Chapter

Chemical Weed Management in Maize (*Zea mays* L.) under Conservation Agricultural Systems: An Outlook of the Eastern Gangetic Plains in South-Asia

Akbar Hossain, Mst. Tanjina Islam, Md. Shohidul Islam, Nurislam, Sharif Ahmed, Khokan Kumer Sarker and Mahesh Kumar Gathala

Abstract

Maize is a widely grown cereal after rice and wheat and contributes almost 5% to the global dietary supply. In the Eastern Gangetic Plains (EGP) including India, Bangladesh, and Nepal, maize is an emerging cash crop, because of its high yield potentiality and also the favorable climatic conditions which allow maize production round the year. In Bangladesh, area and production of maize are escalating due to the increasing demand for poultry, livestock, and fish feed, and fodder for animals and starch industries in the region. Presently, more than 90% of maize is planted by manual dibbling following 5–6 intensive tillage, which increases the cost of cultivation. The conservation agricultural (CA)-based new agricultural practices could overcome those above challenges. CA is cost-effective and environmentally friendly; however, weeds are one of the key challenges in the system. The chapter described the uses of herbicides in different ways of combinations to make effective weed control in CA-based maize to achieve potential production and profits by reducing the intensive pressure of manual weeding. The efficient and right use of pre-plant/sowing, pre- and post-emergence herbicides and their combination may be the best way for effective control of weeds in maize production.

Keywords: conservation agriculture, weed management, herbicides, maize

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal after rice and wheat, which is widely grown in the world and used as a primary staple food in many developing countries. The area and production under maize in the world in 2013–2014 was 177 m ha with 967 Mt. production and contributed almost 5% of the world's dietary energy supply [1]. Recent projection indicates that by 2020 the demand of maize in all developing countries will overtake the demand of wheat and rice [2], with Asia accounting for nearly 60% of the global demand for maize. Half of the world maize is produced in the developing countries where maize grain is one of the major sources of food energy for the poor people and its plant biomass provides feed for animals [3].

Eastern Gangetic Plains (EGP) covering three neighboring countries (India, Bangladesh and Nepal) has a very high yield potential of maize production. In recent decades, maize an emerging as a cash crop for smallholder farmers because of its high yield potentiality due to favorable climatic conditions which allows maize production round the years in three seasons [4]. The EGP is mainly dominated by rice-based farming systems having maximum coverage of rice-rice cropping system which is associated with own problems of high water consumption, production costs and labour use, and further soil health deterioration. All these associated problems make rice-rice production is unsustainable and unprofitable. Farmers are looking for the alternative crop of dry season rice called boro rice (winter rice) to diversify their cropping systems and maize is one of the most suitable crops to provide high yield and profit margin in a more sustainable way.

Presently, more than 90% maize grows in EGP by manual dibbling after intensive tillage operations (4–6 dry tillage) which delayed the maize sowing by at least 1–2 weeks [5]. A number of repetitive tillage operations increase the cost of cultivation due to higher energy and labor use and delayed planting which further reduces the net margins of the farmers. Since, the conservation agricultural (CA) based management practices (minimum/zero tillage) are the new emerging technologies growing an attention worldwide due to higher economic benefits, improvement in soil health and also found more environmental friendly by reducing greenhouse gases.

Although CA-based maize cultivation has many benefits, however weed infestation is one of the serious constraints that limits maize production though weed management is also a major concern in conventional production system. The competition between weeds and maize at critical growth stages could be reduced both the quality and quantity of maize yield over 30% [6] as weeds compete with crop for essential resources [7–9]. For controlling weeds in crop field, farmers are generally adopting mechanical, cultural, biological and chemical control methods. Among them, exhausted by cultural methods, farmers are moving towards other alternative methods due to labour crisis during critical period of weed control [6, 10, 11]. While, the mechanical methods are still useful but are unable to effective control of weeds successfully due to the absence of right machinery [12]. The judicious and right use of a different combination of herbicides as pre-plant, pre-emergence and post-emergence can provide effective and efficient weed control under CA system as well as conventional system [13]. The chemical weed control may be provided cost-effective, faster and better weed control [14–16].

2. Importance of tillage options on weed infestation in the crop field

Weed management strategies are the key to success of the conservation agriculture based crop production especially at the beginning of 2 years. With the shift from conventional agriculture to conservation agriculture there will be a shift dynamic change in weed species, population and diversity. Therefore, initial weed management is an important phenomenon through integrated weed management approaches like stale seed-bed, mulch, and adjustment in planting dates, biological and mechanical control and effective combination use of herbicides. The many long-term studies clearly indicated that if the proper weed management options adopted at initial 2 years then the weed population significantly reduced with time under CA-based practices than conventional practices [17–19]. Tillage systems affect the composition of weeds in a field [20]. Typically, perennial weeds in conventional tillage systems cannot be fixed due to repeated plowing but alteration of soil between the surface to sub-surface exposes new weed seeds. In the other hand, the perennial weeds are more prominent initially in CA-based tillage but also broadleaf weeds may be prominent due to the light-weight and density of seeds which remain on the surface facilitate for conducive germination environment. The several studies showed that *Phalaris minor* populations significantly reduced under zero tillage but broadleaves especially *Rumex* found increases [21–23]. A recent study in the EGP suggested, if initial weeds are not managed properly then *Polygonum* species and sedges dominated under CA systems. However, perennial weeds in these systems, the plant roots are not pulled out shall be subject to the complete eradication [24] may regenerate again. [25] reported that dry weight of weeds in crops without plowing method compared to conventional tillage crops decreased by respectively 61 and 77%. Another earlier findings [26] observed that nutrients uptake by crops under CA systems was enriched when weeds was in CA-system were reduced. CA-based agricultural systems conserve the soil health through improving the soil organic matter as well as soil microbial finally leading for the higher productivity of crops [27, 28].

3. Major weed species in association with maize

Infesting weed species in crop field generally depend on crop species, cropping systems and their management practices, environmental conditions, seasonal variation, soil properties, nutrients and moisture status as well as soil types. The Eastern Gangetic Plain (EGP) as known for high weed seed bank in soils especially lower EGP (Bangladesh and West Bengal) due to flash and steady floods bring weed seeds from distance in their catchment areas. The weed species also highly depend on seasons as maize is grown round the year in three seasons i.e. Kharif (Monsoon; June–September), Rabi (Winter; November–May) and Kharif 1 (Spring; February–June). The high weed seed pressure and diversity make more difficult to manage weeds manually in conservation agriculture as well as also in conventional agriculture. 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. 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. [29–31]. The perennial weeds species dominant round the years but the seasonal weeds are different when maize grown in dry season (winter maize) and the major dominant weeds are *Polygonum persicaria, Polygonum pensylvanicum, Polygonum orientale, Oldenlandia diffusa, Oldenlandia aquatic, Oxalis corniculate, Chenopodium arvensis, Physalis minima, Solanum nigrum, Hydrocotyle ranunculoides, Ageratum conyzoides, Medicago denticulate, Avena ludoviciana* etc. [32, 33].

A field experiment found that the most dominant weeds in maize field were sedge *C. rotundus* and dicot weeds *T. portulacastrum*, *D. arvensis*, *P. niruri* and grass *C. dactylon* [34]. In USA, it observed the most common broadleaves weed species in a maize crop were *Chenopodium album, Asclepias syriaca, Ambrosia artemisiifolia, Physalis heterophylla* and *Polygonum rensylvanicum* and the most common grasses were *Elymus repens and Setaria pumila* [35]. In another studies conducted on sandy loam soils at Hyderabad, India [26, 36], revealed that among the major weeds in maize field *E. colona* (grasses), *E. crus-galli, Paspalum distichum, C. rotundus* (sedges), *Ageratum conyzoides* and *T. portulacastrum, Sonchus oleraceus, Acalypha indica, Eclipta alba and Parthenium hysterophorus* (broad-leaved) were the predominant weeds. A 3 years field survey in Andhra Pradesh of India also confirmed that most dominant weed species in maize field were *E. colona*, followed by *P. repens*, *T. portulacastrum*, and *D. arvensis* [37].

4. The critical period of crop-weed competition

The critical crop growth stages considers as the most vulnerable period for crop-weed competition, during which crop must be weed free in order to prevent yield losses. Earlier studies observed [38–40] that the critical period of weed control in maize ranges from 7 to 56 days after seedling emergence. Other studies also reported [41–46], the critical period usually corresponds for maize up to 8–10 leaf stages. Wider canopy spacing and slow-growing nature of the maize crop should control weeds in first till 21–28 days after sowing for free from crop-weed competition and it was also suggested that if the weeds are not control within the critical crop growth stages, the yield losses may occur 30–100% [47, 48].

Weed species, densities, and their interactions influence maize yield loss [49, 50]. Weed plants compete with maize for their essential growth resources like water, nutrients, space etc. which ultimately reduce the yield up to 65% when weeds control measure was not performed at critical crop growth stages [46]. While, some problematic weeds species as they are similar in nature and life cycle of maize are difficult to control. Massinga et al., [51] reported that the yield reduction in maize could be 91% by competition if more than eight amaranth (*Amaranthus palmeri* S. Wats) plants per meter row length.

5. Weed control in zero-till maize by chemical measures

In maize production, weed management is considered as an important agronomic measure for attaining the potential yield. To minimize the maize yield loss due to weed competition, farmers are practicing several methods for controlling the weeds are available such as mechanical, cultural, biological and chemical control methods. The cultural methods are very expensive and time consuming so, farmers have to move towards other alternative methods of weed control [10]. Furthermore, due to the increasing cost and non-availability of labour for manual weeding during peak and critical maize growth stages significantly influence the maize yield. The role of herbicides is not only control the weeds timely and effectively, but also offer a great scope for minimizing the cost of production [10]. The chemical control method is quick, more effective, time and labour saving method than others [13]. 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 towards problematic weed species [32] or evolution of herbicide-resistant weed biotypes. On the other hand, it is decisive to select the appropriate weedicide depending upon the weed flora exist in a given field. In addition, the precise dose, methods, weed growth stage, timings, soil moisture and application techniques should be followed. A number of herbicides have been evaluated in sequential combination and suggested pre- and post-emergence herbicide application for effective weed control in dry direct drill-seeded rice systems, including under zero-tillage conditions [17]. Use of pre-sowing, 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 under CA based management practices. Pre-emergence herbicides spray will control the weeds up to 25 days after seeding and followed that post-emergence application depending on weed flora will take care to keep weeds below crop injury level. Pre-planting, pre and post-emergence herbicides either in sequential or tank mixture will be taken care of all types of weed flora an ideal means in view of economics and usefulness in maize [17, 31, 32].

6. Effect of pre-sowing herbicides on weed control of maize

Generally, pre-sowing/planting herbicides are non-selective which are applied to control prevailing complex annual and perennial weeds flora erstwhile to planting, particularly under the CA-based cropping system. Among them, herbicide Glyphosate (1 kg ai ha^{-1} or 0.5–1.5% by volume), Glucofosinate, or dicamba and Paraquat (0.5 kg ai ha^{-1} or 0.5% by volume) are the most widely applicable herbicides [52, 53]. Where Glyphosate and Paraquat herbicides are available and popular as these are systemic non-selective and contact herbicides, respectively, and kill both annual and perennial weeds. To be effective, the systemic (Glyphosate) should be applied when weeds are growing actively so that the herbicide is absorbed and translocated into the entire plant system [17], but contact herbicide (Paraquat) can be applied just before the sowing.

Currently, the present rates of many herbicides do not work properly against many weeds, due to their resistance against the target weeds. Therefore, it is important to apply a new product to be available earlier than normal in order to maximize the contribution of residual weed control after crop emergence. The earlier study found that if the pre-sowing herbicide is applied before planting and is incorporated in the soil with light tillage, the efficacy of the applied herbicides was found the maximum [54].

7. Effect of pre-emergence herbicides on weed control in maize

When herbicides apply immediately or 1–4 days after maize seeds sowing, and it can be also mixed with soil during sowing, but it must be applied before weed seed emergence, are known as pre-emergence herbicides. Earlier findings [55] showed that pendimethalin can be applied as pre-emergence to get maximum weed control efficiency and crop selectivity by decreasing the weed population and increased the maize grain yield over the weedy check field [56]. Thus, Mekky et al. [57] reported that when pre-emergence herbicides were applied immediately after seed sowing or pre-emergence, weed control efficiency was the maximum and also increased the maize yield.

A field experiment in the clay loam soils of Guntur, Andhra Pradesh (India), with zero tillage maize found that atrazine 1.5 kg ha^{-1} applied at pre-emergence followed by (*fb*) manual hand weeding (HW) at 30 DAS recorded the tallest plant and the maximum dry-weight over un-weeded check at all stages of crop growth [30]. Scientist [26] reported that when maize was grown under zero till condition with pre-emergence herbicides atrazine at 1.0 kg ha^{-1} and topramezone 0.030 kg ha^{-1} in combination of two hand weeding at 20 and 40 DAS was produced significantly higher plant height, dry matter production of maize.

Recently, a study conducted in a clay loam and sandy loam soils of Bangladesh as a weed management strategy in pre-emergence and post emergence combinations and results showed that the even application of both Pendimethalin and atrazine separately reduces the weed biomass, weed population at 30 days after seeding which further provided better crop yield [58]. In another study clay soils of Rajendranagar (Telangana, India) was found that the highest crop dry matter was recorded with two times HW (at 20 and 40 DAS), which was at par with pre-emergence atrazine at 1.0 kg ha^{-1} + paraquat 0.60 kg ha^{-1}, followed by oxyfluorfen 0.150 kg ha^{-1} + paraquat 0.60 kg ha^{-1} [59]. The sequential application of pre-emergence followed (fb) protected spray of non-selective herbicide (Atrazine as pre-emergence at 1.25 kg ha^{-1} *fb* Paraquat 0.6 kg ha^{-1} at 3 weeks after sowing (WAS) or Pendimethalin as pre-emergence at 1.5 kg ha^{-1} *fb* Paraquat 0.6 kg ha^{-1} at 3 WAS) produced the significantly higher yield than weedy check [60]. An experiment was conducted with application of atrazine or glyphosate herbicide alone and tank mix application of selective (atrazine) and non-selective (glyphosate) herbicides and found that the grain yield was 170 and 70% more when atrazine + glyphosate (5.25 kg ha^{-1}) were applied as tank mixture than weedy check and sole application of atrazine or glyphosate, respectively [26]. Similar to previous study, a field research in the sandy clay loam soils of Kampasagar (Telangana, India) reported that when atrazine 1.25 kg ha^{-1} + paraquat 0.75 kg ha^{-1} were applied as a pre-emergence in tank mixture produced the significantly maximum grains cob^{-1}, cob diameter and 100 grain weight than other herbicides [61]. Similar grain yields were recorded when applied 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 tank mixture of pre-emergence.

8. Effect of post-emergence herbicides on weed control in maize

Application of herbicides after the emergence of maize and weed are well-known as post-emergence herbicides. Generally, post-emergence herbicides spray/apply in standing crop targeting weeds canopy by using the sprayer equipment.

The most popular/well-known herbicides which have been found to be effective when applied as a post-emergence for effectively control of weeds in CA-based maize system are Atrazine, Tembotrione (Laudis), Halosulfuron methyl (Sempra), Tembotrione (Laudis) + Atrazine, Halosulfuron methyl (Sempra) + Atrazine [58]. Earlier findings [62] revealed that pre-emergence herbicides pendimethalin and atrazine reduced the grassy and broadleaves weed population to a significant extent and among the pre-emergence herbicides, later (atrazine) resulted in a higher reduction in grass weed population at the early stage (20 days after seeding) than former (pendimethalin). But further he suggested, the post-emergence herbicides, the mixture of tembotrione + atrazine was more effective in controlling all classes of weed flora at 40 and 60 DAS. Tembotrione alone also showed good control of grasses and broad-leaved weeds. Atrazine as pre-emergence followed by (fb) tembotrione + atrazine as post-emergence found best combination and this combination reduced the weed dry matter to the tune of 98.7 and 97.9% at 40 and 60 DAS, respectively which ultimately resulted in significantly higher grain yields (11.57 t ha^{-1}) with maximum net returns.

However, when a single herbicide is used for a long time for controlling the same weeds it may create resistance against the specific weed(s). Therefore, long term basis continuous use of the same herbicide should be avoided. So, it should be rotated with the use of multiple herbicides with a different mode of action to avoid/delay weed resistance against specific weeds.

Scientists found that application of two or more compatible herbicides use as a tank mixture are more effective to control broaden the spectrum of weeds including grasses, broadleaves, and sedges than a single application [11, 63]. In the USA, Atrazine has been used since 1958 in several million hectares of maize field due to its low cost, control of a broad spectrum of broadleaf weeds, flexible application timing, and also can be used as both pre- and post-emergence in combination with several other herbicides. As a result of long-term and continuous use, the atrazine was found in accumulation in food products, groundwater, and aquatic systems [64]. Therefore, we should be careful to know the residual effect of applied herbicides when using the as short term as well as long term.

9. Precautionary measures during application of herbicides in the crop field

Herbicides are chemical compounds used to control weed species but could also phytotoxic to crops and harmful to animals through entering direct or indirect in food chain. Therefore, herbicides should be carefully selected considering the toxicity, residual persistence in soil and water bodies as well as cropping systems. The herbicide residual persistence can be affected the succeeding crops in a crop rotations and also the runoff of rain water from crop fields to water bodies which may cause the lethal and hazardous to water organism and human beings [65]. However, non-target living organisms that come to direct contact with weedicides can be harmful or poisonous especially if they have carry the chemical of the toxic action [66]. Therefore, while working with herbicides poses an always chemical poisoning risk to exposed workers if precaution measures are not properly followed.

With the use of herbicides, there is a certain risk of intoxication to directly exposed environment, food product, workers, as well as applied crops, since it depends on numerous factors. Therefore, before application of any herbicide, its short and long term toxicity/risk factors should be considered. The risk of worker intoxication with pesticides and herbicides, depends on several factors as how they will be handled and used. It can be grouped under two major factors; the toxicity of the respective herbicide and how it was exposed under specific working condition [66]. Therefore, it is an important to must follow the safety and health management guidelines while working and using the herbicide at all steps as set out by the industrial hygiene [67]. The steps are the ability to antedate, identify, diagnose, evaluate, and minimize the risks in the workplace. Therefore, the Preventive safety measures of worker(s)/personnel such as psychological measures; administrative: legislation, standards, and procedures; and hygiene, cleaning, maintenance, and safety of the environment also important during selection and application of pesticides [68].

10. Conclusion and policy implication

From the above discussion of the chapter, it is confirmed that weeds are the major challenge in CA crop production systems, where almost 16 to 42% yield reduction is occurred due to weed infestation and one-third of the total cost of cultivation is spent on weeding. On an average of 13.1% of crop reproduced is actually lost in the farmers' fields even after adopting in traditional weed control. The zero/strip-tilled/permanent beds or till the soil with fresh beds based crops production system is an alternate option through mechanized precision planting within a single pass. Although, the CA-based crop management techniques will be faced the major concern of weed management initially. Therefore, proper weed management is considered one of the most important prerequisites in CA-based crop cultivation systems including maize to ensure high crop yield. High weed pressure in association with maize, increase to lower the economic returns and, in extreme cases complete failure of the crop. Hence, judicious weed management in CA system is a critical factor for securing and sustaining food security. While, number of repetitive tillage operations increase the cost of cultivation, fuel consumption and delays planting in two ways by repetitive tillage operations followed by manual sowing. After post seeding of maize, farmers are facing major challenges for weed management due to lack of pre-sowing, pre- and post-emergence herbicides.

Since the traditional weed management in maize systems after 30–35 days after seeding; generally, farmers cut the weeds with hand weeding which further consumed more labour or sometimes usually reluctant to control weed in the maize field. However, sometimes they weeded by hand, which proves uneconomical due to be increasing labour wages as well as lack of labours due to migrating from the villages to urban areas for better livelihood. The hand labour based weeding in many developing countries consumes up to half of the total labour demand. Therefore, CA-based new agronomic management practices may be advocated to overcome the above challenges. To address the weed management problems in CA-based maize production under no-till systems with different chemical weed control is a potential means for controlling weeds and more economical compared to hand weeding. Now some herbicides are available in the market for controlling weeds since these should be needed to validate for controlling weeds as well as to know their residual effect on the environment.

Conflicts of interest

The authors declare no conflicts of interest.

Disclaimer

We hereby declare that the book chapter does not have any material which has been accepted to publish any journal or publisher, and also has no copy of any material in previously published, except where due permission and reference is made in the text.

Author details

Akbar Hossain[1*], Mst. Tanjina Islam[2], Md. Shohidul Islam[2], Nurislam[2], Sharif Ahmed[3], Khokan Kumer Sarker[4] and Mahesh Kumar Gathala[5]

1 Bangladesh Wheat and Maize Research Institute (BWMRI), Dinajpur, Bangladesh

2 Department of Agronomy, Hajee Mohammad Danesh Science and Technology University, Bangladesh

3 Bangladesh Office, International Rice Research Institute, Dhaka, Bangladesh

4 Irrigation and Water Management Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh

5 International Maize and Wheat Improvement Center (CIMMYT), Dhaka, Bangladesh

*Address all correspondence to: akbarhossainwrc@gmail.com and tanjimar2003@yahoo.com

References

[1] IndexMundi. Corn: Area & Production by Country in 1000 MT. 2019. Available from: https://www.indexmundi.com/agriculture/?commodity=corn&graph=area-harvested [Accessed: 05 July 2019]

[2] Andersen PP, Pandya-Lorch R, Rosegrant MW. World food prospects: critical issues for the early twenty -first century. Food Policy Report Vision-2020: International Food Policy Research Institute Washington, D.C. 1999. Available from: https://cgspace.cgiar.org/bitstream/handle/10947/1622/world%20food.pdf?...1 [Accessed: 05 July 2019]

[3] Ofori E, Kyei BN. Agrometeorology and maize production. Chpt13c; 2004. Available from: www.agrometeorology/chpt13c [Accessed: 05 July 2019]

[4] Ali MY, Waddington SR, Timsina J, Hodson D, Dixon J. Maize-rice cropping systems in Bangladesh: Status and research needs. Journal of Agricultural Science and Technology. 2009;**3**(6):35-53

[5] Islam KS, Momin MA, Krupnik TJ, Tiwari TP, Rossi FJ, Gathala MK. Best Management Practices for Hybrid Maize Production. Published by International Maize and Wheat Improvement Center (CIMMYT) Bangladesh; 2013. p. 36

[6] Mahmoodi S, Ali R. Estimation of critical period for weed control in corn in Iran. Proceedings of World Academy of Science, Engineering and Technology. 2009;**37**:67-72

[7] Zimdahl RL. Weed-Crop Competition, A Review. Second ed. Ames, Iowa: Blackwell Publishing; 2004

[8] John RT, Michel AC. Subplots facilitate assessment of corn yield losses from weed competition in a long-term system experiment. Agronomy for Sustainable Development. 2010;**30**:445-453

[9] Ahmed S, Salim M, Chauhan BS. Effect of weed management and seed rate on crop growth under direct dry seeded rice systems in Bangladesh. PLoS One. 2014;**9**:e101919. DOI: 10.1371/journal.pone.0101919

[10] Varga P, Bcrcs I, Rcisinger P, Busak P. The influence of soil herbicides on weeds in maize. In: Proc. German Conf. Weed Biology and Weed Control, Germany. Vol. 17. 2011. pp. 641-646

[11] Ahmed S, Chauhan BS. Efficacy and phytotoxicity of different rates of Oxadiargyl and Pendimethalin in dry-seeded rice (*Oryza sativa* L.) in Bangladesh. Crop Protection. 2015;**72**:169-174. DOI: 10.1016/j.cropro.2015.03.021

[12] Chikoye D, Ellis-Jone J, Riches C, Kanyomeka L. Weed management in Africa: Experiences, challenges and opportunities. In: 16th International Plant Protection Congress. 2007. pp. 652-653

[13] Ahmed SE, Shams HM, El-Metwally IM, Shehata MN, El-Wakeel MA. Efficiency of some weed control treatments on growth, yield and its attributes of maize (*Zea mays* L.) plants and associated weeds. Mansoura University Journal of Agricultural Sciences. 2008;**33**(7):4777-4789

[14] Chikoye D, Manyong VM, Carsky RJ, Ekeleme F, Gbehounou G. Response of speargrass (*Imperatacylindrica* (L.) Raeusch) to cover crops integrated with handweeding and chemical control in maize and cassava. Crop Protection. 2002;**21**:145-156

[15] Chikoye D, Schulz S, Ekeleme F. Evaluation of integrated weed management practices for maize in the northern Guinea savanna of Nigeria. Crop Protection. 2004;**23**:895-900

[16] Chikoye D, Udensi UE, Fontem AL. Evaluation of a new formulation of atrazine and metolachlor mixture for weed control in maize in Nigeria. Crop Protection. 2005;**24**:1016-1020

[17] Kumar V, Ladha JK. Direct seeding of rice: Recent developments and future research needs. Advances in Agronomy. 2011;**111**:299-360

[18] Gathala MK, Kumar V, Sharma PC, Saharawat Y, Jat HS, Singh M, et al. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern indo-Gangetic Plains of India. Agriculture, Ecosystems and Environment. 2013;**177**:85-97

[19] Kumar V, Jat HS, Sharma PC, Balwinder-Singh, Gathala MK, Malik RK, et al. Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. Agriculture, Ecosystems & Environment. 2018;**252**:132-147. DOI: 10.1016/j.agee.2017.10.006

[20] Tow P, Cooper I, Partridge I, Birch C. Rainfed Farming Systems. Netherlands: Springer; 2011

[21] Childs D, Jordan T, Ross M, Bauman T. Weed control in no tillage systems: Purdue University cooperative extension service. In: Conservational Tillage Series CT-2. West Lafayette: Purdue University; 2001

[22] Nalewaja J. Weeds and conservation agriculture. In: Conservation Agriculture. Dordrecht: Springer; 2003. pp. 201-210

[23] Chhokar RS, Sharma RK, Jat GR, Pundir AK, Gathala MK. Effect of tillage and herbicides on weeds and productivity of wheat under rice– Wheat growing system. Crop Protection. 2007;**26**:1689-1696

[24] Shrestha A. Conservation Tillage and Weed Management. Oakland, California, USA: University of California, Division of Agriculture and Natural Resources; 2006

[25] Mansouri AD, Bararpour MT, Babaeiangelodar N. Effect of tillage method and row spacing on growth and yield of soybean and weed management. Journal of Agricultural Sciences and Natural Resources. 1980;**Winter**:11. Eighth year. The fourth number

[26] Parameshwari YS. Influence of Rice Crop Establishemnt Methods and Weed Management Practices on Succeeding Zero-till Maize. Ph.D Thesis. Professor JayashankarTelangana State Agricultural University. Hyderabad. 2013

[27] Balota EL, Calegari A, Nakatani AS, Coyne MS. Benefits of winter cover crops and no-tillage for microbial parameters in a Brazilian Oxisol: A long-term study. Agriculture, Ecosystems and Environment. 2014;**197**:31-40

[28] Varvel GE, Wilhelm WW. No-tillage increases soil profile carbon and nitrogen under long-term rainfed cropping systems. Soil and Tillage Research. 2011;**114**:28-36

[29] Reddy MM, Padmaja B, Veeranna G, Reddy DVV. Bio-efficacy and economics of herbicide mixtures in zerotill maize (*Zea mays*) grown after rice (*Oryza sativa*). Indian Journal of Agronomy. 2012;**57**(3):255-258

[30] Rao AS, Ratnam M, Reddy TY. Weed management in zero-till down maize. Indian Journal of Weed Science. 2009;**41**(1 & 2):46-49

[31] Gathala M, Sudhir-Yadav, Mazid MA, Humphreys E, Sharif A, Krupnik T, et al. Guidelines for Dry Seeded Aman Rice (DSR) in Bangladesh. IFAD and CSISA joint publication. Intl. Rice Res. Inst. (IRRI) and Intl. Mexico: Maize and Wheat Improvement Center (CIMMYT); 2014. p. 32

[32] Singh AP, Bhullar MS, Yadav R, Chowdhury T. Weed management in zero-till wheat. Indian Journal of Weed Science. 2015;**47**(3):233-239

[33] Rai A, Mahata D, Lepcha E, Nandi K, Mukherjee PK. A review of weeds in maize. International Journal of Current Microbiology and Applied Sciences. 2018;**7**:2906-2922. DOI: 10.20546/ijcmas.2018.708.308

[34] Mukundam B, Srividya S, Raja V. Productivity and economics of rice-zero till maize as influenced by weed management practices in southern Telangana region of Andhra Pradesh. Indian Journal of Weed Science. 2011;**43**(3&4):163-168

[35] Pleasant J, Burt RF, Frisch JC. Integrating mechanical and chemical weed management in corn (*Zea mays*). Weed Technology. 1995;**8**(2):217-228 [Maize Abst. 1995; 11(3); 240]

[36] Singh S, Sheoran P. Studies on integrated weed management practices in rainfed maize under sub-montaneous conditions. Indian Journal of Dryland Agricultural Research and Development. 2008;**23**(2):6-9

[37] Kiran GGR, Rao AS. Survey of weed flora in zero till sown maize in Krishna zone of Andhra Pradesh. The Andhra Agricultural Journal. 2014;**61**(3):494-496

[38] Perry K, Evans MR, Jeffery LS. Competition between Johnsongrass (*Sorghum halepense*) and corn (*Zea mays*). Proceedings Southern Weed Science Society. 1983;**36**:345

[39] Vernon R, Parker JMH. Maize/weed competition experiments: Implications for tropical small-farm weed control research. Experimental Agriculture. 1983;**19**:341-347

[40] Ghosheh HZ, Holshouser DL, Chandler JM. The critical period of Johnson grass (*Sorghum halepense*) control in field corn (*Zea mays*). Weed Science. 1996;**44**:944-947

[41] Knezevic SZ, Evans SP, Blankenship EE, Van Acker RC, Lindquist JL. Critical period of weed control: The concept and data analysis. Weed Science. 2002;**50**:773-786

[42] Evans SP, Knezevic SZ, Shapiro C, Lindquist JL. Nitrogen level affects critical period for weed control in corn. Weed Science. 2003a;**51**:408-417

[43] Evans SP, Knezevic SZ, Shapiro C, Lindquist JL. Influence of nitrogen level and duration of weed interference on corn growth and development. Weed Science. 2003b;**51**:546-556

[44] Knezevic SZ, Evans SP, Mainz M. Yield penalty due to delayed weed control in corn and soybean. Crop Management Journal. 2003a;**2**. DOI: 10.1094/CM-2003-0219-01-RS

[45] Knezevic ZS, Evans SP, Mainz M. Row spacing influences critical time of weed removal in soybean. Weed Technology. 2003b;**17**:666-673. Available from: http://www.regional.org.au/au/asa/2004/poster/2/4/1/947_knezevicsz.htm [Accessed: 05 July 2019]

[46] Page ER, Cerrudo D, Westra P, Loux M, Smith K, Foresman C, et al. Why early season weed control is

important in maize? Weed Science. 2012;**60**:423-430

[47] Sandhu KS, Singh T, Singh S. Weed competition of maize (*Zea mays*) fields in Punjab. Indian Journal of Weed Science. 1999;**31**:18-24

[48] Knezevic SZ, Weise SF, Swanton CJ. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). Weed Science. 1994;**42**:568-573

[49] Fausey JC, Kekks JJ, Swinton SM, Renner KA. Giant foxtail interference in non-irrigated corn. Weed Science. 1997;**45**:256-260

[50] Scholes C, Clay SA, Brix-Davis K. Velvetleaf (*Abutilon theophrasti*) effect on corn (*Zea mays*) growth and yield in South Dakota. Weed Technology. 1995;**9**:665-668

[51] Massinga RA, Currie RS, Trooien TP. Water use and light interception under palmer amaranth and corn competition. Weed Science. 2003;**51**:523-531

[52] Gupta RK, Ladha JK, Singh S, Singh R, Jat ML, Saharawat Y, et al. Production technology for direct seeded rice. Rice Wheat Consortium Technical Bulletin. 2006;**8**:16

[53] Chauhan BS, Yadav A. Weed management approaches for dry-seeded rice in India: A review. Indian Journal of Weed Science. 2013;**45**(1):1-6

[54] Khaliq A, Matloob A, Ahmed N, Rasul F, Awan IU. Late POST-emergence chemical weed control in direct seeded fine rice. Journal of Animal and Plant Science. 2012;**22**:1101-1106

[55] Wilson RG, Sbatella GM. Integrating irrigation, tillage and herbicides for weed control in dry bean. Weed Technology. 2014;**28**(3): 479-485

[56] Fazal M, Ali K, Khan I, Khan HU, Anwar M. Efficacy of various herbicides against weeds and their impact on yield of maize. Pakistan Journal of Weed Science Research. 2009;**15**(2-3):191-198

[57] Mekky MS, Nassar ANM, Attalla SI. Effect of weed control treatments on weeds, growth, chlorophyll, crude protein and yield of maize (*Zea mays* L.). Egyptian Journal of Basic and Applied Sciences. 2002;**17**(6):219-240

[58] Gathala MK, Tiwari TP, Islam S, Maharjan S, Bruno G. Research Synthesis Report: Sustainable and Resilient Farming Systems Intensification in the Eastern Gangetic Plains (SRFSI). CSE/2011/077. CIMMYT-ACIAR publication. 2018. Available from: www.cimmyt.org

[59] Yakadri M, Rani PL, Prakash TR, Madhavi M, Mahesh N. Weed management in zero till-maize. Indian Journal of Weed Science. 2015;**47**(3):240-245. Available from: http://isws.org.in/IJWSn/File/2015_47_Issue-3_240-245.pdf [Accessed: 05 July 2019]

[60] Srividya S, Chandrasekhar K, Veeraraghavaiah R. Effect of tillage and herbicide use on weed management in maize (*Zea mays*. L). The Andhra Agricultural Journal. 2011;**58**(2):123-126

[61] Pasha ML, Bhadru D, Krishna L, Naik RBM. Evaluation of different herbicides in zero tillage. The Madras Agricultural Journal. 2012;**99**(7-9):471-472

[62] Mitra B, Bhattacharya PM, Ghosh A, Patra K, Chowdhury AK, Gathala MK. Herbicide options for effective weed management in zero-till maize. Indian Journal of Weed Science. 2019;**50**(2):137-141

[63] Ahmed S, Chauhan BS. Performance of different herbicides in dry-seeded rice in Bangladesh. The Scientific World Journal. 2014;**2014**:14. DOI: 10.1155/2014/729418

[64] Ying GG, Kookana RS, Mallavarpu M. Release and behavior of Triazine residues in stabilized contaminated soils. Environmental Pollution. 2005;**134**:71-77

[65] Larini L, Cecchini R. A intoxicação como fenômeno biológico. In: Larini L, editor. Toxicologia. São Paulo: Editora Manole Ltda; 1987. pp. 1-40

[66] Bonsall JL. Measurement of occupational exposure to pesticide. In: Turnbull GI, editor. Occupational Hazards of Pesticide Use. London: Taylor e Francis; 1985. pp. 13-33

[67] Brazil. NR 9—Programa de prevenção de riscos ambientais. Brasília, 2014. Available from: http://portal.mte.gov.br/data/files/FF80808148EC2E5E014961B76D3533A2/NR-09%20(atualizada%202014)%20II.pdf [Accessed: 05 July 2019]

[68] Machado-Neto JG. Safety measures for handlers/workers against herbicide intoxication risk. In: Price A, Kelton J, Sarunaite L, editors. Herbicides, Physiology of Action, and Safety. United kingdom: Intech Open; 2015. Available from: https://www.intechopen.com/books/herbicides-physiology-of-action-and-safety/safety-measures-for-handlers-workers-against-herbicide-intoxication-risk [Accessed: 05 July 2019]