

Review Article

Overviewing of weed management practices to reduce weed seed bank and to increase maize yield

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HIGHLIGHTS

- Weeds have botanical superiority over crop plants especially owing to higher reproduction potential.
- Prevalent manual and mechanical methods are eco-friendly but involve expensive labor.
- Weed-seed bank management through mechano-chemical approaches integration is the potent future strategy.

ABSTRACT

Background: Weeds are unwanted and undesirable plants which deteriorate the quality of agricultural products and interfere with farming activities. Most of the weeds (indigenous and invasive) seeds get preserved in soil horizons as weed seed bank which ensure their survival leading to the spoilage of quantitative and qualitative functioning of agricultural farms.

Objective: To keep weeds below threshold level, elimination of weeds seed before germination can be a viable and pro-ecological approach. To achieve this objective, weed seeds reserved in the soil which serve as an effective pool to ensure their survival necessitate weed-seed bank management. Thus the ultimate goal was to synthesize and analyze research findings on weed seed bank management leading to formulating the most effective strategy encompassing viable control of weeds in maize.

Methods: This study reviewed and analyzed the characteristics which impart botanical superiority to weeds and impact of all prevalent weed control strategies on weed seed bank, weeds density and maize yield. The research findings pertaining to different agronomic practices and technological packages were critically analyzed to sort out the most effective and eco-friendly approach to control weed-seed bank and weeds density in maize crop.

Results: The synthesis and critical evaluation of research findings pertaining to weed control methods revealed that manual and mechanical methods were eco-friendly but involved expensive labor, while the chemical approach involving the use of herbicides led to serious deterioration of agro-environmental resources. Two or more techniques used in coherence which encompassed deep tillage to bury weeds seed and prevented their germination through mulches of biotic and synthetic materials along with optimizing sowing method especially raised bed technique reduced weed seed bank and weeds density in maize.

Conclusions: It is inferred that integrated approach entailing cultural, manual, mechanical and chemical control can be developed as a pro-environmental and farmer friendly approach for weed control by reducing weed seed reserves which can potentially lead to higher economic returns through higher maize yield.

1 INTRODUCTION

A plant is considered weed when it is undesirable in human controlled places and present in an unwanted place. Weeds can be indigenous or exotic and tend to grow aggressively in new habitats. Weeds possess certain distinctive characteristics which interfere with crop plants and have negative impact on farming and human activities (Iqbal et al., 2015a; Silva et al., 2014). Weeds presence in terrestrial ecosystems causes environmental, economic and health problems (Lee and Christian, 2017). Among all the pests of crops, weeds cause the highest yield losses (37%), while the animals (18%), diseases (16%) and viruses (2%) were not in match to weeds (Oerke, 2005). Several narrow leaved weeds infest maize fields such as madhona grass (*Dactyloctenium aegyptium* L.) wild oat (*Avena fatua* L.), canary grass (*Phalaris minor* L.), lambsquarters (*Chenopodium album* L.) and bermuda grass (*Cynodon dactylon* L.) while broad leaved weeds include dock (*Rumex dentatus* L.), sweet clover (*Melilotus indica* L.), wild medic (*Medicago polymorpha* L.), crow pea (*Lathyrus aphaca* L.) and field bind weed (*Convolvulus arvensis* L.) (Westendorff et al., 2014; Muhammad et al., 2009). Weeds compete with crops for water, nutrients, space and light (Bhatt and Singh, 2007) and thus reduce maize yield (Iqbal et al., 2015b; Oerke and Dehne, 2004). Kuo et al. (1992) reported that bentgrass (*Agrostis stolonifera*) absorbed more phosphorus (P) compared to crop plants on P-deficient acidic soils. For grain crops, the presence of weeds seeds deteriorated market value of the produce to a great extent (Renton et al., 2006). Weeds were found to be the major factor in decreasing the qualitative and quantitative functioning of agriculture farms along with wide-scale adaptation of organic farming (Lee and Christian, 2017).

The prime aim of any weed control system (cultural, mechanical, biological and chemical) is to create a detrimental environment for the weeds (Harker and O'Donovan, 2013). For centuries, weed control was thought to be a part of seed bed preparation. Hoeing was in use to control weeds which also helped in making different nutrients available (Timmons, 2005). Later research has

showed that hoeing increased water infiltration which in turn increases nutrient availability. Mechanical method is a speedy way to tackle weeds and large area can be covered in shorter time but weather dependence, soil erosion and damage to crop stand make its scope limited (Van Der Weide et al., 2008). Cultural method of weed control is regarded as an effective and cheaper strategy but immediate weed control is not possible, while high labour cost has made it impossible to stick to this traditional weed control practice (Oerke and Dehne, 2004; Oerke, 2005). Biological strategy to control weeds offer long lasting and environmental safer package but host specificity and limited success are the hurdles in the way of its adaptation (Charudattan, 2001). Finally, chemical weed control has been adopted as quick and highly economical measure to keep weeds below threshold level. The biggest concern for using herbicides is the environmental pollution and residual problem for the succeeding crop (Aktar et al., 2009). Every weed control strategy has varying level of effectiveness and their efficiency in controlling weeds cannot be improved without complete understanding.

There is a specific critical period in all crops, during which weed control is critical to evade incurring yield losses especially of maize (Khaliq et al., 2019; Iqbal et al., 2017; Ali et al., 2016; Knezevic et al., 2002). Integrated weed management through destroying weed seed reserves in soil through optimized tillage operations, sowing methods, mulching, hand weeding and herbicides use could be a way to keep weeds below the threshold level (Iqbal et al., 2014; Chauhan and Johnson, 2010). This study reviewed and analyzed the characteristics imparting superiority to weeds over crop plants and impact of different weed control measures on weed-seed bank, germinated weeds density and grain yield of maize under varying pedo-climatic conditions.

2 CHARACTERISTICS IMPARTING SUPERIORITY TO WEEDS OVER CROP PLANTS

Weeds have many distinguished characteristics which make them superior competitor compared to the crop plants. Sutherland (2004) reported that rapid growth of weeds, higher reproduction potential, seed

viability for a longer time, short life span, lack of insect-pest attack and potential for multiple generations in one growing season made them superior to crop plants. In addition, it was recorded that onset of flowering in weeds started earlier and went on till late season, while their flowering stage was the most resilient life stage to biotic and abiotic stresses (Dolferus, 2014). Being self-compatible (ability to pollinate itself with its own pollen) and wind pollinated instead of depending on specialized pollinator guaranteed successful seed production of weeds. Another characteristic imparting resilience to weeds was the development of underground stems which spread under soil surface making weed control strategies ineffective. Furthermore, the presence of spines, pungent smell and allelopathic characteristics kept weeds safe from herbivores. Weeds infestations resulted in crops yield loss, crop contamination, difficulties in harvesting and mechanical operations along with serving as the host of different pests (Roskopf et al., 1999).

3 WEED SEED BANK

Seed is an important entity for maintenance, growth and further propagation of plant species including weeds. Seed population of weeds in the soil is termed as weed seed bank, put forth an impression that soil is a safekeeping place for the weeds but the fact is that only a smaller fraction of weed seeds germinate. Seeds may remain dormant for a long period of time and seed dormancy also influences weed emergence patterns and weed control decisions (Forcella et al., 2000). The weed seed bank in soil represents the source of most weed infestations and weed seed pool affects all agricultural production systems. Weed seed bank density may vary in different soils ranging from zero in virgin soils to 4100-137700 m⁻² (Lee and Christian, 2017).

Managing weed seed bank to lessen the number of viable weed seeds in the soil could be an effective weed control strategy as reducing the number of viable seeds could reduce the weed population. Beckie et al. (2005) found that integrated weed management prevented weeds to shed their seeds in the field, weed patches were reduced by 35%. Thus, it was inferred that failure to control weeds before the onset of reproductive stage could lead to buildup of weed-seed bank and preventing weed seeds to deposit in a particular field not only reduced the weeds in the field but also in neighboring fields. Therefore, efforts should be directed at reducing the weed seed deposition and improving the methods to remove seed from the soil. In addition, higher reproductive potential of weeds

coupled with longer persistence of weed seeds in soil necessitates managing weed seed bank. Changes in the soil seed bank were reported to be influenced by tillage practices, crop rotation and weed control measures (Riemens et al., 2007). Along with moisture, temperature and light which alter the micro-climate of soil, position of seeds in soil profile also determined weed infestations (Knezevic et al., 2002). It was also inferred that seed buried to the greater depths face toxic and germination inhibiting gases which reduce germination (Benvenuti and Macchia, 1998).

4 EFFECT OF TILLAGE ON WEED SEED BANK, WEEDS AND MAIZE YIELD

Tillage includes any physical manipulation of the soil for having better crop production (Rasmussen, 1999). Tillage operations influenced weed seed reserves by inverting the soil along with uprooting weeds seedling and deep burying of the mature seeds (Atkinson et al., 2007). Alongside this, the previously buried seeds were also returned to the soil surface (Streit et al., 2003). Seeds returned to the soil surface as a result of tillage operations germinated and infested the field. However, diversity of weed seeds returning to shallow depths owing to frequent soil disturbance hindered the domination of a few problematic weed species. Perennial weeds tend to increase in number after several years of reduced tillage as their seeds tend to accumulate near the soil surface compared to conventional tillage system (Cardina et al., 1991; Swanton et al., 2008). Deep tillage helped in achieving weed control goal by burying the weed seeds deeper or by destroying the roots of perennial weeds. In contrast, tillage was reported to work more efficiently after the weed seeds had germinated as the weed seeds which had escaped deep burial were eliminated by subsequent tillage (Buhler, 2002). Aikins et al. (2012) employed various tillage operations in maize field and concluded that plowing followed by disc harrow recorded the lowest weed density and the highest yield attributes such as dry cob weight (356 g) and 1000 grain weight (186 g) while no-tillage recorded the highest weed population and lowest grain yield.

Another disadvantage associated with weed control through tillage was its ineffectiveness against the perennial weeds having rhizomes like root system which gained re-growth and re-sprout after tillage operation. However, tillage in dry soil effectively controlled weeds as remaining plant parts dried out in dry soil while moist soil assisted in their re-establishment (Swanton et al., 2008). There are contrasting views about the effectiveness of tillage on

the weed seed bank as Feldman et al. (1997) reported that tillage systems quite effective in reducing weeds density and lowering the profile of weed seed bank. On the other hand, Unger et al. (1999) inferred that tillage was ineffective against weed-seed bank particularly for the weed seeds which were near to the soil surface. In contrast, Cousens and Moss (1990) concluded that different tillage systems influenced the abundance, depth and distribution of weed species in the soil. The used a transition matrix model to predict vertical movement of weed seeds after tillage practices. It was observed that weed seeds accumulated near the soil surface in no-till field and distributed uniformly in fields cultivated by mould-board plough and disk plough. Similar results were recorded by Ball (1992) and Buhler (1995) where weed seed bank was affected by tillage operations. Seed bank of weeds in soil was reported almost two times greater in chiesel ploughed soils compared to no tillage system (duCroix et al., 2000). Tillage practices significantly modified the distribution and abundance of seeds in the soil (Mulugeta and Stoltenberg, 2001) along with altering the weed seed composition in top soil (0-15 cm) compared to seeds lying deeper in the soil (Barberi and Cascio, 2001). In contrast, no tillage operation was reported to suppress the annual broadleaf weeds emergence (Peachy et al., 2004).

In zero tillage system, seeds remained closer to the surface so seeds requiring light to germinate were favored (Chauhan and Johnson, 2008). Jasinskaite et al. (2009) reported the advantage of two-layer ploughing in decreasing perennial weed density and weed biomass. Weed seed emergence were favoured in zero tillage system where seeds were mostly confined to upper 1cm soil layer (Widderick et al., 2010). Soil inversion and depth of tillage strongly affected vertical distribution of weed seeds. Douglas et al. (2001) also confirmed the concentration of weed seed in the upper 10 cm of the soil due to different cultural and mechanical operations. Reduction in the germination of the seeds was due to deep burial of seeds as experienced in deep tillage practices while weed seed burial also resulted in seed persistence for a longer time (Walker et al., 2010).

To advance the existing knowledge seed movement in deeper soil horizons, Mohler et al. (2006) conducted an experiment by employing different coloured seed-like beads at different soil depths. Plowing was done by mould-board plough, chisel plough with straight blades, chisel plough with curved blades, heavy tandem disks, or left untilled. It

was found that 97% of the seeds in 4 cm of the soil profile came from the deeper layers where mould-board plough was used while the probability of seed movement from more than 14 cm depth to the upper layer was only 4%. It was suggested that tillage depleted the surface weed seed bank, however further research is needed to manage weed seed reservoirs in deeper soil layers for developing further management strategies.

5 EFFECT OF MULCHES ON WEED SEED BANK, WEEDS AND MAIZE YIELD

Mulching is the practice of covering the soil with different biological and synthetic material in order to make it more favorable for plant growth and efficient crop production. Rye mulch effectively controlled weeds owing to its allelopathic characteristics (Narwal and Haouala, 2013). On the other hand, mulches of leguminous crops delayed the release of nutrients, while some of the materials released phytotoxic chemicals which made weed seeds unable to germinate. The effectiveness of allelopathic potential of natural mulches and chemical inhibition for reducing weed seedling growth was also established (Westerman et al., 2005).

Soil solarization involving a clear plastic sheet placed over the soil to trap radiations for raising the soil temperature assisted in weed control owing to increment in temperature which was harmful to insects, weed seeds and plant pathogens (Lee and Christian, 2017). This technique could be more effective for weed seeds which were susceptible to increase in temperature. Soil solarization effectively controlled winter weeds requiring lesser temperatures to germinate while the germination of summer annual weeds increased under plastic mulches. Another beneficial aspect of soil solarization was the release of nutrients tied up in the soil organic matter along with killing the unwanted plants and making them a part of soil organic matter. Mulching affected daily fluctuations of day and night temperature which effected the germination of weed seeds (Nijjer et al., 2002). By blocking sun light, there is no more photosynthetic activity of weeds under black plastic mulch (Saroa and Lal, 2003).

The global concern to impart greater sustainability to organic agricultural production has resulted in the use of living mulch systems. Organic mulches instead of plastic mulches also perform some additional tasks by increasing organic matter content and cation exchange capacity (CEC) of the soil along with improving biological activity and nutrient status of soil

(Tian et al., 1994; Lal, 1995). In addition, Ligneau and Watt (1995) also observed a significant germination suppression of annual weeds with application of composted material. Creamer et al. (1995) developed a well modified under-cutter to cut the roots of the cover crops while leaving them intact on the ground as mulch. The aim was to mulch the field with minimum soil disturbance and avoiding shredding of the crop residues (Mohler and Calloway, 1992). They also found that broad leaved weeds such as *Chenopodium*, *Portulaca* and *Digitaria* were more affected by a living mulch crop of rye compared to narrow leaf weeds species. Straws and residues of different crops could be used as mulch which suppressed the weeds by producing allelopathic exudates which killed the weed seedlings (Teasdale and Mohler, 2000). Positive maize yield response due to mulch was observed by Khurshid et al. (2006) as mulch increased moisture content of the soil. They also observed that mulching enhanced soil fauna and flora activities leading to highest crop yield. Crop residues present on the top of the soil suppressed the factors leading to weed seed germination.

Plastic mulches could be more feasible for gardens, cash crops and highly valued agricultural systems, while cover crops may serve the same purpose for large farms. Glab and Kulig (2008) reported that mulch provided moderate soil temperature, porosity and infiltration during rains and assisted in controlling weeds as well as water runoff during intensive rainfall. Some of the associated factors, such as low temperature close to the soil surface, lower light intensity and the residues that release allelopathic contents also favor the crops by suppressing weeds. Isik et al. (2009) also supported cover crops and mulches for reducing weed infestation. Higher moisture content near the soil surface owing to mulching enhanced fertilizer use efficiency (FUE). Essien et al. (2009) reported that instead of more frequent weeding in non-mulched plot, mulched plot gave the better yield due to the fact that mulches have smothering effect on weeds. Bunna et al. (2011) reported that rice straw limited weed biomass from 164 to 123 kg ha⁻¹ in mung bean.

Uwah and Iwo (2011) evaluated the mulching effect on weed suppression and maize yield and found that un-mulched plots had 11 times more weed infestations as compared to the plots having 8 ton ha⁻¹ mulch. When grain yield was averaged, it was observed that increasing mulch rate from 1-2 ton ha⁻¹, grain yield was increased up to 61%, while mulch rate increase of 4 ton ha⁻¹ gave 87.5% higher yield. Kelton et al. (2011)

found that adding crop residue as mulch in conservation tillage system can cause a remarkable reduction in weed seeds in upper 7-8 cm of the soil which led to higher productivity of maize.

6 EFFECT OF HERBICIDES ON WEED SEED BANK, WEEDS AND MAIZE YIELD

In spring planted maize, it is difficult to control weeds manually in hot and harsh conditions (Hassan and Ahmed, 2005; Schaub et al., 2006). Therefore a number of herbicides have been used in maize and are classified according to the various stages of development of crop when they are applied such as pre-emergence or post-emergence herbicides (Devender et al., 1998; Timmons, 2005; Steckel et al., 2007). Babiker et al. (2013) suggested that use of herbicidal mixture (Stomp at the rate of 1.5 L ha⁻¹ a.i. + Gesaprim at the rate of 1.6 kg ha⁻¹ a.i.) controlled weeds in maize crop up to 96.9%. This chemical control was comparable to the hand weeded plot where 100% weed control was ensured. Only the weed *Xanthium barasilicum* which was resistant to herbicides remained successful in escaping chemical control.

The effect of chemical weed control on weed seed bank in the soil is more or less selective. Its effect may be direct when it allows specific weeds to germinate but do not let others to germinate or indirect when herbicides are applied to fully matured plants (Derksen et al., 1995). Vencill and Banks (1994) confirmed that high herbicide input result in decreasing the soil seed bank in grain sorghum (*Sorghum bicolor*) irrespective of the other treatments. Pre harvest application of Glyphosate decrease seed production and viability in late flowering weeds. Herbicides have proved to be an effective weed control measure applied at different rates (Ali and Tunio, 2002). Weed seed bank densities tend to be lesser in systems reliant on herbicides (Robert and Shirliffe, 2009) compared to no-till systems. Rahman et al. (2001) inferred that pre emergence atrazine, alachlor and atrazine + alachlor helped in reducing the soil weed seed bank significantly as compared to no herbicide treatment. They also concluded that reduced use of herbicides resulted in build-up of weed seed bank. Rinella et al. (2010) used a different way to reduce the seed bank deposit in the soil profile through growth regulator herbicides applied at late growth stage which led to reduced seed production of the weeds.

Ullah et al. (2008) conducted an experiment using Pendimethalin and hand weeding to control weeds in maize crop. The highest grain yield (3.6 ton ha⁻¹) was

obtained with the treatment stomp + hand weeding at 4 weeks after sowing. Likewise, Ali et al. (2011) evaluated Primextra gold (1 L ha^{-1}), wheat straw, newspaper mulch, black plastic mulch, sorghum mulch and hand weeding. Primextra gold along with hand weeding remained on top producing the greatest 1000 grain weight (245.7 g) and grain yield (4.3 ton ha^{-1}) of maize.

7 EFFECT OF SOWING METHODS ON WEED SEED BANK, WEEDS AND MAIZE YIELD

Agronomic practices including sowing methods affect weeds population depending upon the space available to them to grow (Belachew and Abera, 2010). Tollenaar and Aguilera (1992) found that number of days taken to tasseling, grain per cob, grain weight and harvest index of maize were significantly affected by planting methods. Significantly higher plant height, 1000 grain weight and grain yield were obtained by ridge sowing method owing to lesser weed density (Sandhu and Hundal, 1991). In contrast, raised bed planting method resulted in lower weed density which increased water and nutrient use efficiency (Wang et al., 2004; Ali and Seyedeh, 2008). Govaerts et al. (2004) and Ortega et al. (2008) also confirmed that raised bed sowing method produced higher grain yield of maize and the minimum weeds dry weight.

Bakht et al. (2007) concluded that the maximum number of grains per cob, 1000 grain weight and grain yield were obtained from ridge sown maize. Memon et al. (2007) found the highest germination percentage, seed index the maximum grain yield (6.35 ton ha^{-1}) of maize sown on ridges compared to drilling and broadcasting methods. Abdullah et al. (2008) investigated the effect of sowing methods and herbicides and their interaction effect on yield and yield components of maize. They observed the maximum plant height, leaf area (346.79 cm^2) and biological yield with ridge planting of maize.

Maize was sown in 30 cm spaced single rows and 45 cm apart double rows by Ahmad et al. (2012) and the results depicted that the maximum plant height, leaf area, crude protein and crude fiber were observed in maize sown at 30 cm apart single rows, while weed density was also reduced. In contrast, Lambe et al. (1998) observed the highest yield of maize with row spacing of 60 cm compared to 30, 45 and 60 cm. Zamir et al. (2013) also investigated the effect of sowing methods and mulches on weed density and yield of spring planted maize and concluded that single row ridges of maize remained superior to alternate double row ridges, furrow and

flat sowing methods as far as the grain yield and weeds biomass were concerned.

8 EFFECT OF HAND WEEDING ON WEED SEED BANK, WEEDS AND MAIZE YIELD

Hand pulling, hoeing and roughing are different names of hand weeding. Hand weeding involves the physical damage to the weed plants or soil disturbance with the aim of uprooting or burying the weeds. Hoeing separates top from the roots and seedlings dry off. Most effective weed control was achieved from breaking, crushing, cutting and crimping their stems mechanically (Creamer and Dabney, 2002). It should be ensured to hand pull the weeds before the start of reproductive stage otherwise seed shattering and dispersal fill the weed seed bank.

Ali et al. (2011) reported that on hand weeding produced the maximum yield attributes which led to the highest grain yield of maize. Highest 1000 grain weight (245.7 g), biological yield (12.5 ton ha^{-1}) and grain yield (4.3 ton ha^{-1}) of maize was obtained when weeds were controlled by hand weeding while wheat straw mulch, sorghum mulch, newspaper mulch and plastic mulch remained insignificant as far as grain yield of maize was concerned. Riaz et al. (2007) reported that on hand weeding in maize at 20 and 50 DAS gave the maximum yield compared to chemical control. Hand weeding produce 42% more yield compared to mechanical weeding done at 20 DAS and hand weeding at 50 DAS. Weed biomass also remained lower in plots where hand weeding was done. Munsif et al. (2009) favored hand weeding as it remained superior to chemical weed control by giving the highest grain yield ($3.147 \text{ ton ha}^{-1}$) and harvest index (34.8%) of maize. Babiker et al. (2013) concluded that on hand weeding was a promising strategy as far as weed control and maize yield were concerned. Maize gave the maximum cob weight, number of grains per plant, grain weight per plant and grain yield in plots where hand weeding was performed. However, in-depth research is needed to investigate the impact of hand weeding on weed-seed bank in upper and deeper soil layers.

Environmental pollution caused by excessive use of herbicides has necessitated integrated weed management involving multiple tools and practices to keep weed population below threshold level. Weed-seed bank in soil serves as a source of weed reserve which needs to be managed for keeping check on weeds germination. Although, herbicides offered one of the most effective method to control weed

population, but other agronomic management methods like tillage assisted in burying weed seeds into the deeper soil layers which reduced weed germination. Mulching effectively reduced weed seeds germination by increasing soil temperature and inhibiting light penetration. Sowing methods and hand weeding also imparted significant influence on weed density in maize but more in-depth research is needed to assess their impact on weed-seed bank.

9 INTEGRATED WEED MANAGEMENT

Despite years of efforts to control weeds, these continued to remain a biggest challenge to agricultural economy. An integrated approach employing multiple tactics to limit weed population and enhance competitive ability of crops could yield better results in terms of weed control (Jones and Medd, 2005; Swanton et al., 2008; Smith et al., 2010; Gibson et al., 2013). Although, weed control by using different chemicals is an effective approach however; manipulating different agronomic practices under an integrated package could be comparatively more biologically and economically viable for controlling weeds (Westerman et al., 2005). Integration of variety of tools, practices and organisms along with manipulating the agroecosystem was recorded to be efficient and economical for keeping the competitive balance in favor of crops against the weeds (Thomas et al., 2010). Integrated weed management resulted in reducing the reliance on herbicides by lowering the germination rate of weeds through directly effecting weed-seed bank which helped in controlling environmental pollution caused by heavy usage of pesticides (Gibson et al., 2011; Sogaard and Lund, 2007; Llewellyn et al., 2005).

10 CONCLUSIONS

To conclude with, weeds have comparatively higher potential to survive and propagate even under harsh agro-climatic conditions and ultimately inflict colossal quantitative and qualitative deterioration to cereals including maize. Weeds maintain a healthy reserve of their seeds in different soil horizons which serves as surety bank to maintain their existence whenever germination conditions become favorable. The management of weed seed bank by employing a holistic approach through integration of strategies such as deep tillage, practicing mulching of both biological and synthetic materials and optimizing crop sowing method especially raised bed technique can pave the way to reducing weeds seed bank deposits. Moreover, cover crops, crop rotation, directed placement of fertilizers and soil amendments may reduce the

density of germinated weeds leading to enhanced maize yield. However, integrated approaches of weed seed bank management and weed control are not without limitations as holistic strategy results in increased production costs making it difficult to combine different practices and operations. In addition, selection of different tools for controlling weed-seed bank and weeds density require detailed agroecological knowledge to integrate and implement all the tactics which is presently lacking for most part of agricultural regions of the developing world. The efforts to switch agriculture to more conservational and environment friendly farming have open new avenues to control the weeds which necessitates further in-depth research for controlling weed-seed bank.

11 CONTRIBUTIONS

QM developed the idea and synthesized the literature, RNA conceived the idea and furnished guidance, MAQ reviewed the literature and prepared the initial draft, SKA reviewed the draft and added latest literature, AI added literature and reviewed the article, AS critically reviewed the literature and formatted it as per journal's format.

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13 REFERENCES

- Abdullah GH, Khan IA, Khan SA, Ali H. Impact of planting methods and herbicides on weed biomass and some agronomic traits of maize. *Pak J Weed Sci Res.* 2008;14:121-30.
- Ahmad W, Azrf-UL-Haq A, Muhammad SIZ, Muhammad A, Mohsin AU, Khalid F, et al. Qualitative and quantitative response of forage maize cultivars to sowing methods under subtropical conditions. *J Anim Plant Sci.* 2012; 22:318-23.
- Aikins SHM, Afuakwa JJ, Owusu-Akuoko O. Effect of four tillage practices on maize performance under rainfed conditions. *Agric Biol J N Am.* 2012;3:25-30.
- Aktar M.W. Sengupta D, Chowdhury A. Impact of pesticides use in agriculture: their benefits and hazards. *Interdiscip Toxicol.* 2009;2(1):1-12.
- Ali QM, Tunio S. Effect of various planting pattern on weed population and yield of wheat. *Asian J Plant Sci.* 2002;1:216-7.
- Ali RS, Seyedeh NH. Effects of alternate furrow irrigation and nitrogen application rates on yield and water-and nitrogen-use efficiency of winter wheat (*Triticum aestivum* L.). *Plant Prod Sci.* 2008;11:250-9.
- Ali K, Munsif F, Hussain Z, Khan I, Ahmad N, Khan N, Shahid M. Effect of different weed control methods on weeds and maize grain yield. *Pak J Weed Sci Res.* 2011;17:313-321.

- Ali AA, Iqbal A, Iqbal MA. Forage maize (*Zea mays* L.) germination, growth and yield get triggered by different seed invigoration techniques. *World J Agric Sci*. 2016;12(2):97-104.
- Atkinson HS, Sparkes DL, Mooney SJ. Using selected soil physical properties of seedbeds to predict crop establishment. *Soil Till Res*. 2007;97:218-28.
- Babiker MM, Salah AE, Mukhtaret MU. Impact of herbicides Pendimethalin, Gesaprim and their combination on weed control under maize (*Zea mays* L.). *J AIS*. 2013;1:17-22.
- Bakht J, Siddique MF, Shafi M, Akbar H, Tariq M, Khan N, et al. Effect of planting methods and nitrogen levels on the yield and yield components of maize. *Sarhad J Agric*. 2007;23:553-9.
- Ball DA. Weed seed bank response to tillage, herbicides, and crop rotation sequence. *Weed Sci*. 1992;40:654-9.
- Barberi P, Cascio BL. Long-term tillage and crop rotation effects on weed seed bank size and composition. *Weed Res*. 2001;41:325-40.
- Beckie H, Hall LM, Schubat B. Patch management of herbicide-resistant wild oat (*Avena fatua*). *Weed Technol*. 2005;19:697-705.
- Belachew T, Abera Y. Response of maize (*Zea mays* L.) to tied ridges and planting methods at Goro, Southeastern Ethiopia. *Am Eur J Agron*. 2010;3:21-4.
- Benvenuti S, Macchia M. Phytochrome mediated germination control of *Datura stramonium* L. seeds. *Weed Res*. 1998;38:199-205.
- Bhatt MD, Singh SP. Soil seed bank dynamics of weed flora in upland and lowland paddy cultivation areas of far western Nepal. *Sci World*. 2007;5:54-9.
- Buhler DD. Influence of tillage system on weed population dynamics and management in corn and soybean in the central USA. *Crop Sci*. 1995;35:1247-58.
- Buhler DD. Challenges and opportunities for integrated weed management. *Weed Sci*. 2002;50:273-280.
- Bunna S, Sinath P, Makara O, Mitchell J, Fukaiet S. Effects of straw mulch on mungbean yield in rice fields with strongly compacted soils. *Field Crops Res*. 2011;124:295-301.
- Cardina J, Regnier E, Harrisonet K. Long-term tillage effects on seed banks in three Ohio soils. *Weed Sci*. 1991;39:186-94.
- Chauhan BS, Johnson DE. Germination ecology of Chinese sprangletop (*Leptochloa chinensis*) in the Philippines. *Weed Sci*. 2008;56:820-5.
- Chauhan BS, Johnson DE. The role of seed ecology in improving weed management strategies in the tropics. *Adv Agron*. 2010;105:221-62.
- Charudattan R. Biological control of weeds by means of plant pathogen: significance for integrated weed management in modern agro-ecology. *BioControl*. 2001;46:229-60.
- Cousens R, Moss SR. A model of the effects of cultivation on the vertical distribution of weed seeds within the soil. *Weed Res*. 1990;30:61-70.
- Creamer NG, Plassman B, Bennett MA, Wood RK, Stinner BR, Cardina J. A method for mechanically killing cover crops to optimize weed suppression. *Am J Alt Agric*. 1995;10:157-62.
- Creamer NG, Dabney S. Killing cover crops mechanically: review of recent literature and assessment of new research. *Am J Alternative Agric*. 2002;17:2-40.
- Derksen DA, Thomas AG, Lafond GP, Loeppky HA, Swanton CJ. Impact of post emergence herbicides on weed community diversity within conservation tillage systems. *Weed Res*. 1995; 35:311-20.
- Devender S, Tyagi RC, Agarwal SK, Singh D. Weed control methods in spring maize. *Haryana Agric Uni J Res*. 1998;28:21-5.
- Dolferus R. To grow or not to grow: a stressful decision for plants. *Plant Sci*. 2014;229:247-61
- Douglas DB, Kohler KA, Thompson RL. Weed seed bank dynamics during a five-year crop rotation. *Weed Technol*. 2001;15:170-6.
- duCroix, SMJ, Asker RCV, Derksen DA, Thomas AG. Depth of seedling recruitment of five weed species measured in-situ in conventional and zero-tillage fields. *Weed Sci*. 2000;48:327-32.
- Essien BA, Essien JB, Nwite JC, Eke KA, Anaele UM, Ogbu JU. Effect of organic mulch materials on maize performance and weed growth in the derived savanna of south eastern Nigeria. *Nig Agric J*. 2009;40:255-62.
- Feldman SR, Alzugaray C, Torres PS, Lewis P. The effect of different tillage systems on the composition of the seed bank. *Weed Res*. 1997;37:71-6.
- Forcella F, Arnold RLB, Sanchez R, Ghersa CM. Modeling seedling emergence. *Field Crops Res*. 2000;67:123-39.
- Gibson DJ, Gage KL, Matthews JL, Young BG, Owen MDK, Wilson RG, et al. The effect of weed management systems and location on arable weed species communities in glyphosate-resistant cropping systems. *Appl Veg Sci*. 2013;16:676-87.
- Gibson KD, McMillan J, Hallett SG, Jordan T, Weller SC. Effect of a living mulch on weed seed banks in tomato. *Weed Technol*. 2011;25:245-51.
- Glab T, Kulig B. Effect of mulch and tillage system on soil porosity under wheat (*Triticum aestivum*). *Soil Till Res*. 2008;99:169-78.
- Govaerts B, Sayre KD, Deckers J. Stable high yields with zero tillage and permanent bed planting. *Field Crops Res*. 2004;79:116-8.
- Harker KN, O'Donovan JT. Recent weed control, weed management, and integrated weed management. *Weed Technol*. 2013;27:1-11.
- Hassan AAA, Ahmed MKA. The influence of some herbicides and additional hoeing in maize growth and yield and yield components. *Int J Agri Biol*. 2005;7:708-11.
- Iqbal A, Iqbal MA, Iqbal A, Aslam Z, Maqsood M, Ahmad Z, et al. Boosting forage yield and quality of maize (*Zea mays* L.) with multi-species bacterial inoculation in Pakistan. *Phyton- Int J Exp Bot*. 2017;86:84-8.
- Iqbal MA, Ahmad MM. Boosting spring planted irrigated maize (*Zea mays* L.) grain yield with planting patterns adjustment. *Am Eur J Agric Environ Sci*. 2015a;15(3):315-9.

- Iqbal MA, Qaiser M, Rana NA, Asif I, Sher A, Nadeem A. An appraisal of benzoic acid and sorgaab effect on weed management and wheat (*Triticum aestivum* L.) yield. *ARPN J Agric Biol Sci.* 2015b;10(2):44-7.
- Iqbal A, Iqbal MA, Ali R, Nadeem A, Rana NA, Haroon ZK. Integrated nitrogen management studies in forage maize. *Am Eur J Agric Environ Sci.* 2014;14(8):744-7.
- Isik D, Kaya E, Ngouajio M, Mennan H. Weed suppression in organic pepper (*Capsicum annuum* L.) with winter cover crops. *Crop Prot.* 2009;28:356-63.
- Jasinskaite S, Pilipavicius V, Lazauskas P. Perennial weed control by two layer ploughing. *Agron Res.* 2009;7:227-82.
- Jones RE, Medd RW. A methodology for evaluating risk and efficacy of weed management technologies. *Weed Sci.* 2005;53:505-14.
- Kelton JA, Price AJ, Santen EV, Balkcom KS, Arriaga FJ, Shaw JN. Weed seed bank density and composition in tillage and landscape variability study. *CBCS.* 2011;6:21-30.
- Khaliq A, Iqbal MA, Zafar M, Gulzar A. Appraising economic dimension of maize production under coherent fertilization in Azad Kashmir, Pakistan. *Cust Agroneg.* 2019;15(2):243-53.
- Khurshid KM, Iqbal M, Arif MS, Nawaz A. Effect of tillage and mulch on soil physical properties and growth of maize. *Int J Agric Biol.* 2006;8:593-6.
- Knezevic SZ, Evans SP, Blankenship EE, VanAcker RC, Lindquist JL. Critical period for weed control: the concept of data analysis. *Weed Sci.* 2002;50:773-86.
- Kuo S, Brauen SE, Jellum EJ. Phosphorus availability in some acid soils influences bentgrass and annual bluegrass growth. *Hort Sci.* 1992;27:370-4.
- Lal R. Tillage and mulching effects on maize yield for seventeen consecutive seasons on a tropical alfisol. *J Sustain Agric.* 1995;5:79-93.
- Lambe DL, Patil SM, Jiotode DJ. Drainage. Effect of irrigation levels and row spacing on yield of rabi maize (*Zea mays* L.). *J Soil Crops.* 1998;8:95-9.
- Lee N, Christian T. Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. *Agron Sustain Dev.* 2017;37:48-72.
- Ligneau LAM, Watt TA. The effects of domestic compost upon the germination and emergence of barley and 6 arable weeds. *Ann Appl Biol.* 1995;126:153-62.
- Llewellyn RS, Pannell DJ, Lindner RK, Powles SB. Targeting key perceptions when planning and evaluating extension. *Aust J Exp Agric.* 2005;45:1627-33.
- Memon SQ, Baig MB, Mari GR. Tillage practices and effect of sowing methods on growth and yield of maize crop. *Agric Trop Subtrop.* 2007;40:89-100.
- Mohler CL, Calloway MB. Effects of tillage and mulch on the emergence and survival of weeds in sweet corn. *J Appl Ecol.* 1992;29:21-34.
- Mohler CL, Finch JC, McCulloch CE. Vertical movement of weed seed surrogates by tillage implements and natural processes. *Soil Till Res.* 2006;86:110-22.
- Muhammad S, Khan Z, Cheema TA. Importance value index (IVI) of weed flora of some maize fields. *Pak J Weed Sci.* 2009;15:91-105.
- Mulugeta D, Stoltenberg DE. Increased weed emergence and seed bank depletion by soil disturbance in no tillage systems. *Weed Sci.* 2001;45:234-41.
- Munsif F, Ali K, Khan I, Khan HU, Anwar M. Efficacy of various herbicides against weeds and their impact on yield of Maize. *Pak J Weed Sci Res.* 2009;15:191-8.
- Narwal SS, Haouala R. Role of allelopathy in weed management for sustainable agriculture. *Allelopathy.* 2013;217-49.
- Nijjer S, Lankau RA, Rogers WE, Siemann E. Effects of temperature and light on Chinese Tallow (*Sapiu sebiferum*) and Texas sugarberry (*Celtis laevigata*) seed germination. *Tex J Sci.* 2002;54:63-8.
- Oerke EC. Crop losses to pest. *J Agri Sci.* 2005;143:1-13.
- Oerke EC, Dehne HW. Safeguarding Production losses in major crops and the role of crop production. *Crop Prot.* 2004;23:275-285.
- Ortega AL, Mir EV, Rangel EE. Nitrogen management and wheat genotype performance in a planting system on narrow raised beds. *Cereal Res Commun.* 2008;36:343-52.
- Peachy RE, William RD, Smith CM. Effect of no-till or conventional planting and cover crops residues on weed emergence in vegetable row crops. *Weed Technol.* 2004;18:1023-30.
- Rahman A, James TK, Mellsop JM, Grabavac N. Weed seed bank dynamics in maize under different herbicide regimes. *NZ Plant Prot.* 2001;54:168-73.
- Rasmussen KJ. Impact of ploughless soil tillage on yield and soil quality: a Scandinavian review. *Soil Till Res.* 1999;53:3-14.
- Renton M, Peltzer S, Diggle A. Using the Weed Seed Wizard to Understand and Manage the Weed Seed bank. Australian Society of Agronomy, 2006.
- Riaz M, Jamil M, Mahmood TZ. Yield and yield components of maize as affected by various weed control methods under rain-fed conditions of Pakistan. *Int J Agri Biol.* 2007;9:152-5.
- Riemens MM, Groeneveld RMW, Lotz LA, Kropff MJ. Effects of three management strategies on the seed bank, emergence and the need for hand weeding in an organic arable cropping system. *Weed Res.* 2007;47:442-51.
- Rinella MJ, Masters RA, Bellows SE. Growth regulator herbicides prevent invasive annual grass seed production under field conditions. *Range Ecol Manag.* 2010;63:487-90.
- Robert HG, Shirliffe SJ. Weed seed banks: biology and management. *Prairie Soils Crops J.* 2009;2:46-52.
- Roskopf EN, Charudattan R, Kadir JB. Handbook of Biological Control. Academic Press, 1999.
- Sandhu BS, Hundal SS. Effects of method and date of sowing on productivity of winter maize (*Zea mays*). *Indian J Agric Sci.* 1991;61:178-81.
- Saroa GS, Lal R. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in Central Ohio. *Land Degrad Dev.* 2003;14:481-93.

- Schaub B, Marley P, Elzein A, Kroschel J. Field evaluation of an integrated *Striga hermonthica* management in Sub-Saharan Africa: synergy between *Striga* mycoherbicides (biocontrol) and sorghum and maize resistant varieties. *J Plant Dis Protec.* 2006;20:691-9.
- Silva DRO, Vargas L, Agostinetto D, Mariani F. Glyphosate-resistant hairy fleabane competition in soybean. *Bragantia.* 2014;73:451-7.
- Smith RG, Mortensen DA, Ryan MR. A new hypothesis for the functional role of diversity in mediating resource pools and weed-crop competition in agro ecosystems. *Weed Res.* 2010;50:37-48.
- Sogaard HT, Lund I. Application accuracy of a machine vision controlled robotic micro-dosing system. *Biosyst Eng.* 2007;96:315-22.
- Steckel LE, Sprague CL, Stoller EW, Wax LM, Simmons FW. Tillage, cropping system and soil depth effects on common waterhemp (*Amaranthus rudis*) seed-bank persistence. *Weed Sci.* 2007;55:235-9.
- Streit B, Rieger SB, Stamp P, Richner W. Weed populations in winter wheat as affected by crop sequence, intensity of tillage and time of herbicide application in cool and humid climate. *Weed Res.* 2003;43:20-32.
- Sutherland S. What makes a weed a weed: life history, traits of native and exotic plants in the USA. *Oecologia.* 2004;141:24-39.
- Swanton CJ, Mahoney KJ, Chandler K. Integrated weed management: knowledge based weed management systems. *Weed Sci.* 2008;56:168-72.
- Teasdale JR, Mohler CL. The quantitative relationship between weed emergence and the physical properties of mulches. *Weed Sci.* 2000;48:385-92.
- Thomas AG, Legere A, Leeson JY, Stevenson FC, Holm FA, Gradin B. Weed community response to contrasting integrated weed management systems for cool dryland annual crops. *Weed Res.* 2010;51:41-50.
- Tian G, Kang B, Brussoard L. Mulching effects of plant residue with chemically contrasting composition of maize growth and nutrient accumulation. *IITA Res.* 1994;9:7-11.
- Timmons FL. A history of weed control in the United States and Canada. *Weed Sci.* 2005;53:748-61.
- Tollenaar M, Aguilera A. Radiation use efficiency of old and new maize hybrids. *Agron J.* 1992;84:536-41.
- Ullah W, Khan MA, Sadiq M, Rehman H, Nawaz A, Sher MA. Impact of Integrated weed management on weeds and yield of maize. *Pak J Weed Sci Res.* 2008;14:141-51.
- Unger PW, Miller SD, Jones OR. Weed seeds in long term dryland tillage and cropping system plots. *Weed Res.* 1999;39:213-23.
- Uwah DF, Iwo GA. Effectiveness of organic mulch on the productivity of maize (*Zea mays* L.) and weed growth. *J Anim Plant Sci.* 2011;21:525-30.
- Van Der Weide RY, Bleeker PO, Achten VTJM, Lotz LAP, Fogelberg F, Melander B. Innovation in mechanical weed control in crop rows. *Weed Res.* 2008;48:215-24.
- Vencill WK, Banks PA. Effects of tillage systems and weed management on weed populations in grain sorghum (*Sorghum bicolor*). *Weed Sci.* 1994;42:541-2.
- Walker SR, Wu H, Bell K. Emergence and seed persistence of *Echinochloa colona*, *Urochloa panicoides* and *Hibiscus trionum* in the sub-tropical environment of north-eastern Australia. *Plant Protec Quar.* 2010;25:127-32.
- Wang F, Xuqing W, Sayre K. Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. *Field Crops Res.* 2004;87:35-42.
- Westerman PA, Liebman M, Menalled FD, Heggenstaller AH, Hartzler RG, Dixon PM. Are many little hammers effective? Velvet leaf (*abutilon theophrasti*) population dynamics in two and four year crop rotation systems. *Weed Sci.* 2005;53:382-92.
- Westendorff NR, Agostinetto D, Ulguim AR, Perboni LT, Silva BM. Yield loss and economic thresholds of yellow nutsedge in irrigated rice as a function of the onset of flood irrigation. *Bragantia.* 2014;73:32-8.
- Widderick MJ, Walker SR, Sindel BM, Bell KL. Germination, emergence and persistence of *Sonchus oleraceus*, a major crop weed in sub-tropical Australia. *Weed Biol Manag.* 2010;10:102-12.
- Zamir MSI, Yaseen G, Javeed HMR, Ahmad AUH, Tanveer A, Yaseen M. Effect of different sowing techniques and mulches on the growth and yield behavior of spring planted maize (*Zea mays* L.). *Cercet Agron Moldova.* 2013;46:77-82.