Weed dynamics in no-till maize system and its management: A review

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Abstract
Among different factors, tillage and weed management are two important factors that influence remarkably the growth and yield of maize. The present review reveals that *Echinochloa colona* L. is the most dominant weed species with an importance value index (IVI) of 41 followed by *Papaver rhoeas* L. (32.6), *Descurainia Sophia* L. (22.27) and *Polygonum aviculare* L (16.16) in no-till maize. Wider spacing and initial slow growth of maize during the first 3-4 weeks provides enough opportunity for weeds to invade and offer severe competition, resulting in 60-81% in maize yield losses. The shift of the weed population towards perennial was observed under NT. Species like *Xanthium strumarium, Solanum nigrum, Euphorbia helioscopia, Convolvulus arvensis, Sorghum halepense, Digitaria sanguinalis, Sonchus oleraceus* and *Euphorbia vermiculata* were associated with no-till *Zea mays*. The highest weed seed density was found in conservation agriculture practices (no-tillage, no-fertilizer and no-herbicide use) with the highest seed distributed in 0-1 cm depth followed by 1-3 cm depth. Weed control efficiency of Nicosulfuron @0.90 kg/ha was found the highest (98.8%) followed by Atrazine + Tembotrione + Atrazine (@1 kg/ha + 120 g/ha + 0.5 kg/ha) (98.7%) and Tembotrione + atrazine (@ 120 g/ha + 0.5 kg/ha) (96.5%), therefore were very effective in controlling weed in no-till *Zea mays*.

Keywords: Maize, management, no-till, weeds

Introduction

Maize (*Zea mays* L.), is one of the most important cereal crops belonging to the family Poaceae. It ranks third in the world production after wheat and rice but it surpasses all cereals in productivity (Deshmukh *et al.,* 2009). The productivity of maize in Nepal is 2.83 (AITC, 2020). Yield losses in maize of 60-81% occur due to weed infestation (Lagoke *et al.,* 1998). The ear number per plant and 1000-seed weight of grains decreased linearly with increasing duration of weed interference and seed number per ear was the most sensitive yield component to weed interference (Evans *et al.*, 2003). Imoloame and Omolaiye (2017) reported that the weed interference in maize for 6 weeks after sowing and beyond significantly depressed growth parameters and grain yield. Plots left weedy for only 3 weeks after sowing produced significantly higher yield which was comparable to the maximum.

Appropriate tillage operations are desired for better crop yields and as a result of which the total production increases (Memon *et al.,* 2012). In recent years, the traditional deep tillage is gradually replaced by the no-tillage system because it reduces soil erosion, increases soil organic carbon, improves water quality, reduced soil compaction, optimizes soil moisture, increases yield and reduces fuel consumption (Oerke, 2005). Changes from traditional tillage to a conservation tillage system can lead to shifts in weed species composition (Ball and Miller, 1993). Some species display a greater capacity of infestation when the intensity of tillage is reduced (Buhler *et al.,* 1994). Several researchers have observed that changes in weed species composition could occur by the adoption of the conservation tillage system (Ball and Miller, 1993). There were more kinds and quantities of weeds in no-tillage farmland, so its consumption of herbicides was much higher (Bo *et al.,* 2013). Reducing herbicide consumption and avoiding weed resistance in the conservation tillage system has become the key issues of modern sustainable agriculture (Brainard and Mirsky, 2013). Careful monitoring and management of the weed flora during the initial period of transition from conventional tillage to conservation tillage are stressed (Santin Montany *et al.,* 2004). Soil disturbance is considered an important factor in breaking dormancy and might explain lower weed densities under no-tillage compared to the other tillage systems (Blackshaw *et al.,* 2002). Studies have compared weed growth parameters as influenced by tillage (Cardina *et al.,* 2002; Davis *et al*., 2005).

Methodology

An extensive review was done to collect pertinent data going through several proceedings, annual reports, pamphlets, and booklets, thesis works and so on from different national, public and private organizations. Similarly, the findings are mainly based on the secondary information of the thesis available in the Central Library of Agriculture and Forestry University, Rampur, Chitwan in the respective field.

Discussions

Weed dynamics under different tillage systems

Tillage affects weeds by uprooting, dismembering, and burying them deep enough to prevent emergence, by moving their seeds both vertically and horizontally, and by changing the soil environment and so promoting or inhibiting weed seed germination and emergence. Any reduction in tillage intensity or frequency may, therefore, influence the weed infestation. The composition of weed species and their relative time of emergence differ between conservation tillage systems and soil-inverting conventional tillage systems. Their germination and emergence may be accelerated by the type of equipment used in soil-inverting tillage systems than by CT machinery. Shifts in weed populations from annuals to perennials have been observed in conservation tillage systems. Weeds cause enormous damage (30 to 50 %) to the maize crop depending upon the growth and persistence of the weed population in standing crop (Rout and Satyapathy, 1996). Weeds reduce crop yield by competing for light, water, nutrients and carbon dioxide, interfere with harvesting and increase the cost involved in crop production depending on the type of weed flora, intensity and duration of crop weed competition (Oerke, 2005). The effect of tillage on the weed community dynamics was greater when the cereal crop was present (Alarcóna *et al.*, 2018).

Critical period of crop-weed competition

The critical crop growth stages consider as the most vulnerable period for crop-weed competition, during which crop must be weed free to prevent yield losses. In the no-tillage system, a critical time of weed removal (CTWR) of 33 and 31 DAE (Helvig *et al.*, 2020). Wider spacing and the slow-growing nature of the crop during the first 3-4 weeks provide enough opportunity for weeds to invade and offer severe competition resulting in 30-100% yield reduction (Sandhu *et al.*, 1999). Yield losses of 60-81% in maize due to weed infestation (Lagoke *et al.*, 1998). Due to infestation of grasses, non-grassy weeds and sedges in maize yield losses of 77.4%, 44.2% and 38.4% were observed respectively (Pandey *et al.*, 2002).

Effect of tillage on weed species composition

The nature and growth of weed species are greatly influenced by tillage. Various types of tillage practices are adopted worldwide, out of which conventional and conservation are most predominant. Certain weed species germinate and grow more profusely than others under the continuous ZT system. The shift in weed population towards perennials have also been observed in conservation tillage systems simply because of less or no disturbance of the root system of perennial weeds and no or less effect of the herbicides which are mainly used to control annual weeds under ZT systems. However, differential responses of weed species are found to varying tillage practices, irrespective of dicot or monocot. Species like *Ageratum conyzoides, Digitaria ciliaris, Echinochloa colona, Eclipta prostrata, Eleusine indica, Amaranthus* species *(A. retroflexus* and *A. powelli), Echinochloa crusgalli, Sida rhombifolia, Sonchus oleraceus* and *Portulaca oleracea* have been reported to be greater in no-till system than in conventional tillage system (Chauhan and Johnson, 2009). *Cynodon dactylon, Convolvulus arvensis* and *Cirsium arvense, Conyza canadensis, Tribulus terrestris, Convolvulus arvensis* and *Cyperus rotundus* are easily controlled under conservation tillage systems (Demjanová *et al.*, 2009) whereas weeds like *Dinebra* sp. and *Digitaria* sp. and dicot weeds such as *Euphorbia*, *Eclipta* sp., *Alternanthera philoxeroides* were found more under conventional tillage (Blaise *et al.*, 2015). *Saccharum spontaneum* is generally observed only in the reduced tillage and no-tillage systems. Eliçin *et al.*, (2018) reported dominant weed species *Xanthium strumarium, Solanum nigrum, Euphorbia helioscopia, Convolvulus arvensis* and *Sorghum halepense* than other weeds species in NT. Similarly, *Chenopodium album, Euphorbia heterophylla,* *Molluga verticillata* and *A. retroflexus* were associated with Conventional tillage (Helvig *et al.,* 2020). *Digitaria sanguinalis*, *Sonchus oleraceus* and *Euphorbia vermiculata* were associated with NT (Swanton *et al.,* 1999). Zero tillage significantly delayed the emergence of *Commelina benghalensis* by 2-3 days over other tillage methods because of deep placement (35.4 mm) of its seeds/rhizomes in zero tillage plots as compared to plots with other tillage methods (29-32 mm) (Chopra *et al.,* 2014).

Table 1. Dominant weed flora found in no-till condition

Weed species	Family	Importance value index (%)	References
Echinochloa colona	Grasses	41	Rao *et al.,* (2009)
Papaver rhoeas	Broadleaf	32.6	Alarcóna *et al*., (2018)
Descurainia Sophia	Broadleaf	22.27	Alarcóna *et al*., (2018)
Polygonum aviculare	Grasses	16.16	Alarcóna *et al*., (2018)
Chrozophora rottleri	Broadleaf	15	Rao *et al.,* (2009)
Trianthema portulacastrum	Broadleaf	13	Rao *et al.,* (2009)
Merremia emerginata	Broadleaf	12	Reddy *et al*. (2012)
Dinebra. retroflexa	Grasses	11	Reddy *et al*. (2012)
Chenopodium album	Broadleaf	10.91	Alarcóna *et al*., (2018)
Digeria arvensis	Broadleaf	9	Reddy *et al*. (2012)
Euphorbia hirta	Broadleaf	9	Reddy *et al*. (2012)
Cyperus rotundus	Sedges	8	Reddy *et al*. (2012)
Panicum repens	Grasses	8	Reddy *et al*. (2012)
Leptochloa chinensis	Grasses	7	Reddy *et al*. (2012)
Galium tricornutum	Broadleaf	4.08	Alarcóna *et al*., (2018)
Veronica hederifolia	Broadleaf	3.77	Alarcóna, *et al*., (2018)
Anacyclus clavatus	Broadleaf	3.42	Alarcóna, *et al*., (2018)
Phyllanthus niruri	Broadleaf	3	Rao *et al.,* (2009)
Avena sterilis	Grasses	2.7	Alarcóna *et al*., (2018)
Cynodon dactylon	Sedges	2	Rao *et al.,* (2009)
Amaranthus blitoides	Broadleaf	1.36	Alarcóna *et al*., (2018)
Papaver hybridum	Broadleaf	1.36	Alarcóna *et al*., (2018)
Lactuca serriola	Broadleaf	0.92	Alarcóna *et al*., (2018)

Effect of tillage practices on the weed seedbank

The natural storage of various weed seeds at different depths in the soil is referred to as weed seed bank. The seed bank in the soil builds up through seed production and dispersal, while it depletes through germination, predation and decay. The distribution of weed seeds within the soil profile is mainly influenced by different types of tillage practices. Repeated tillage reduces the number of weed propagules in the plough layer. Weed seed burial by tillage is difficult or negligible in case of no-tillage due to the absence of soil inversion process. The no-tillage system leaves most of the weed seeds in the top one cm of the soil profile, whereas conventional tillage tends to uniformly distribute seeds throughout the profile. Redistribution of seeds in the soil profile is stimulated by tillage practices that favour germination. In the NT system, the weed seed bank remains on or close to the soil surface after crop planting (Chauhan *et al.*, 2006). Better tilth and exposure of the weed seeds to upper soil may be responsible for higher weed infestation under conventional tillage than NT. Seeds of some species like *R. dentatus* are sensitive to burial depth, which could not emerge at a burial depth of 4 cm (Dhawan, 2005). Most of the weed seedlings emerge from the top 0.5 to 2 cm depth of soil layer but some weeds species like *Mimosa invisa* and *E. crusgalli* can emerge from 8 cm depth (Chauhan *et al.,* 2010). As seeds in NT are on the soil surface and are prone to rapid desiccation result in lower emergence of seedlings of some weed species.

Differential vertical distribution of seeds in soil differs in the availability of moisture, diurnal temperature fluctuation, light exposure and activity of predators that affect seedling emergence and weed population dynamics. In conservation tillage, as minimum soil disturbance occurs, most of the weed seeds remain on the soil surface after crop planting. Such conditions may also be more favourable for grain feeding fauna such as ants and other insects. Thus, under conservation tillage, weed seeds remaining on the soil surface are most vulnerable to surface-dwelling seed predators. Under a no-tillage system, seed predation could be important where newly produced seeds remain on the soil surface. On the other hand, tillage can damage the nests of harvester ants and redistribute the weed seeds stored in superficial chambers. Thus, seed predation can substantially reduce the size of the weed seed bank (Chauhan *et al.,* 2010). Crop residue should be retained in the field rather than removing or burning, and this may provide forage to seed predators. A similar result was reported by Yenish *et al.*, (2015) (Table 2). Beneficial soil-dwelling Arthropods (spider, centipede, flies, ant etc) consumed more weed seeds in the NT treatment and preferred broad-leaf weed seeds (*C. album* and *K. scoparia*) as compared with grassy weed seeds (E. *crusgalli* and *S. pumila*) (Pretorius *et al*., 2018). Fertilization increases the weed seed density in soil under deep tillage and no herbicide management, but reduced that under no tillage and no herbicide management (Ge *et al.,* 2018). The highest weed seed density was found in conservation agriculture management (no-tillage, no-fertilizer and no-herbicide use) (Ge *et al.*, 2018).

Table 2. Distribution of weed seed by depth in soil as affected by tillage and weed management at Arlington, West Indies

Tillage	Weed management	Weed seed as affected by depth (cm)					
		0-1	1-3	3-6	6-9	9-14	14-19
		no./m^3 soil x 10^{-4}					
Mouldboard plough	Untreated	74	53	53	59	120	113
	Herbicide	49	30	33	41	48	40
	Weed free	45	42	33	47	45	50
Chisel plough	Untreated	411	281	240	206	59	20
	Herbicide	209	157	121	105	34	15
	Weed free	203	139	112	79	36	17
No-tillage	Untreated	1803	311	94	47	20	14
	Herbicide	542	190	65	46	16	10
	Weed free	328	97	44	28	12	8

Source: Yenish *et al., (2015)*

Effect of tillage on weed density and dry weight

The highest forb covers and grass cover was under NT and amounted to 276 weeds/m^2 and 185 weeds/m^2 followed by Conventional tillage (Odhiambo *et al.*, 2015). However, in the second year, NT demonstrated a 61.4% decline in grass cover and 72.3% decline in forb cover with no change in the third year. The lowest abundance of *Cyperus rotundus* (9 weeds/m^2) (grass) and *Commelina benghalensis* (7 weeds/m^2) and *Richardia brasiliensis* (6 weeds/m^2) was observed in NT (Odhiambo *et al.*, 2015). Among different forms of tillage, no-tillage increases the density as well as dry weight of certain annual and perennial weeds. Increasing density leads to the flourish of the weeds vigorously, causing significant yield losses in different field crops. The density and dry weight of weed species like *R. dentatus* have been reported to be significantly higher under NT compared to conventional tillage (Eliçin *et al.,* 2018). The greater density of dicot weeds was observed under reduced tillage compared to conventional tillage systems. However, significantly lower density and dry biomass of monocot and dicot weeds under reduced tillage than conventional tillage have also been reported (Shrivastav *et al.*, 2015). As a result, weeds under reduced tillage accumulate less dry matter. In general, the density and dry weight of weeds is the lowest under conventional tillage and the highest in conservation tillage (NT) practices. Conventional tillage which places the seeds closest to the soil surface results in the highest weed density. Also, for the species with heavy seeds, densities generally increase with ploughing (Blaise *et al.*, 2015). Rotational tillage systems result in the reduction of seed density of *A. ludoviciana, Amaranthus powellii, C. iria, Medicago hispida,* and *Solanum sarrachoides* compared to continuous NT and conservation tillage (Peachey *et al.*, 2006). Maize yields were found to be highest in maize monoculture with fertilizer under conventional tillage compared to zero tillage or flat till practice due to more weed infestation in the latter (Mafongoya *et al.*, 2016).

Table 3. Effect of tillage system and sweet corn cultivar on weed dynamics, corn plant height, and canopy cover

Tillage	Texas weed *Panicum* (weeds/ha (x 10^5)	*Amaranthus spp*.(weeds/ha (x 10^5)	*Purslane*(weeds / ha (x 10^5)	All weeds(weeds/ ha (x 10^5)	Total dry wt. (t/ha)	Plant height (cm)
Conventional	0.65^{b}	0.80^{b}	3.95	5.65	2.74^{b}	159
No tillage	3.10^{a}	1.35^{ab}	3.10	7.55	8.28^{a}	164

Source: (Makus, *2000*)

Table 4. Weed density (per m^2) and diversity as affected by tillage systems in maize

Tillage systems	Annual	Weeds		Perennial	weeds	All weeds
	Chenopodium album	*Echinochloa colonum*	*Cucumis prophetarum*	*Cynadon dactylon*	*Cyperus rotundus*	
No-till (NT)	17	62	18	86	117	300
Reduced tillage (RT)	17	83	9	33	69	211
Deep tillage (DT)	20	44	6	35	101	206

Source: Arif *et al., (2007)*

Weed management

Several non-chemical methods and chemical method are used to keep the weeds below the threshold level, out of which crop residue or mulching, time of sowing and herbicidal methods play an important role. Herbicide combination must be blended for each specific condition because the wide variations in weed infestations may cause a combination that is excellent in one situation to be poor in another (PANS, 1971).

Crop residue or mulching

Crop residues, when uniformly and densely present, under conservation tillage, can suppress and smother weed seedling emergence, delay the time of emergence, and allow the crop to gain an initial advantage in terms of early vigour over weeds. No-tillage and residue retained level had a significantly lower number of grasses as compared to conventional tillage (Dahal and Karki, 2014). Due to the sufficient moisture in long term no-tillage treatment; there is sufficient growth of maize (Dahal, 2014), which creates the shedding effect of maize for weed growth and germination. Long term use of rice straw on maize converts to mineralized nutrient which causes sufficient growth of maize, may be the probable reason for the suppression of weeds by the shedding effect (Dahal, 2014). Combining good agronomic practices including depth and timeliness of tillage operation with retaining crop residues on the soil surface can effectively improve weed control efficiency (Chauhan *et al.*, 2012) . Finger millet as a cover crop can effectively manage weed biomass under minimum tillage to a level as achieved under conventional tillage without a cover crop at an early stage of growth of Maize (Samarajeewa *et al.*, 2006). Crop residue controls the germination of weeds. Six ton per ha of live mulch can reduce significantly the weed population (Eliçin *et al.,* 2018). But, Black plastic mulch was found much effective as compared to live mulch, weed mulch and white plastic mulch for reducing the weed biomass (Gul *et al.,* 2011).

Herbicide application

Tillage practices also need to be coupled with an appropriate choice of herbicides and their timely application towards achieving better efficacy in weed management. Weed management using herbicides is becoming popular because of a handful of advantages in terms of cost, efficacy and efficiency in weed management. The introduction of herbicides has proved ZT and other conservation tillage effective by managing weeds in different cropping systems. Weeds that are present at the time of planting of crops in NT may need to be controlled with a non-selective herbicide like glyphosate during the turnaround period. Spraying of broad-spectrum herbicide glyphosate at the rate of 2 litres/ha by mixing with 200L of water at 15-18 days before planting and supplementing with one-time hand weeding at 40 days after sowing (40DAS) is found to be an effective weed control option in maize during turnaround period (Kebede *et al.,* 2018). Application of pre-emergence herbicide like pendimethalin in NT was found to be effective to control grassy weeds (Blaise *et al.,* 2015). Poor control of *D. aegyptium, E. colona* and a few other weeds by the herbicides in NT system had also been reported (Chauhan *et al*., 2006; Chauhan and Johnson, 2009). On the other hand, conventional tillage combined with pre-emergence herbicide pendimethalin at 1.0 a.i. kg/ha followed by hand weeding at 40 days after sowing (DAS) recorded lower weed density and biomass (Baskaran and Kavimani, 2014). Crop residue can intercept 15-80% of the applied herbicides (Chauhan *et al.,* 2006). The recent development of post-emergence broad-spectrum herbicides provides an opportunity to control weeds in conservation tillage systems. Normally herbicides applied as granule formulated to provide better weed control in a no-till system because granules are supposed to move through the stubble more effectively than its liquid formulation. On the other hand, under intensive tillage with high soil disturbance, the herbicide loss is minimized because of better incorporation in the soil (Duary *et al.,* 2016). As the farm size decreases, conservation tillage adoption has been decreased resulting in increased adoption rates of no-till and reduced-till systems and ultimately increases Glyphosate-Resistant crop cultivation (GR corn) in their cropping sequence (Givens *et al.,* 2009). Wide herbicide band (38 cm) treatment was found to be effective in controlling the weed and maintaining the maize yield than the narrow band (19 cm) treatment (Hanna *et al.,* 2000). Atrazine @ 1.25 kg/ha followed by 2,4-D @ 2.0 kg/ha recorded significantly higher plant height (183.7 cm) and LAI at 60 DAS (4.29) as compared to unweeded check and was on a par with an application of atrazine @ 1.25 kg/ha (Kumar and Angadi, 2014).

Table 5. Different herbicides, doses, time of application and their weed control efficiency

Herbicides	Doses	Time of application	Weed control efficiency	References
Nicosulfuron	0.90kg/ha	Post-emergence	98.8%	Amare *et al.,* 2015
Metolachor	1.5 kg/ha	Pre-emergence	87.1%	Amare *et al.,* 2015
Atrazine	3 kg/ha	Pre-emergence	83.9%	Amare *et al.,* 2015
Atrazine + glyphosate	0.75kg a.i./ha + 2.5 mL/ L	Pre-emergence	42.67%	Shrivastav *et al.,* 2015
Atrazine + pendimethalin	0.75kg a.i./ha + 2.0 mL/ L	Pre-emergence	24.66%	Shrivastav *et al.,* 2015
Tembotrione	120g/ha	Post-emergence	89.6%	Mitra *et al*., (2018)
Tembotrione + atrazine	120g/ha + 0.5 kg/ha	Post-emergence	96.5%	Mitra *et al*., (2018)
Halosulfuron +	90 g/ha + 0.5	Post-emergence	80.6%	Mitra *et al*., (2018)

Herbicides	Doses	Time of application	Weed control efficiency	References
Atrazine	kg/ha			
Atrazine + Tembotrione	1 kg/ha + 120g/ha	Pre-emergence+ post emergence	96.1%	Mitra *et al*., (2018)
Atrazine + Tembotrione + Atrazine	1 kg/ha + 120g/ha + 0.5 kg/ha	Pre-emergence+ post-emergence + postemergence	98.7%	Mitra *et al*., (2018)

Conclusion

The findings of the various studies indicated the weed stress on the productivity of maize (*Zea mays* L.) under no-till condition. Weed management practices should be mainly based on the critical period of weed competition (CPWC). Similarly, by understanding the nature of weed seed bank, various methods of integrated weed control should be formulated. Concerning weed control, no-till maize should never be implemented in monoculture systems but can be done with a proper cropping system. The adoption of recommended agronomic practices, understanding the nature of the weeds and conservation agriculture can help the farmers to obtain the maximum productivity of maize under no-till condition.

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