was recorded in the plot where Pendimethalin was applied immediately after sowing (Table 29). In the case of post-emergence herbicides applied at 15 DAS in both years, the tallest plants were observed in the first season in all herbicide treatments. Among these post-emergence herbicides, the tallest plant was recorded in the plot where Bispyribac-sodium + Pyrazosulfuron was applied as post-emergence in the first year and Fenoxoprop + Ethoxysulfuron in the second year, followed by Bispyribac-sodium and Fenoxoprop *fb* Halosulfuron applied plots. The shortest plant was recorded in the control plot (Table 29).

In the case of sequential application of pre-and post-emergence herbicides, Oxadiazin in combination with other post-emergence herbicides produced the tallest plants in both years. However, Oxadiazin and no pre-emergence treatment in combination with Bispyribac-sodium + Pyrazosulfuron produced the tallest plant in the first season, followed by Bispyribac-sodium and Fenoxoprop *fb* Halosulfuron applied plots, and the shortest plant was recorded in control plot (Table 29).

5.4.6 Effect of pre-and post-emergence herbicides and their interaction effect on the yield and yield attributes of rice

5.4.6.1 Panicles (no. m⁻²)

The number of panicles m⁻² of rice was influenced significantly by the pre-emergence herbicides in both years. In 2018, the maximum number of panicles was recorded in the plots where Oxadiazon (162.7) and Pendimethalin (162.5) were applied, and the minimum number of panicles (133.2) was recorded in control plots (Table 30). In 2019, Pendimethalin produced the maximum number (139.4) of panicles m⁻² of rice and the minimum number of panicles m⁻² was recorded in Oxadiazon (95.3) applied plot. In the plots where post-emergence herbicides were applied the panicle number m⁻² was influenced significantly in both growing years. The highest panicle was observed in the plots where Bispyribac-sodium was applied in combination with Pyrazosulfuron (185.5), and the lowest panicle was found in the no post-emergence herbicides applied plot (113.8). The second highest number of panicle m⁻² was found in the Bispyribac-sodium applied plot, which was statistically similar to Fenoxoprop *fb* Halosulfuron (149.4) and Fenaxoprop + Ethoxysulfuron (131.4) (Table 30). The sequential application of pre-emergence herbicides in combination with post-emergence herbicides significantly influenced the number of panicles m⁻². However, in the first year, the sequential application of Oxadiazon as pre-emergence with Bispyribac-sodium (197.3) produced the maximum panicles m⁻², followed by only post-application of Bispyribac-sodium + Pyrazosulfuron (188.7) and combination of Oxadiazon as pre-emergence and Bispyribac-sodium + Pyrazosulfuron (184.7) as the post-emergence application (Table 30).

In the second year, the maximum number of panicles was recorded in Pendimethalin (139.4) applied plot and the minimum number of panicles m⁻² (95.3) was recorded in Oxadiazon applied plot (Table 30). In the case of post-emergence herbicides, the maximum panicles m⁻²

(167.0) was recorded in the plots where Bispyribac-sodium was applied in combination with Pyrazosulfuron (167.0), and the lowest panicles were found in the no post-emergence herbicides applied plot (61.4). The second highest panicle m^{-2} was found in the Bispyribac-sodium applied plot (125.6) (Table 30).

The sequential application of both pre-emergence herbicides in combination with post-emergence herbicides significantly influenced the number of panicles m^{-2} . However, singly (without the combination of pre-emergence herbicides) post-application of Bispyribac-sodium + Pyrazosulfuron produced the maximum panicles m^{-2} (217.3), followed by Pendimethalin as pre-emergence in combination with Fenoxoprop *fb* Halosulfuron (168.7) as the post-emergence application (Table 30).

The results in the study related to the findings of Khaliq *et al.* (2014), who reported that the number of panicles m^{-2} of rice increased significantly in the plots where weeds were controlled by different pre- and post-emergence herbicides. Singh *et al.* (2016) found the maximum numbers of effective tillers (398-446 m^{-2}) in the weed-free treatment and as expected, the minimum numbers of effective tillers (112-162 m^{-2}) were recorded in non-treated weedy plots. They also reported that the number of effective tillers m^{-2} of 375, 372, 368, and 363 are produced with the sequential application of Pendimethalin pre- *fb* Bispyribac-sodium + Azimsulfuron post-, pendimethalin pre- *fb* Bispyribac-sodium or Azimsulfuron post- and oxadiargyl pre- *fb* Bispyribac-sodium post-emergence, respectively, while single application of oxadiargyl pre-, Bispyribac-sodium post- and non-treated control produced a minimum number of 326, 307 and 112, respectively.

Table 30. Yield and yield attributes of ZT direct-seeded rice are influenced by both pre-and post-emergence herbicides in both years

		Post-emergence herbicides					Mean	CV (%) (Pre-emergence herbicides)
Herbicides		No post-emergence	Bispyribac-sodium	Bispyribac-sodium + Pyrazosulfuron	Fenaxoprop + Ethoxysulfuron	Fenoxoprop <i>fb</i> Halosulfuron		
Pre-emergence	Panicle m ⁻² in 2018							
	No pre-emergence	46.0 c	170.0 b	188.7 a	128.0 b	133.3 b	133.2	5.84
	Pendimethalin	157.0 a	184.0 a	183.3 a	153.7 a	134.7 b	162.5	
	Oxadiazon	138.3 b	197.3 a	184.7 a	112.7 c	180.3 a	162.7	
	Mean	113.8	183.8	185.5	131.4	149.4		
	CV (%) (Interaction)			4.97				
F-test				**				
Pre-emergence	Panicle m ⁻² in 2019							
	No pre-emergence	26.7 b	174.3 a	217.3 a	64.5 c	125 b	121.6	12.46
	Pendimethalin	120.0 a	142.7 b	133.8 b	131.7 a	168.7 a	139.4	
	Oxadiazon	37.7 b	59.7 c	150.0 b	150.0 b	79.3 c	95.3	
	Mean	61.4	125.6	167.0	115.4	124.3		
	CV (%) (Interaction)			12.14				
F-test				**				
Pre-emergence	Grains panicle ⁻¹ in 2018							
	No pre-emergence	166.0 b	185.0 b	192.3 a	191.7 a	177.7 b	182.5	6.45
	Pendimethalin	219.0 a	213.0 a	215.0 a	216.3 a	231.3 a	218.9	
	Oxadiazon	232.0 a	219.0 a	189.7 a	204.0 a	197.0 b	208.3	
	Mean	205.7	205.7	199.0	204.0	202.0		
	CV (%) (Interaction)			8.13				
F-test				**				
Pre-emergence	Grains panicle ⁻¹ in 2019							
	No pre-emergence	37.7 c	188.3 b	275.0 a	256.0 a	247.3 a	200.9	5.71
	Pendimethalin	205.0 a	206.7 ab	188.3 b	213.0 b	195.7 b	201.7	
	Oxadiazon	107.0 b	217.7 a	199.3 b	231.7 b	237.0 a	198.5	
	Mean	116.6	204.2	220.9	233.6	226.7		
	CV (%) (Interaction)			6.32				
F-test				**				

NS indicates non-significant; **&*** indicate significant at 5% and 1% levels of probability. In a column, means with the similar letter(s) are significantly similar with each other; *fb*; followed by

5.4.6.2 Number of grains panicle⁻¹

The number of grains panicle⁻¹ of ZT-DSR rice was also influenced significantly by the pre-emergence herbicides like the number of panicle m⁻² in both years. In the first year, as compared with no pre-emergence herbicide, a higher and statistically similar number of grains panicle⁻¹ were recorded in the plots where Pendimethalin (218.9) and Oxadiazon (208.3) were applied as pre-emergence. While, in the second year, Pendimethalin produced the maximum number of grains panicle⁻¹ (201.7), followed by no pre-emergence herbicide (200.9) (Table 30).

Post-emergence herbicides also significantly influenced the number of grains panicle⁻¹ in both years. In the first year, the maximum and a similar number of grains were recorded in both no post-emergence (205.7) and Bispyribac-sodium (205.7) applied plots, followed by Fenoxoprop + Ethoxysulfuron (204.0). The results indicate that post-emergence herbicides especially Fenoxoprop + Ethoxysulfuron and Fenoxoprop *fb* Halosulfuron found better than Bispyribac-sodium + Pyrazosulfuron. The decreasing trend of the number of grains panicle⁻¹ in Bispyribac-sodium + Pyrazosulfuron was their phototoxic effect, which ultimately decreased the number of grains panicle⁻¹ (Table 30). The assumption of our present study related to the phytotoxic also supported by Rodrigues and Almeida (2005), and Petter *et al.* (2013), who reported that the phytotoxic effect characterized by chlorosis is typical of herbicides with physiological action by limiting the metabolism of plants. They found more phototoxic effects in the plot where Bispyribac-sodium was applied. In the second year, the maximum number of grains panicle⁻¹ was recorded in the plots where Fenoxoprop + Ethoxysulfuron was applied as post-emergence (233.6), followed by Fenoxoprop *fb* Halosulfuron (226.7). The minimum number of grains panicle⁻¹ was recorded in the control plot (116.6) (Table 30).

The sequential use of pre-and post-emergence herbicides influenced significantly the grains panicle⁻¹ of ZT-DSR rice. However, the highest grains panicle⁻¹ was found in the plots where two pre-emergence herbicides (Oxadiazon and Pendimethalin) were applied in

combination with four post-emergence herbicides. In the first year, statistically similar and maximum grains panicle⁻¹ was recorded in pre-emergence herbicide Oxadiazon in combination with no post-emergence herbicide (232.0) and Pendimethalin applied as pre-emergence in combination with Fenoxoprop *fb* Halosulfuron (231.3) applied plot. While in the second year, the statistically similar and maximum number of grains panicle⁻¹ was recorded in combination with no pre-emergence herbicides followed by Bispyribac-sodium + Pyrazosulfuron (275.0), Fenaxoprop + Ethoxysulfuron (256.0), and Fenoxoprop *fb* Halosulfuron (247.3) applied as post-emergence plots (Table 30). The lower number of grains in panicle⁻¹ was recorded in the weedy check plot in both years (Table 30). A similar result was also found by Singh *et al.* (2015), who conducted a field experiment in Madhuban and Taraori of India, and reported that compared with the weedy check, the number of grains panicle⁻¹ was higher by 84-137% and 87-144% with herbicide treatments, respectively. The increase in the number of grains panicle⁻¹ was more in the case of sequential applications of pre-*fb* post compared to single pre or post.

5.4.6.3 1000-grain weight (g)

Two pre-emergence herbicides did not influence the 1000-grain weight in all treatments in both years (Table 31). Similar to pre-emergence herbicides, post-emergence herbicides also did not influence the 1000-grain weight of ZT-DSR rice. In the first season, numerically higher 1000-grain weight was observed in the plots where no post-emergence herbicide was applied (24.0), Bispyribac-sodium + Pyrazosulfuron, Fenaxoprop + Ethoxysulfuron and Fenoxoprop *fb* Halosulfuron applied plots (23.9). In the second year, Fenoxoprop *fb* Halosulfuron (23.7), and Bispyribac-sodium + Pyrazosulfuron (23.1) produced the maximum 1000-grain weight (Table 31).

The sequential use of pre-and post-emergence herbicides also did not differ significantly for 1000-grain weight in ZT-DSR rice. In first year, the sequential use of pre-emergence

herbicide Oxadiazon in combination with no post-emergence (25.0), Fenoxoprop + Ethoxysulfuron (24.3), Bispyribac-sodium (24.0), Bispyribac-sodium + Pyrazosulfuron (24.0) and Fenoxoprop *fb* Halosulfuron (24.0) produced the higher and statistically similar 1000-grain weight. In the case of the second year, post-emergence herbicide Fenoxoprop *fb* Halosulfuron (24.3) produced the maximum 1000-grain weight without the combination of pre-emergence herbicide, followed by no pre-emergence herbicide in combination with Bispyribac-sodium + Pyrazosulfuron (23.7) applied plot (Table 31).

Sequential use of two pre-emergence herbicides (Oxadiazon and Pendimethalin) applied immediately after rice seeding with post-emergence Fenoxoprop + Ethoxysulfuron and Bispyribac-sodium produced numerically higher 1000-grain weight followed by Bispyribac-sodium + Pyrazosulfuron and Fenoxoprop *fb* Halosulfuron applied at 15 DAS in both years (Table 31). The results of the study related to the 1000-grain weight of ZT-DSR rice increased significantly in the plots where weeds were controlled by different pre-and post-emergence herbicides also supported by Khaliq *et al.* (2014) and Singh *et al.* (2016).

Table 31. Yield and yield attributes of zero-till direct seeded rice are influenced by both pre-and post-emergence herbicides in both years

		Post-emergence herbicides					Mean	CV (%) (Pre-emergence herbicides)
Herbicides		No post-emergence	Bispyribac-sodium	Bispyribac-sodium + Pyrazosulfuron	Fenaxoprop + Ethoxysulfuron	Fenoxoprop <i>fb</i> Halosulfuron		
Pre-emergence	1000-grain weight (g) in 2018							
	No pre-emergence	23.0 c	23.7 a	24.0 a	23.7 a	23.7 a	23.6	2.76
	Pendimethalin	24.0 b	23.3 a	23.7 a	24.0 a	23.7 a	23.7	
	Oxadiazon	25.0 a	24.0 a	24.0 a	24.0 a	24.3 a	24.3	
	Mean	24.0	23.7	23.9	23.9	23.9		
	CV (%) (Interaction)			1.87				
F-test			**					
Pre-emergence	1000-grain weight (g) in 2019							
	No pre-emergence	13.0 c	23.0 a	23.7 a	23 a	24.3 a	21.4	5.73
	Pendimethalin	22.7 a	22.7 a	22.3 a	22.3 a	23.3 a	22.7	
	Oxadiazon	20.7 b	22.7 a	23.3 a	23.0 a	23.3 a	22.6	
	Mean	18.8	22.8	23.1	22.8	23.7		
	CV (%) (Interaction)			3.18				
F-test			**					
Pre-emergence	Grain yield (t/ha) in 2018							
	No pre-emergence	1.6c	4.3a	4.4a	4.8a	3.8b	3.8b	4.56
	Pendimethalin	1.6c	3.9c	5.3a	4.7a	5.1a	4.1ab	
	Oxadiazon	1.7c	4.9a	5.0a	4.9a	4.6a	4.2ab	
	Mean	1.6b	4.4ab	4.9a	4.8a	4.5a		
	CV (%) (Interaction)			15.49				
F-test			**					
Pre-emergence	Grain yield (t/ha) in 2019							
	No pre-emergence	1.5c	4.6a	4.1ab	3.8b	4.3a	3.8b	6.12
	Pendimethalin	2.4c	5.2a	4.6a	4.2b	4.7a	4.2b	
	Oxadiazon (Ronstar)	1.5c	4.8a	4.7a	4.5a	3.9b	3.8b	
	Mean	1.8	4.9	4.4	4.2	4.3		
	CV (%) (Interaction)			9.31				
F-test			**					

NS indicates non-significant; **&*** indicate significant at 5% and 1% levels of probability. In a column, means with a similar letter(s) are significantly similar with each other; *fb*; followed by

5.4.6.4 Grain yield (kg ha⁻¹)

The grain yield of ZT-DSR rice differed significantly by two pre-emergence herbicides. Among the two pre-emergence herbicides, Oxadiazon was applied plot produced a higher grain yield as compared to Pendimethalin (Table 31). Among the herbicides, the highest grain yield in both years was found in the sequential use of pre-emergence herbicide Pendimethalin applied immediately after rice seeding followed by the application of post-emergence herbicides ‘Bispyribac Sodium + Pyrazosulfuron’ (5.3 t ha⁻¹ in the first year) and ‘Bispyribac-sodium’ (5.2 t ha⁻¹ in second year). The results in these studies related to the previous studies where the grain yield of ZT-DSR rice increased significantly in the plots where weeds were controlled by different pre-and post-emergence herbicides (Khaliq *et al.*, 2014; Singh *et al.*, 2016; Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015). Earlier researchers also reported that herbicides that are effective for post-emergence weed control in the dry-ZT-DSR system are Pyrazosulfuron, Bispyribac-sodium, Fenoxaprop-ethyl, Penoxsulam, Fenoxaprop-ethyl+safner, Cyhalofop-butyl, Propanil, Azimsulfuron, Ethoxysulfuron, Triclopyr, 2,4-D ethyl ester, Carfentrazone, Chlorimuron+metsulfuron, Bispyribac + Azimsulfuron (Kumar and Ladha, 2011; Gathala *et al.*, 2014; Ahmed and Chauhan, 2014, 2015; Hossain *et al.*, 2019).

5.4.6.5 Straw yield (t ha⁻¹)

The straw yield of ZT-DSR rice differed significantly by two pre-emergence herbicides. However, in both years, Pendimethalin applied as pre-emergence produced the highest straw yield (5.4 and 4.0 t ha⁻¹) as compared to Oxadiazon (4.9 and 3.6 t ha⁻¹) in both years (Table 32). Similar to the pre-emergence herbicides, the post-emergence herbicides also influenced the straw yield of ZT-DSR rice significantly in both years. All post-emergence herbicides applied plots showed the highest and statistically similar biomass yield as compared with no-post-emergence herbicides applied plots (Table 32). Among these herbicides, the statistically similar

and maximum straw yield was recorded in the plots where both Bispyribac Sodium + Pyrazosulfuron (6.1 and 4.4 t ha⁻¹) and Bispyribac Sodium (6.0 and 4.4 t ha⁻¹) were applied as post-emergence. The lowest straw yield (2.2 and 2.3 t ha⁻¹) was recorded in the control (no post-emergence) plot (Table 32). The sequential use of pre- and post-emergence herbicides significantly influenced the straw yield of ZT-DSR rice. The highest straw yield was recorded in the sequential use of Pendimethalin applied immediately after rice seeding with Bispyribac-sodium + Pyrazosulfuron (7.1 and 5.4 t ha⁻¹) in both years, which was statistically similar to the sequential use of pre-emergence herbicide Oxadiazon in combination with Bispyribac-sodium (6.9 t ha⁻¹) in the first year and no pre-emergence in combination with Bispyribac-sodium (5.2 t ha⁻¹) in the second year (Table 32). The straw yield of ZT-DSR rice increased significantly in the plots where weeds were controlled by sequential use of different pre-and post-emergence herbicides also supported by Khaliq *et al.* (2014), Singh *et al.* (2016), Kumar and Ladha (2011); Gathala *et al.* (2014); Ahmed and Chauhan (2014, 2015).

Table 32. Yield and yield attributes of zero-till direct seeded rice are influenced by both pre-and post-emergence herbicides in both years

		Post-emergence herbicides					Mean	CV (%) (Pre-emergence herbicides)
		Herbicides	No post-emergence	Bispyribac-sodium	Bispyribac-sodium + Pyrazosulfuron	Fenaxoprop + Ethoxysulfuron		
Pre-emergence	Straw yield (t ha ⁻¹) in 2018							
	No pre-emergence	1.5 b	5.1 b	4.8 b	3.8 b	5.2 a	4.1	11.93
	Pendimethalin	2.2 ab	6.1 a	7.1 a	5.9 a	6.01 a	5.4	
	Oxadiazon	2.9 a	6.9 a	6.4 a	4.4 b	3.7 b	4.9	
	Mean	2.2	6.0	6.1	4.7	5.0		
	CV (%) (Interaction)	10.95						
F-test	**							
Pre-emergence	Straw yield (t ha ⁻¹) in 2019							
	No pre-emergence	1.6 b	5.2 a	4.4 b	3.5 a	3.5 a	3.6	9.85
	Pendimethalin	2.5 a	4.5 b	5.4 a	3.8 a	3.8 a	4.0	
	Oxadiazon	2.8 a	4.5 ab	3.4 c	3.8 a	3.5 a	3.6	
	Mean	2.3	4.7	4.4	3.7	3.6		
	CV (%) (Interaction)	11.10						
F-test	**							
Pre-emergence	Harvest index (%) in 2018							
	No pre-emergence	50.4 a	45.6 a	48 a	55.9a	42 b	48.4	8.52
	Pendimethalin	41.8 b	39 b	42.7 a	44.3 b	46.1 b	42.8	
	Oxadiazon	36.8 b	42.5 ab	43.6 a	52.6 a	55.5 a	46.2	
	Mean	43.0	42.3	44.8	50.9	47.9		
	CV (%) (Interaction)	8.19						
F-test	**							
Pre-emergence	Harvest index (%) in 2019							
	No pre-emergence	48.1 a	46.9 b	51.8 a	52.1 a	55.4 a	50.9	3.66
	Pendimethalin	49.2 a	53.6 a	45.8 b	52.7 a	55.3 a	51.3	
	Oxadiazon	35.6 b	51.5 a	54.8 a	54.3 a	52.4a	49.7	
	Mean	44.3	50.7	50.8	53.0	54.4		
	CV (%) (Interaction)	3.68						
F-test	**							

NS indicates non-significant; * & *** indicate significant at 5% and 1% levels of probability. In a column, means with a similar letter(s) are significantly similar with each other; *fb*; followed by

5.4.6.6 Harvest Index (%)

The harvest index of ZT-DSR rice differed significantly by two pre-emergence herbicides. Among the two pre-emergence herbicides, the highest harvest index was recorded in the first year where no pre-emergence herbicide (48.4), while in the second year, the maximum harvest index was recorded in Pendimethalin (51.3) applied plot (Table 32). Similar to the pre-emergence herbicides, the post-emergence herbicides also influenced the harvest index of ZT-DSR rice. With a little exception, all post-emergence herbicides showed the highest and statistically similar harvest index as compared with control plots (Table 32). The sequential use of pre- and post-emergence herbicides significantly influenced the harvest index of ZT-DSR rice.

In the first year, the highest harvest index was recorded in the plot where Fenoxoprop + Ethoxysulfuron (55.9) was applied without the combination of pre-emergence herbicides, followed by Oxadiazon applied as pre-emergence in combination with Fenoxoprop *fb* Halosulfuron (55.5) as post-emergence (Table 32). In the second year, Fenoxoprop *fb* Halosulfuron (55.4) produced the highest harvest index without the combination of pre-emergence herbicide, followed by the combination of Pendimethalin with Fenoxoprop *fb* Halosulfuron (55.3) (Table 32). The harvest index of ZT-DSR rice increased significantly in the plots where weeds were controlled by sequential use of different pre-and post-emergence herbicides also supported by Khaliq *et al.* (2014), Singh *et al.* (2016), Kumar and Ladha (2011), Gathala *et al.* (2014), Ahmed and Chauhan (2014, 2015).

5.4.7 Economic performance of pre-and post-emergence herbicides for weed control in zero-till direct-seeded rice

From the economic point of view, the maximum net benefit was recorded in the plot, where Pendimethalin was applied as pre-emergence in combination with Bispyribac + Pyrazosulfuron (two years' average 100179 Tk. ha⁻¹) applied as post-emergence, followed by Oxadiazon as pre-emergence in combination with the sole application of Bispyribac-sodium (two years' average 95873 Tk. ha⁻¹) and Fenaxoprop + Ethoxysulfuron (92291 Tk. ha⁻¹) were applied as post-emergence, while the minimum net benefit (two years' average 15439 Tk. ha⁻¹) was recorded in weedy check plots in both years (Table 33).

Table 33. The economic study of pre-and post-emergence herbicides for controlling weeds in zero-till direct seeded rice in both years

Treatments		Cost of controlling weeds (Tk. ha ⁻¹)		Gross return after controlling weeds (Tk. ha ⁻¹)		Net benefit after controlling weeds (Tk. ha ⁻¹)		Overall benefit after controlling weeds in both years (Tk. ha ⁻¹)
		2018	2019	2018	2019	2018	2019	
PH1	PO1	24861	24861	41500	39100	16639	14239	15439
	PO2	28227	28227	112600	119300	84373	91073	87723
	PO3	26896	26896	114800	121900	87904	95004	91454
	PO4	26809	26809	123800	99800	96991	72991	84991
	PO5	31549	31549	100200	111300	68651	79751	74201
PH2	PO1	27736	27736	42200	61600	14464	33864	24164
	PO2	31192	31192	103600	133900	72408	102708	87558
	PO3	29771	29771	139600	120300	109829	90529	100179
	PO4	29684	29684	123400	109700	93716	80016	86866
	PO5	34424	34424	133510	122600	99086	88176	93631
PH3	PO1	27911	27911	45400	39200	17489	11289	14389
	PO2	31277	31277	129400	124900	98123	93623	95873
	PO3	29946	29946	131400	107500	101454	77554	89504
	PO4	29859	29859	126900	117400	97041	87541	92291
	PO5	34599	34599	118700	102100	84101	67501	75801

Pre-emergence herbicides: **PH1:** No pre-emergence herbicides, 24861Tk; **PH2:** Pendimethalin, 2525tk; **PH3:** Oxadiazon, 27911Tk

Post-emergence herbicides: **PO1:** No post emergence, 0tk; **PO2:** Bispyribac-sodium, 3366Tk; **PO3:** Bispyribac + Pyrazosulfuron, 2035Tk; **PO4:** Fenaxoprop + Ethoxysulfuron, 1948Tk; **PO5:** Fenoxoprop *fb* Halosulfuron, 6688

Labour wage: 350 labour⁻¹day⁻¹, Herbicide application cost (Tk.): 1 labour ha⁻¹ round⁻¹ @ 350 labour⁻¹ day⁻¹, Irrigation cost (Tk.): 8 labours ha⁻¹ for 4 times irrigation in both years @ 350 labour⁻¹ day⁻¹, Harvest and post-harvest processing cost (Tk.): 45 labours ha⁻¹@ 350 labour⁻¹day⁻¹; sowing cost (Direct-seeded zero-till machine): 3743

The market price of rice grain (Tk. kg⁻¹): 25.0 and straw: 1.0.

Gross return = {grain yield (t ha⁻¹) × market price (Tk t ha⁻¹)} + {straw yield (t ha⁻¹) × market price (Tk t ha⁻¹)}, Net benefit = Gross income – Cost of production.

5.5 Conclusion

Results of the two-year study showed that all weeds were effectively controlled by the sequential use of pre- and post-emergence herbicides. Considering plant growth, yield and yield attributing of direct seeded *Aman* rice, all parameters were significantly influenced by the application of pre-emergence herbicides (Pendimethalin, Oxadiazon) immediately after rice seeding followed by post-emergence herbicides (sole application of Bispyribac-sodium, Bispyribac-sodium + Pyrazosulfuron, Fenoxoprop + Ethoxysulfuron, Fenoxoprop *fb* Halosulfuron) applied at 15 DAS (days after seeding). Among the herbicides, the highest grain yield in both years was found in the sequential use of pre-emergence herbicide Pendimethalin applied immediately after rice seeding followed by the application of post-emergence herbicides 'Bispyribac Sodium + Pyrazosulfuron' (5.3 t ha^{-1} in the first year) and 'Bispyribac-sodium' (5.2 t ha^{-1} in second year). From the economic point of view, the maximum net benefit was recorded in the plot, where Pendimethalin was applied as pre-emergence in combination with Bispyribac + Pyrazosulfuron (two years' average $100179 \text{ Tk. ha}^{-1}$) applied as post-emergence, followed by Oxadiazon as pre-emergence in combination with the sole application of Bispyribac-sodium (two years' average $95873 \text{ Tk. ha}^{-1}$). Based on the two years of yield and the economic benefit, the sequential application of Pendimethalin and Oxadiazon as pre-emergence immediately after sowing of rice seeding in combination with Bispyribac + Pyrazosulfuron or Fenoxoprop + Ethoxysulfuron or sole application of Bispyribac Sodium as post-emergence may be recommended for weed control in ZT DSR *Aman* rice.

CHAPTER 6

SUMMARY, CONCLUSION AND RECOMMENDATION

From the above discussion, it is confirmed that weed infestation is the major challenge in the CA-based crop production system, where almost 16 to 42 % yield reduction occurs due to weed infestation, and one-third of the total cost of cultivation is spent on weeding. An average of 13.1% of crop reproduced is actually lost in the farmers' fields even after adopting traditional weed control in Bangladesh. Therefore, proper weed management is considered one of the most important prerequisites in CA-based W-M-R and M-M-R cropping systems to ensure higher crop yield. Higher weed pressure in dry-seeded rice lowers the economic returns, and in extreme cases, it causes complete failure of the rice crop. Hence, judicious weed management in a CA-based system is a critical factor for securing and sustaining food security in developing countries including rice-based cropping systems in South Asia. While, the number of repetitive tillage operations increases the cost of cultivation, and fuel consumption and delays planting in two ways repetitive tillage operations are followed by manual sowing. After post-seeding wheat, rice and maize growers are facing major challenges in weed management due to the lack of pre- and post-emergence herbicides in the region.

The traditional weed management in wheat, rice and maize systems after 30-35 DAS generally farmers control the weeds with hand weeding which further consumed more labour or is sometimes usually reluctant to control weeds in a wheat field. However, sometimes they weeded by hand, which proves uneconomical due to increasing labour wages as well as lack of labour due to migration from the villages to urban areas for better livelihood. The hand labour-based wedding in many developing countries consumes up to half of the total labour demand. Therefore, CA-based new agronomic management practices are advocating to overcome these challenges. The ZT/permanent beds or till the soil with fresh beds-based crop production is an alternate

option through mechanized precision planting in a single pass. However, the CA-based crop management techniques are faced with the major concern of weed management initially. To address the weed management problems in CA-based wheat, rice and maize production under no-till systems with different chemical weed control is a potential means for controlling weeds and is more economical compared to hand weeding. Now some herbicides are available in the market which are needed for validation for controlling weeds. However, information on herbicide efficacy in wheat is sporadic or lacking in Bangladesh.

It is well known that weeds limit crop production by competing with crops for their essential resource of variations like space, light, water, nutrients, etc. While weed infestation is higher in the CA system as compared with the conventional system due to a lack of tillage in the CA-based system. In Bangladesh, CA-based crop production is at the initial stage, and there is a lack of available herbicides in the market for controlling weeds in the system.

The use of pre-and-post-emergence herbicides makes herbicidal weed control more acceptable to farmers which does not change the existing agronomic practices but allows for complete control of weeds. The usage of pre-emergence herbicides assumes greater importance because of their effectiveness from the initial stages. Pre-emergence application of herbicides controlled the weeds based on the crop species and after that post-emergence application is given so that further growth of weeds is also controlled. Pre-emergence and post-emergence herbicides are ideal means for controlling the weeds because of the economics and effectiveness in wheat, maize and rice. However, information on the efficacy and economics of different pre-and post-emergence herbicides used alone or sequentially in the CA-based ZT-DSR rice, wheat and maize production system is still sporadic or lacking in Bangladesh.

Considering the important issue for crop production under CA-based system, several studies were conducted to know the efficacy and economics of different pre-and post-emergence herbicides in CA-based zero-till wheat, maize and rice under wheat-mungbean-rice

(W-M-R) and maize-mungbean-rice (M-M-R) cropping systems in consecutive two years of 2017-18 and 2018-19. This observation consisted of three experiments: Expt. 1. Efficacy and Economics of Different Post-Emergence Herbicides for Controlling Weeds in Wheat under Zero-Till Condition; Expt. 2. Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in Maize under Zero-Till Condition and Expt. 3. Efficacy and Economics of Different Pre-and Post-Emergence Herbicides for Controlling Weeds in Zero-Till Direct Seeded Aman rice. Treatments of the first experiment were: Ready-mix formulation (Sulfosulfuron+Metsulfuron); Ready-mix formulation (Mesosulfuron + Idosulfuron); Pinoxaden; Ready-mix formulation (Carfentrazone + Isoproturon); Pinoxaden + Metsulfuron; Pinoxaden + Carfentrazone; Halosulfuron; Halosulfuron + Pinoxaden; Weedy Check and Weed free. All these treatments were arranged in a RCBD and repeated all treatments in three times. After two years of observation, the results of the study revealed that the highest yield ($4860.0 \text{ kg ha}^{-1}$) was recorded in weed-free treatment in the first season, which was statistically similar to Pinoxaden + Metsulfuron in both years (4643.33 and 5683.33 ha^{-1} , respectively), and the lowest grain yield was recorded in the weedy check in both years (2595 and 3880 ha^{-1} , respectively). From an economic point of view, the maximum net benefit (Tk.ha⁻¹) in the first year was recorded in Pinoxaden + Metsulfuron treatment ($121386 \text{ Tk.ha}^{-1}$), but in the second season, the maximum benefit was recorded in Halosulfuron + Pinoxaden ($212578 \text{ Tk.ha}^{-1}$). Therefore, both combinations of these herbicides may be recommended for weed control in wheat under irrigated conditions.

In 2nd experiment, treatments were three pre-emergence herbicides (i.e., PH1: No pre-emergence; PH2: Pendimethalin and PH3: Atrazine and six post-emergence herbicides (i.e., PO1: No post-emergence; PO2: Atrazine; PO3: Tembotrione; PO4: Halosulfuron; PO5: Tembotrione + Atrazine and PO6: Halosulfuron + Atrazine. All treatments were arranged in a split-plot design and repeated all treatments in three times. After two years of observation, the

findings of the study revealed that the sequential use of pre- and post-emergence herbicides significantly influenced the grain yield of zero-till maize. In the first season, the highest grain yield (13.9 t ha^{-1}) was recorded in the sequential application of Pendimethalin applied immediately after maize seeding with post-emergence herbicides Tembotrione + Atrazine applied at 15 DAS. On the other hand, in the second season, the sequential application of Atrazine applied immediately after maize seeding with post-emergence herbicides Tembotrione (17.2 t ha^{-1}) applied at 15 DAS, which was statistically similar to the application of Tembotrione + Atrazine (16.6 t ha^{-1}) applied as post-emergence and the lowest was recorded in the control plot (10.9 t ha^{-1}). From the economic point of view, the maximum net benefit (two years' average) was recorded from Pendimethalin & Atrazine (both as pre-emergence) and Atrazine (as post-emergence) (367807 & $362907 \text{ Tk. ha}^{-1}$) applied plots, followed by Pendimethalin & Atrazine (both as pre-emergence) and Tembotrione + Atrazine (as post-emergence) (362582 & $363832 \text{ Tk. ha}^{-1}$), while the minimum net benefit ($258907 \text{ Tk. ha}^{-1}$) was recorded in weedy check treatment. Therefore, sequential use of pre-emergence herbicides Pendimethalin and Atrazine applied immediately after maize seeding with post-emergence herbicides Atrazine, Tembotrione, applied at 15 DAS may be recommended for weed control as well as higher grain yield of zero-till maize.

In 3rd experiment, treatments of three pre-emergence herbicides (i.e., PH1: No pre-emergence; PH2: Pendimethalin and PH3: Oxadiazon), and five post-emergence herbicides (i.e., PO1: No post-emergence; PO2: Bispyribac-sodium; PO3: Bispyribac-sodium+Pyrazosulfuron; PO4: Fenoxoprop + Ethoxysulfuron and PO5: Fenoxoprop *fb* Halosulfuron. All treatments were arranged in a split-plot design and repeated all treatments in three times. Results of the two-year study showed that all weeds were effectively controlled by the sequential use of pre- and post-emergence herbicides. Considering plant growth, yield and yield attributing of direct seeded *Aman* rice, all parameters were significantly influenced by the

application of pre-emergence herbicides (Pendimethalin, Oxadiazon) immediately after rice seeding followed by post-emergence herbicides (sole application of Bispyribac-sodium, Bispyribac-sodium + Pyrazosulfuron, Fenaxoprop + Ethoxysulfuron, Fenoxoprop *fb* Halosulfuron) applied at 15 DAS (days after seeding). Among the herbicides, the highest grain yield in both years was found in the sequential use of pre-emergence herbicide Pendimethalin applied immediately after rice seeding followed by the application of post-emergence herbicides 'Bispyribac Sodium + Pyrazosulfuron' (5.3 t ha⁻¹ in the first year) and 'Bispyribac-sodium' (5.2 t ha⁻¹ in second year). From the economic point of view, the maximum net benefit was recorded in the plot, where Pendimethalin was applied as pre-emergence in combination with Bispyribac + Pyrazosulfuron (two years' average 100179 Tk. ha⁻¹) applied as post-emergence, followed by Oxadiazon as pre-emergence in combination with the sole application of Bispyribac-sodium (two years' average 95873 Tk. ha⁻¹).

Based on the two years of yield and economic benefits, the combination of herbicides Pinoxaden + Metsulfuron and Halosulfuron + Pinoxaden may be recommended for weed control in wheat under zero-tillage conditions. In the case of zero-till maize, sequential application of Pendimethalin and Atrazine applied as pre-emergence immediately after sowing of maize in combination with sole Atrazine or combination with Tembotrione + Atrazine as post-emergence may be recommended for weed control in the zero-till maize field. While, in zero-till DSR rice, the sequential application of Pendimethalin and Oxadiazon as pre-emergence immediately after sowing of rice seeding in combination with Bispyribac + Pyrazosulfuron or Fenaxoprop + Ethoxysulfuron or sole application of Bispyribac Sodium as post-emergence may be recommended for weed control in ZT DSR Aman rice.

CHAPTER 7

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CHAPTER 8

APPENDICES

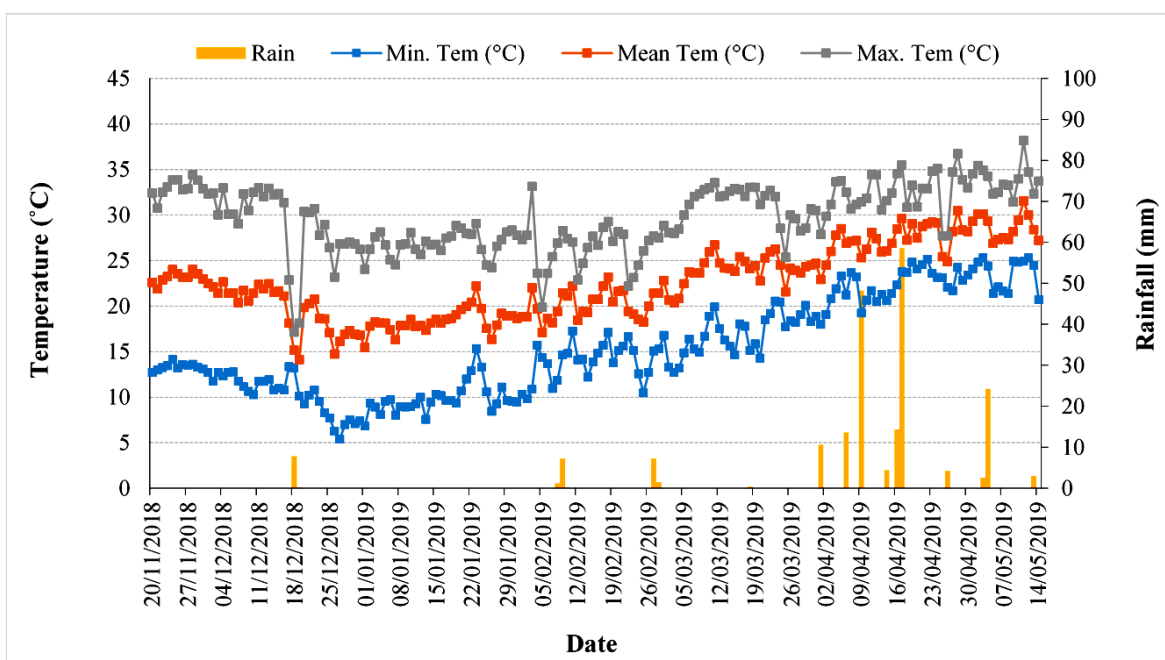
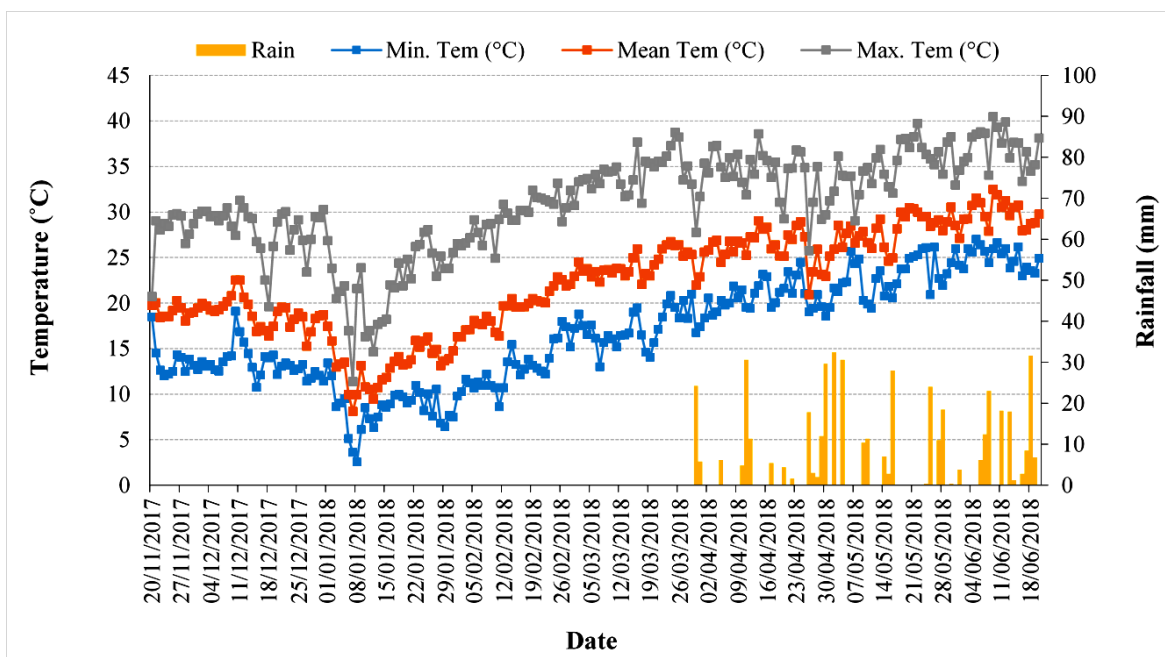
Appendix 1. Year-wise work plan to complete the proposed research

Activity	First-year		2nd year	
	Started	Finished	Started	Finished
Expt. 1. Efficacy and economics of different post-emergence herbicides for controlling weeds in zero-till wheat	Nov. 2017	Mar. 2018	Nov. 2018	Mar. 2019
Expt. 2. Efficacy and economics of different pre-and post-emergence herbicides for controlling weeds in strip-till maize.	Dec. 2017	May 2018	Dec. 2018	May 2019
To increase the fertility status of the soil, mungbean was incorporated between the two cereals of the W–M–R and M-M-R cropping systems	Mar.(W-M-R)/ May (M-M-R) 2018	Jun.(W-M-R)/ Aug. (M-M-R) 2018	Mar. (W-M-R)/ May (M-M-R) 2019	Jun. (W-M-R)/ Aug. (M-M-R) 2019
Expt. 3. Efficacy and economics of different pre-and post-emergence herbicides for controlling weeds in zero/direct seeded Aman rice	Jun.(W-M-R)/ Aug.(M-M-R) 2018	Oct.(W-M-R)/ Dec.(M-M-R) 2018	Jun.(W-M-R)/ Aug.(M-M-R) 2019	Oct.(W-M-R)/ Dec.(M-M-R) 2019
Data processing & analysis	Dec. 19		Feb. 20	
Thesis writing	Mar. 20		Aug. 22	
Submission & Presentation	September 2022			

Appendix 2. Initial soil physical and chemical properties at the experiment site

Soil depth	pH	Total N	Ext P	K	Ext S	Ext Zn	Ext B	Soil texture (%)		
		(%)	(mg/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/ kg)	Sand	Silt	Clay
0 -15	4.9	0.07	44.9	0.14	21	1.54	0.32	55	28	17
15- 30	5.4	0.06	16.8	0.09	12	0.71	0.16	48	27	25
30 - 60	5.7	0.03	1.30	0.08	13	0.19	0.12	53	23	24
60-90	5.6	0.03	2.80	0.05	20	0.20	0.13	70	19	11
90-120	5.5	0.02	29.3	0.03	30	0.22	0.13	76	18	6
120-150	5.6	0.01	23.6	0.03	18	0.17	0.02	90	8	2
150-180	5.7	0.01	26.0	0.02	9	0.09	0.01	94	5	1

Methods used for analysis of the experimental soil: pH_(1.5) (ISO, 2005); bicarbonate -extractable P (Colwell, 1963); extractable K (Thomas and Allison, 1975); P- extractable S (Fox *et al.*, 1964); DTPA extractable Zn (Lindsay and Norvell, 1978); hot-water extractable B (Bingham,1982); USDA particle size distribution (Sochan *et al.*, 2012).



Appendix 3. Weather conditions during Rabi season of 2017-2018 and 2018-2019

Appendices for herbicide options for weed management in zero-till wheat

APPENDIX 4. Mean square values for density and dry weight of grass recorded at 45 DAS in zero-till wheat fields in both years

Source of variation	df	Density of grass weeds		Dry weight of grass weeds	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	27.3000	10.5333	0.1030	0.0863
Treatments	9	12345.7815**	1518.5037**	19.3294**	2.0110**
Error	18	6.0037	8.2370	0.1369	0.0669

APPENDIX 5. Mean square values for density and dry weight of broadleaved at 45 DAS in zero-till wheat field in both years in both years

Source of variation	df	Density of broadleaved weeds		Dry weight of broadleaved weeds	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	882.7000	18.6333	1.3316	0.2269
Treatments	9	80825.0704**	6135.1704**	94.9732**	54.7668**
Error	18	644.7370	30.8926	1.0379	1.0455

APPENDIX 6. Mean square values for density and dry weight of sedge at 45 DAS in zero-till wheat field in both years in both years

Source of variation	df	Density of sedge weeds		Dry weight of sedge weeds	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	0.0125	0.0073	0.0006	0.0004
Treatments	9	2.5626**	0.3945**	0.2738**	0.1141**
Error	18	0.0141	0.0073	0.0030	0.0004

APPENDIX 7. Mean square values for density and dry weight of grass at 60 DAS in zero-till wheat field in both years in both years

Source of variation	df	Density of grass weeds		Dry weight of grass weeds	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	9.3000	12.9000	0.6741	0.0015
Treatments	9	6064.4593**	1770.5519**	35.1267**	5.5324**
Error	18	17.1148	9.6407	0.8947	0.0618

APPENDIX 8. Mean square values for density and dry weight of broadleaved at 60 DAS in a zero-till wheat field in both years both-year

Source of variation	df	Density of broadleaved		The dry weight of broadleaved	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	83.2000	23.4253	1.1731	1.3613
Treatments	9	52226.1333**	49283.9135**	333.0479**	645.3598**
Error	18	40.5333	15.1068	1.0902	0.7832

APPENDIX 9. Mean square values for density and dry weight of sedge weeds at 60 DAS in a zero-till wheat field in both years in both years

Source of variation	df	Density of sedge weeds		Dry weight of sedge weeds	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	0.1000	0.0000	0.0063	0.0010
Treatments	9	83.4963**	1.4010NS	4.1182	0.0955**
Error	18	1.0630	0.0000	0.0594	0.0004

APPENDIX 10. Mean square values for plant height at harvest, spikes m⁻² of wheat in a zero-till wheat field in both years in both years

Source of variation	df	Plant height at harvest		Spikes m ⁻²	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	0.2895	1.6861	17.2000	24.1000
Treatments	9	59.8238**	14.2545**	4376.9815**	3577.5889**
Error	18	0.5514	0.5353	16.5704	21.5444

APPENDIX 11. Mean square values for spike length and spikelets spike⁻¹ of wheat in a zero-till wheat field in both years in both years

Source of variation	df	Spike length		Spikelets spike ⁻¹	
		2017-18	2018-19	2017-18	2018-19
Replication	2	0.1029	0.4122	0.6510	0.0523
Treatments	9	2.7723**	1.0167**	6.7413**	5.6808**
Error	18	0.1175	0.1533	0.2132	0.3268

APPENDIX 12. Mean square values for grains spike⁻¹ and 1000 grain weight in a zero-till wheat field in both years in both years

Source of variation	df	Grains spike ⁻¹		1000 grain weight	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	0.3323	1.3360	0.8333	0.1000
Treatments	9	121.4283**	48.8752**	9.7222**	30.4778**
Error	18	1.5553	1.2162	0.8333	0.3222

APPENDIX 13. Mean square values for grain yield (kg ha⁻¹) and harvest index (%) in the zero-till wheat field in both years in both years

Source of variation	df	Grain yield (kg ha ⁻¹)		Harvest index (%)	
		2017-2018	2018-2019	2017-2018	2018-2019
Replication	2	7682.5000	4410.8333	3.2487	1.1560
Treatments	9	1465854.1667**	837140.8333**	33.2616**	42.0352**
Error	18	7585.2778	7885.8333	1.7653	1.3159

APPENDIX 14. Mean square values for biomass at harvest (kg ha⁻¹) and straw at harvest (kg ha⁻¹) in zero-till wheat fields in both years

Source of variation	df	Biomass at harvest (kg ha ⁻¹)		Straw at harvest (kg ha ⁻¹)	
		2017-18	2018-19	2017-18	2018-19
Replication	2	81000.8333	19815.8333	131350.8333	38447.5000
Treatments	9	4243849.6296**	5274846.6667**	1143927.8704**	3759524.1667**
Error	18	83627.6852	58393.6111	81646.2037	64836.3889

Appendices for herbicide options for weed management in zero-till maize

APPENDIX 15. Mean square values for density of grass and broadleaved at 15 DAS in both years

Source of variation	DF	Density of grass		Density of broadleaved	
		2017-18	2018-19	2017-18	2018-19
Rep	2	22.4630	260.1517	0.2491	1.1572
PreHerb	2	457393.69**	17958771.40**	6.2178*	41.7482*
Error (a)	4	90.3241	502.7147	0.3328	0.7212
PostHerb	5	48851.35**	91726.51**	1.5939**	5.7419**
PostHerb × PostHerb	10	57951.4**	97993.11**	0.9106**	2.7674**
Error (b)	30	73.3037	471.1844	0.1948	0.3368

APPENDIX 16. Mean square values for the density of sedge at 15 DAS and density of the density of grass at 30 DAS in both years

Source of variation	DF	Density of sedge		Density of grass	
		2017-18	2018-19	2017-18	2018-19
Rep	2	1.0790	0.4789	2.4726	319.4696
PreHerb	2	0.1548	1.4527ns	376.7167**	492357.8535**
Error (a)	4	0.4300	0.2213	2.6309	191.5641
PostHerb	5	1.5964*	3.5659**	82.6690**	48143.0789**
PostHerb × PostHerb	10	2.3974**	1.3764**	38.5240**	38231.6440**
Error (b)	30	0.3748	0.1226	3.0957	112.5141

APPENDIX 17. Mean square values for density of broadleaved and sedge weeds recorded at 30 DAS in both years

Source of variation	DF	Density of broadleaved weeds		Density of sedge weeds	
		2017-18	2018-19	2017-18	2018-19
Rep	2	5.6665	2.2724	0.3121	1.3404
PreHerb	2	15.1387	5660.1835**	0.6573 ns	14.5848*
Error (a)	4	6.6898	10.6596	0.1259	0.3844
PostHerb	5	13.2361	4416.2069**	0.4783*	8.8107**
PostHerb × PostHerb	10	6.7488	2640.9051**	0.3154*	3.7534**
Error (b)	30	7.1262	9.9490	0.1232	0.7911

APPENDIX 18. Mean square values for dry weight of grass and broadleaved weeds were recorded at 30 DAS in both years

Source of variation	DF	Dry weight of grass weeds		Dry weight of broadleaved weeds	
		2017-18	2018-19	2017-18	2018-19
Rep	2	0.1378	0.0037	0.0890	1.3937
PreHerb	2	2.8601*	122.2801**	0.0544	14.9579*
Error (a)	4	0.0532	0.2562	0.0265	0.2489
PostHerb	5	1.1903**	15.4754**	0.0613	13.2125**
PostHerb × PostHerb	10	0.7533**	10.6781**	0.0700	3.5590**
Error (b)	30	0.0365	0.2704	0.0722	0.7501

APPENDIX 19. Mean square values for dry weight of sedge and total biomass of all weed species at 30 in both years

Source of variation	DF	Dry weight of sedge		Total biomass of all weed species	
		2017-18	2018-19	2017-18	2018-19
Rep	2	0.0036	0.6513	0.0893	0.9131
PreHerb	2	0.0140	0.1148	3.6917*	112.2778**
Error (a)	4	0.0200	0.5475	0.0945	1.3866
PostHerb	5	0.0170	0.5126	0.8686**	15.4564**
PostHerb × PostHerb	10	0.0103	0.8122	0.7434**	6.7824**
Error (b)	30	0.0119	0.6071	0.1170	1.6243

APPENDIX 20. Mean square values for density of grass and broadleaved at 60 DAS in both years

Source of variation	DF	Density of grass weeds		Density of broadleaved weeds	
		2017-18	2018-19	2017-18	2018-19
Rep	2	0.0420	9.8099	0.0091	76.1296
PreHerb	2	1269.3993**	1236.4345**	0.0091	6568.3519**
Error (a)	4	6.0268	5.2420	0.0091	38.0741
PostHerb	5	593.0503**	283.8662**	0.0091	9221.3074**
PostHerb × PostHerb	10	163.2176**	118.7487**	0.0091	6407.9519**
Error (b)	30	8.9572	5.0746	0.0091	66.9593

APPENDIX 21. Mean square values for density of sedge and dry weight of grass at 60 DAS in both years

Source of variation	DF	Density of sedge		Dry weight of grass	
		2017-18	2018-19	2017-18	2018-19
Rep	2	3.5621	2.3329	1.3108	0.2481
PreHerb	2	126.0819*	35.8311 ns	279.1861**	442.8480**
Error (a)	4	9.4122	7.0969	0.6316	5.1208
PostHerb	5	115.7583**	75.1252**	84.9009**	96.3420**
PostHerb × PostHerb	10	45.9496**	20.6352**	34.7723**	36.6577**
Error (b)	30	7.853	5.8778	1.1750	0.9833

APPENDIX 22. Mean square values for dry weight of broadleaved and sedge at 60 DAS in both years

Source of variation	DF	Dry weight of broadleaved		Dry weight of sedge	
		2017-18	2018-19	2017-18	2018-19
Rep	2	189.8102	1.5227	0.6393	0.1974
PreHerb	2	852.0880ns	1.9547	22.2135*	6.2782*
Error (a)	4	181.8657	2.1419	0.9454	0.4524
PostHerb	5	1431.8269**	11.3965**	8.5936*	11.1539**
PostHerb × PostHerb	10	1224.9657**	7.1127**	3.0761ns	5.0580**
Error (b)	30	189.4028	0.9543	1.5689	0.6294

APPENDIX 23. Mean square values for dry weight of all weed species at 60 DAS and plant height at 30 DAS in both years

Source of variation	DF	Dry weight of all weed species at 60 DAS		Plant height at 30	
		2017-18	2018-19	2017-18	2018-19
Rep	2	1.4111	240.6667	0.0741	0.0556
PreHerb	2	223.4809**	135512.7222**	2.0185*	0.7222
Error (a)	4	0.6668	193.9722	0.0741	0.3611
PostHerb	5	67.7601**	20852.8000**	1.8852**	1.8222*
PostHerb × PostHerb	10	29.5112**	11634.6556**	1.0185**	0.4111
Error (b)	30	0.6005	223.0704	0.2074	0.5037

APPENDIX 24. Mean square values for plant height at 60 DAS and harvest in both years

Source of variation	DF	Plant height at 60 DAS		Plant height at harvest	
		2017-18	2018-19	2017-18	2018-19
Rep	2	11.6296	69.4074	0.0077	0.0068
PreHerb	2	107.7963ns	2062.7963**	0.0002	0.1979*
Error (a)	4	16.1852	20.0185	0.0220	0.0092
PostHerb	5	484.4185**	105.8519**	0.0387**	0.0470**
PostHerb × PostHerb	10	42.9074**	97.1296**	0.0028	0.0281**
Error (b)	30	12.0000	23.8593	0.0093	0.0039

APPENDIX 25. Mean square values for grains cob⁻¹ and 1000-grain weight of zero-till maize in both years

Source of variation	DF	Grains cob ⁻¹		1000-grain weight	
		2017-18	2018-19	2017-18	2018-19
Rep	2	145.7963	700.5185	93.4074	1.1296
PreHerb	2	7240.0185**	9849.1296**	1606.7969**	2234.5741**
Error (a)	4	61.2130	216.9907	37.0741	42.6852
PostHerb	5	2779.3630**	3365.9407**	2117.2741**	2262.8741**
PostHerb × PostHerb	10	2828.8630**	2813.7296**	1949.7741**	2661.2630**
Error (b)	30	396.8074	498.2111	47.3185	27.9222

APPENDIX 26. Mean square values for grain and straw yield of zero-till maize in both years

Source of variation	DF	Grain yield (t ha ⁻¹)		Straw yield (t ha ⁻¹)	
		2017-18	2018-19	2017-18	2018-19
Rep	2	1.2215	0.6646	0.8229	3.1030
PreHerb	2	0.8080	19.9673*	5.4352	6.7595
Error (a)	4	0.7713	1.2382	1.7520	1.8607
PostHerb	5	4.0908**	4.3801**	10.7358**	2.6506*
PostHerb × PostHerb	10	2.1866**	3.9623**	5.3395**	2.7761*
Error (b)	30	0.5724	0.5316	1.2630	1.0348

APPENDIX 27. Mean square values for biomass and harvest index of zero-till maize in both years

Source of variation	DF	Biomass yield (t ha ⁻¹)		Harvest index (%)	
		2017-18	2018-19	2017-18	2018-19
Rep	2	1.5986	6.1549	8.5504	7.2137
PreHerb	2	9.4778ns	48.2768*	12.2401	7.7258
Error (a)	4	1.9470	3.1643	12.0558	12.2224
PostHerb	5	22.5520**	9.1443**	29.5690**	19.5537*
PostHerb × PostHerb	10	12.0149*	9.4998**	12.1788*	14.9099*
Error (b)	30	2.5378	1.9507	4.1801	5.4741

Appendices for herbicide options for weed management in zero-till direct-seeded rice

APPENDIX 28. Mean square values for density of grass and broadleaved at 15 DAS in both years

Source of variation	DF	Density of grass weeds		Density of broadleaved weeds	
		2018	2019	2018	2019
Rep	2	0.0951	7.5242	7.2062	1.9349
PreHerb	2	104.8355**	6361.4836**	11718.7056**	2093.4962**
Error (a)	4	0.2775	1.9852	1.0642	4.1592
PostHerb	4	5.0598**	518.2202**	1048.9108**	649.7969**
PostHerb × PostHerb	8	4.4953**	1728.4627**	1260.1036**	662.7671**
Error (b)	24	0.2044	2.6082	3.1585	1.3900

APPENDIX 29. Mean square values for density of sedge and all weed species at 15 DAS in years both

Source of variation	DF	Density of sedge weeds		Density of all weed species	
		2018	2019	2018	2019
Rep	2	0.0325	0.5100	8.0622*	11.2337
PreHerb	2	0.8445ns	81.3845**	13840.6171**	16215.2340**
Error (a)	4	0.1559	0.4350	0.3564	11.7457
PostHerb	4	1.0278**	280.4162**	1064.0485**	1561.2152**
PostHerb × PostHerb	8	0.8354**	98.8258**	1262.4793**	3761.2830**
Error (b)	24	0.0838	0.6535	3.1290	4.5116

APPENDIX 30. Mean square values for density of grass and broadleaved at 35 DAS

Source of variation	DF	Density of grass weeds		Density of broadleaved weeds	
		2018	2019	2018	2019
Rep	2	0.2296	0.2889	8.4362	6.5420
PreHerb	2	6.5839*	5109.6889**	43421.1382**	1253.9162**
Error (a)	4	0.5014	1.5556	19.1791	8.4692
PostHerb	4	52.5936**	1844.0889**	94348.7616**	342401.1419**
PostHerb × PostHerb	8	3.9371**	481.0222**	12861.4057**	51431.7992**
Error (b)	24	0.2935	2.7444	14.2007	8.2622

APPENDIX 31. Mean square values for density of sedge and all weed species at 35 DAS in both years

Source of variation	DF	Density of sedge weeds		Density of all weed species	
		2018	2019	2018	2019
Rep	2	0.5595	0.5438	16.5769	7.1242
PreHerb	2	53.5625**	249.9294**	47132.3950**	9023.5730**
Error (a)	4	0.3612	0.7933	17.7891	11.2584
PostHerb	4	298.7833**	148.4946**	104984**	398272.7515**
PostHerb × PostHerb	8	43.3538**	89.9207**	12893.3108**	60706.4127**
Error (b)	24	0.3898	0.4941	12.7402	8.2473

APPENDIX 32. Mean square values for dry weight of grass and broadleaved at 35 DAS in both years

Source of variation	DF	Dry weight of grass weeds		Dry weight of broadleaved	
		2018	2019	2018	2019
Rep	2	0.0301	0.0482	0.5511	0.5660
PreHerb	2	14.3793**	4002.5769**	4.4961*	2078.3726**
Error (a)	4	0.0968	1.9406	0.2626	5.1940
PostHerb	4	51.9060**	8495.7537**	63.3078**	2952.3298**
PostHerb × PostHerb	8	8.3920**	1565.6013**	3.4143**	916.2066**
Error (b)	24	0.1572	2.4256	0.2523	1.8469

APPENDIX 33. Mean square values for dry weight of sedge and all weed species at 35 DAS in both years

Source of variation	DF	Dry weight of sedge		Dry weight of all types of weed	
		2018	2019	2018	2019
Rep	2	0.3837	1.9059	1.8144	3.9887
PreHerb	2	2.4729*	621.6973	55.7837**	188.2987*
Error (a)	4	0.2698	2.5310	1.5584	11.2733
PostHerb	4	32.4645**	1507.2498**	329.3058**	19721.6348**
PostHerb × PostHerb	8	4.5070**	237.4027**	13.4165**	1431.9889**
Error (b)	24	0.2586	4.6622	0.8973	10.3646

APPENDIX 34. Mean square values for density of grass and broadleaved at 60 DAS in both years

Source of variation	DF	Density of grass		Density of broadleaved	
		2018	2019	2018	2019
Rep	2	1.2354	4.2360	0.6381	2953.3389
PreHerb	2	9.2277*	219.5194**	63.5032**	22610.0389*
Error (a)	4	0.9473	9.7460	0.9400	2982.2472
PostHerb	4	29.6519**	2341.0718**	92.4285**	34486.0694**
PostHerb × PostHerb	8	3.5643**	814.5387**	34.3978**	38048.7403**
Error (b)	24	0.8115	5.9852	0.6313	3083.8333

APPENDIX 35. Mean square values for density of sedge weeds and all weed species at 60 DAS in both years

Source of variation	DF	Density of sedge weeds		Density of all weed species	
		2018	2019	2018	2019
Rep	2	0.0522	0.1305	3.4032	2959.2226
PreHerb	2	14.4688*	1.9898*	198.8353**	27292.1031*
Error (a)	4	0.9130	0.1285	5.9752	3212.7958
PostHerb	4	28.8022**	11.0676**	154.2636**	31124.5599**
PostHerb × PostHerb	8	6.1785**	3.5376**	70.6618**	40640.2310**
Error (b)	24	0.9643	0.1476	4.9808	3206.2112

APPENDIX 36. Mean square values for dry weight of grass and broadleaved at 60 DAS in both years

Source of variation	DF	Dry weight of grass weeds		Dry weight of broadleaved weeds	
		2018	2019	2018	2019
Rep	2	1.7950	624.2376	4.2782	233.8247
PreHerb	2	107.8477**	16935.2889*	6.6894	3451.7030*
Error (a)	4	1.4756	682.2993	2.0372	239.1808
PostHerb	4	101.6931**	126456.6947**	227.3733**	99249.5303**
PostHerb × PostHerb	8	63.7374**	87047.4300**	31.4652**	17776.5703**
Error (b)	24	1.0567	618.3629	1.3286	204.9691

APPENDIX 37. Mean square values for dry weight of sedge and all weed species at 60 DAS in both years

Source of variation	DF	Dry weight of sedge		Dry weight of all weed species	
		2018	2019	2018	2019
Rep	2	0.1462	0.0844	0.2889	1644.6889
PreHerb	2	1.0015	5.7854**	174.4889**	34287.2889*
Error (a)	4	0.3816	0.0458	0.2889	1725.3222
PostHerb	4	8.3050**	51.6685**	533.2000**	20122.4222**
PostHerb × PostHerb	8	4.4385**	5.7063**	136.6000**	118059.9556**
Error (b)	24	0.2457	0.1804	1.4833	1529.9444**

APPENDIX 38. Mean square values for dry weight of all weed species at harvest and plant density m² in both years

Source of variation	DF	All weed species at harvest		Plants/m ²	
		2018	2019	2018	2019
Rep	2	38.4222	112.3556	268.0667	2590.4667
PreHerb	2	12978.8222**	7702.0222**	30141.0667**	8620.0667ns
Error (a)	4	38.9222	182.6889	41804333	2242.9333
PostHerb	4	34811.6889**	6812.5778**	8505.9222**	18554.3556**
PostHerb × PostHerb	8	7585.4889**	15478.7444**	3978.9556**	1613.7889ns
Error (b)	24	50.0056	531.5222	287.2278	2627.6944

APPENDIX 39. Mean square values for plant height at 30 DAS and 60 DAS in both years

Source of variation	DF	Plant height at 30 DAS		Plant height at 60 DAS	
		2018	2019	2018	2019
Rep	2	0.0889	2.4667	15.0889	31.4889
PreHerb	2	34.9556**	54.2000**	15.0889ns	29.7556ns
Error (a)	4	0.8889	1.6667	6.8556	15.1889
PostHerb	4	4.8333**	80.2556**	2.1444ns	76.8333**
PostHerb × PostHerb	8	11.9000**	6.3389**	19.9778**	93.2833**
Error (b)	24	0.7611**	2.3778	2.4333	19.9833

APPENDIX 40. Mean square values for plant height at harvest and grains/spike in both years

Source of variation	DF	Plant height at harvest		Grains spike ⁻¹	
		2018	2019	2018	2019
Rep	2	6.4889	1.2327	560.0667	217.3556
PreHerb	2	14.15556ns	138.3327**	5257.4000**	41.0889ns
Error (a)	4	7.8222	5.2583	171.6667	130.8222
PostHerb	4	218.4222**	132.5264**	71.7000ns	20820.4222**
PostHerb × PostHerb	8	59.4889**	85.0104**	662.9000*	8034.8389**
Error (b)	24	3.2667	1.4773	273.3833	160.4167

APPENDIX 41. Mean square values for 1000 grain weight and grain yield in both years

Source of variation	DF	1000 grain weight (g)		Grain yield (t ha ⁻¹)	
		2018	2019	2018	2019
Rep	2	0.0667	0.4222	0.3503	0.0229
PreHerb	2	1.8667ns	7.6222ns	0.7588**	0.9628**
Error (a)	4	0.4333	1.6222	0.0339	0.0574
PostHerb	4	0.1333ns	34.5556**	17.1105**	13.3262**
PostHerb × PostHerb	8	0.533**	18.3722**	0.4840**	0.3067**
Error (b)	24	0.2000	0.5000	0.3918	0.1330

APPENDIX 42. Mean square values for straw yield and harvest index in both years

Source of variation	DF	Straw yield (t ha ⁻¹)		Harvest index (%)	
		2018	2019	2018	2019
Rep	2	0.0717	0.0313	6.1083	4.0175
PreHerb	2	6.7401**	0.7262ns	120.0850**	10.0387ns
Error (a)	4	0.3292	0.1356	15.2036	3.4310
PostHerb	4	22.4650**	8.1458**	115.4991**	135.6423**
PostHerb × PostHerb	8	2.0587**	1.0326**	82.4983**	67.8939**
Error (b)	24	0.2771	0.1722	14.0728	3.4675

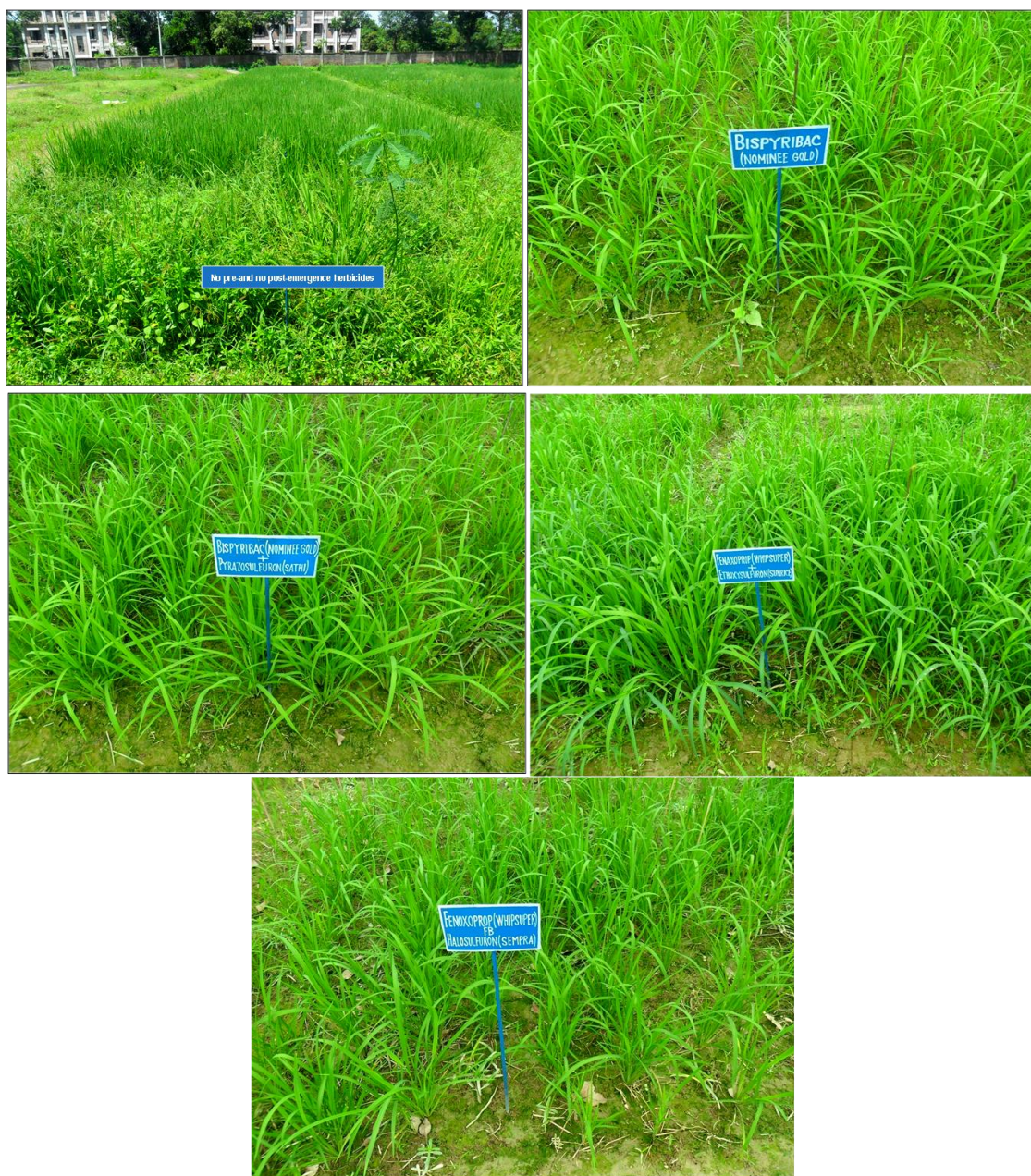
Appendices: Treatments-wise field view of all observations



Appendix 43. Field appearance in treatments-wise weed and crop growth in zero-till wheat



Appendix 44. Field appearance in treatments-wise weed and crop growth in zero-till maize



Appendix 45. Field appearance in treatments-wise weed and crop growth in zero-till direct-seeded rice