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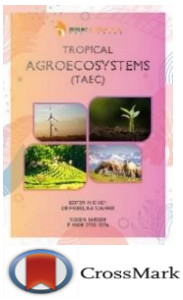

RESEARCH ARTICLE

STATUS OF HERBICIDE RESISTANCE IN WEEDS AND THE WAYS TO MITIGATE IT FROM GLOBAL PERSPECTIVE

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ABSTRACT

Survivability of a few plants with natural resistance after herbicide application and their reproduction followed by herbicide application on each successive generation results in herbicide resistance and this phenomenon is rampant in present day agricultural fields. The study design is thus, focused on the overall status of herbicide resistance weeds and their distribution, mechanism of herbicide resistance in weed biotypes and the practices that are adopted and need to be adopted in order to curb the resistance development mechanism. The first herbicide resistance evidence was identified in triazine resistant to common groundsel (Senecio vulgaris). However, herbicide resistance was reported against 2,4-D from Hawaii as early as 1957. Currently, 512 unique cases (species×site of action) of herbicide resistant weeds with 262 species are on light globally. Herbicide-resistant weeds have been reported in 70 countries across 92 crops, with 619 scientists from around the world contributing new cases of exposure.Wheat is the crop with the highest evidence of herbicide resistant weeds, followed by maize and rice. The sharp increase in resistant weeds from the 1980s to 2020 directs the trend as a "growing peril" on agriculture that must be addressed timely and prudently.

KEYWORDS

agriculture, generation, reproduction, triazine, weed

1. INTRODUCTION

Weed Science Society of America (WSSA) defined herbicide resistance as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type". The occurrence of resistance in a plant may be due to naturally occurring or induced by the techniques such as selection of variants produced by tissue culture, by genetic engineering or by mutagenesis. Based on the biochemical mechanism by which an active ingredient affects a target plant, herbicide resistance can be classified on mode of action (Kim et al., 2015) as herbicide cross resistance and herbicide multiple resistances. When any plant is resistant to one class of herbicide within one group or many herbicide classes within a group, herbicide cross resistance occurs. Due to the selection pressure from herbicides attacking Acetolactate Synthase (ALS) which will act on a particular site and will be resistant to all herbicides, the resistant biotype has evolved (Vargas & Wright, 2004). On the other hand, the changes at the site of action of herbicides cause multiple resistance. (Won et al., 2015) mentioned that multiple resistance process as a resistance mechanism developed by a weed biotype to multiple modes or sites of action of herbicide for which the resistance due to separate selection process. Where among the same individual or population, multiple resistance mechanisms involve both target site and non-target site resistance mechanism, there may be difficulty in weed control due to complicated situations (Powles & Preston, 2016).

Table 1: Most important Herbicide Resistant weed species worldwide

SN	Scientific name	Common name	Number of sites of action
1	Lolium rigidum	Rye grass	11
2	Echinochloa crus-galli var. crus-galli	Banyard grass	10
3	Poa annua	Annual bluegrass	9
4	Alopecurus myosuroides	Black grass or twitch grass	7
5	Eleusine indica	Goosegrass	7
6	Amaranthus palmeri	Pigweed	6
7	Lolium perenne ssp. Multiflorum	Italian ryegrass	6
8	Amaranthus hybridus	Smooth pigweed	6
9	Ambrosia artemisiifolia	Annual regweed	5
10	Avena fatua	Common wild oat	5
11	Conyza Canadensis	Fleabane or horseweed	5
12	Kochia scoparia	Ragweed	5
13	Raphanus raphanistrum	Wild radish or jointed charlock	5

Source: (Heap I. , 2017)

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Weeds emerged in the agricultural fields time and again with new complexities have been one of the major biotic cause of crop yield loss due to their competition with crops for space, light, oxygen, carbon dioxide, nutrient, moisture etc. Recurrent application of efficacious herbicides with the same site of action; efficient seed or pollen gene dissemination, annual weed species occurring at high population densities with wide distribution, genetic variability; few dominant weed species favoring simple cropping system are the major risk factors associated with the evolution of herbicide resistant weeds (Owen, 2001) (Thill & Lemerle, 2001). From global perspective, some important herbicide resistant weeds include annual ryegrass (*Lolium rigidum*), wild oat (*Avena fatua*), Amaranthus spp.,redroot pigweed (A retroflexus,), smooth pigweed (A hybridus), common lambsquarters (Chenopodium album), green foxtail (Setaria viridis), barnyardgrass (Echinochloa crus-galli), goosegrass (Eleusine indica), kochia (Kochia scoparia), horseweed (*Conzya canadensis*) and black grass (*Alopecurus myosuroides*) (Heap I. , 2005).

The herbicide resistance is target-site based for the majority of the herbicide resistance weeds due to the larger phenotypic effect or influence of the major gene with high dominance degree (Powles et.al.1997). The priority of farmers for short term economic return or their incapability to find out the economic risks associated with the herbicide resistant weeds are the reasons for reluctance or unaware for managing such weeds (Rotteveel et al.,1997).

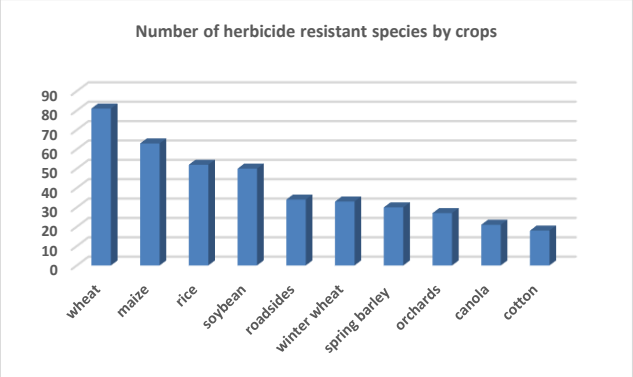


Figure 1: Number of herbicide resistant species by crops (Top 10)

Source: (Heap I. , 2020)

On an average, world suffer about 34% yield loss of arable crops due to weed population (Oerke, 2006). The USA alone faced a loss of greater than 26 billion US dollar of annual cost of crop loss as a result of weeds (Pimentel, 2000) . Rapidly growing weed population is becoming a major threat to global food security. Until the marketing of first herbicide in the late 1940s, the process of weed control was labor-intensive in early agriculture system (Oerke, 2006). Herbicide resistance was first evident in wild carrot (Daucas carota) where it evolved resistance to auxin analogue herbicide class after a number of seasons of use of 2,4-D (Switcher, 1957) (Whitehead & Switcher, 1967). Also, another was evident on groundsel (*Senecio vulgaris*) resistant to simazine and atrazine after the one or two applications of these herbicides for consecutive 10 years period (Ryan, 1970). About 362 confirmed weed resistance evidences have been reported since then, in 115 dicots and 83 monocots (total of 198 species) (Heap, 2011). The north-central and southern regions of United States, where there is high crop production have been evident with more than one third of these resistant weed biotypes (Heap, 2011). The rapid spread and evolution of herbicide resistant weeds is mainly caused due to the persistent herbicide selection across a large crop area on multiple population of genetically diversified weed species (Powles & Yu, 2010). Use of herbicide is an effective method for weed control and is considered appropriate tools ever developed as they reduce the targeted weed population by 90-99 % (Foster, 1993). The other methods of weed control other than herbicide application are considered heavy labor-intensive and can be similarly effective to herbicide control method, not when solely applied but by combining several methods (Baastians, 2008). Before the concept on weed resistance emerged, there were no adoption practices regarding Integrated Weed Management (IWM) practices. Farmers increased the adoption of IWM practices after the development of herbicide resistance in weeds (Beckie & Gill, Strategies for managing herbicide-resistant weeds, 2006). The increase in number of herbicide resistant weeds biotypes resulted decrease in the performance and yield of crops. (Powles. et al., 1997) addressed that the impulse for utilization of a number of IWM practices in agricultural cropping system was due to cross resistance and multiple resistance in weed species. The cost for prevention is significantly less than a full developed resistance, where a few alternative herbicides are available or where intergroup herbicide resistance occur (Orson, The cost to the producer of herbicide resistance, 1999). Due to the lack of alternative herbicide groups to control target weeds or due to the expectation of forthcoming technology of that new herbicide may be the reason for low adoption of resistance-avoidance tactics (Llewellyn et al., 2002). The tactics for managing herbicide resistance are with limited recommendations to farmers. (Friesen et al., 2000) addressed that some major socio-economic factors leading to the farmers of developed countries to be more reliant on herbicides are farmers demographics, increase in farm size with labor scarcity, low availability of time, high leased land with limited knowledge on previous herbicide use history, preference of annual cropping system based on choice and cash flow and lack of motivation for reducing the use of herbicides.

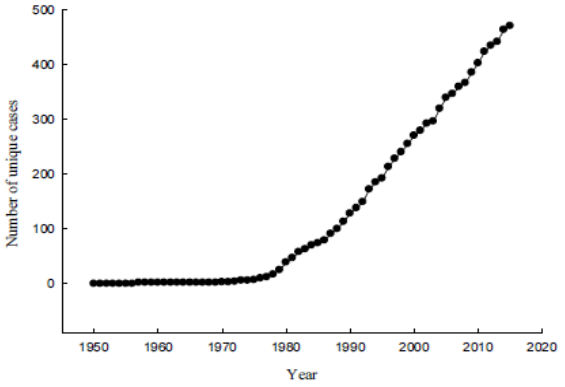
2. Materials and Methods

The study is primarily based on the number of literature reviews with plethora of materials regarding pesticide use status on global and Nepalese context. The sources of information which I have gone through thoroughly such as journal articles, conference proceedings, book sections, websites, report etc., have been cornucopia of information to complete and embellish the article.

3. Results and Discussion

3.1 Global Herbicide Resistance Scenario

The first report of herbicide resistance was reported in triazine herbicide resistant common groundsel (*Senecio vulgaris*) (Ryan, 1970) although herbicide resistance was reported against 2,4-D from Hawaii as early as 1957 (Bhatti, et al., 2013). Comparing to the incidences of insecticides or fungicides resistance, herbicide resistance has been increased exponentially (Bhatti, et al., 2013)



Source: (Heap I. , 2020)

Herbicide resistance in weeds is not as old as resistance of insecticides and fungicides on insects and fungal pathogens and is about 40 years old. Prior to the late 1960s, there were relatively few reports of herbicide resistance. However, detection of *Senecio vulgaris*, a triazine-resistant weed was evident in 1968 and since then, there has been a steady increase in the number of resistances weed species and the classes of herbicides to which resistance evolved.

(Ryan, 1970). By 1990, 113 herbicide-resistant weed biotypes have been evolved worldwide (Lebaron, 1991) and of that total, 58 species (41 dicotyledonous and 17 grass weeds) resistant to triazine herbicides like atrazine, and rest 55 species (36 dicotyledonous and 19 grass weeds) resistant to 14 other classes of herbicides. The biotypes of 36 species of weeds have developed resistance to the triazine herbicides in Europe (Van Oorschot, 1991) and seven of them had been recorded in UK namely *Matricaria matricarioides, Poa annua, Senecio vulgaris, Solatium nigrum, Chenopodium album, Epilobium ciliatum* and *Erigeron Canadensis* (Clay, 1989).

Currently, there are 512 unique cases (species× site of action) of herbicide resistant weeds globally, with 262 species contributing the total by 152 dicots and 110 monocots, according to the weed science database. Of the 26 known sites of actions of herbicides, the weeds have evolved resistance to 23 sites of action and 167 different herbicides. Herbicide resistance weeds have been reported in 92 crops in 70 countries of the world.

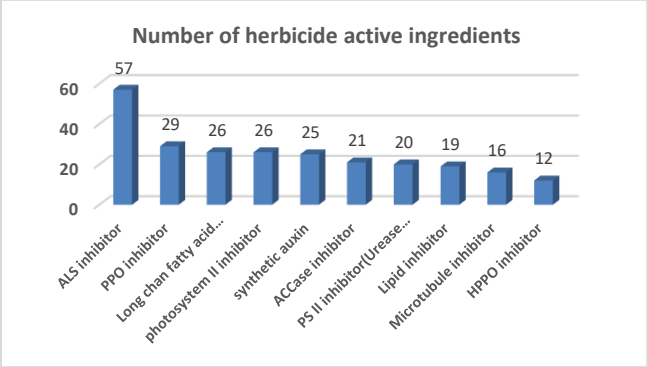


Figure 2: Graph showing number of herbicide active ingredients.

Source: (Heap I. , 2020)

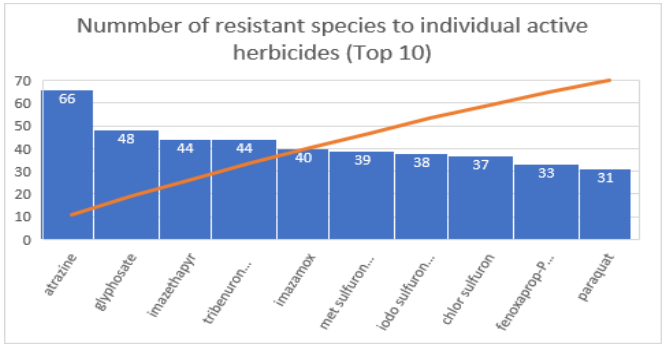


Figure 3: Number of resistant species to individual species to individual active herbicides

Source: (Heap I. , 2020)

Table 2: Most recent cases of herbicide resistant weeds (Top 15)

Date last updated	Species	Country
May 20, 2020	*Eleusine indica*	United States (Alabama)
January 22, 2020	*Poa annua*	Australia (Victoria)
January 22, 2020	*Poa annua*	Australia (New South Wales)
January 22, 2020	*Avena fatua*	Australia (Queensland)
November 28, 2019	*Amaranthus hybridus*	Brazil
November 28, 2019	*Amaranthus palmeri*	United states (North Carolina)
November 28, 2019	*Secale cereale*	United States (Colorado)
November 28, 2019	*Echinochloa crus-galli var. crus. galli*	Argentina
November 22, 2019	*Avena sterilis ssp. ludoviciana*	Australia (New South Wales)
November 22, 2019	*Sanchus asper*	United Kingdom
November 19, 2019	*Rumex obtusifolius*	France
November 4, 2019	*Eleusine indica*	Colombia
October 24, 2019	*Capsella bursa-pastoris*	Norway
October 1, 2019	*Carduus acanthoides*	Argentina
September 28, 2019	*Echinochloa colona*	Colombia

Source: (Heap I. , 2020)

3.2 Reasons Of Increasing Herbicide Resistant Weeds

There may be several mechanisms that lead a plant to be resistant to herbicide (CropScience, 2015). (Powles & Yu, 2010) stated that in the weed species there is a single or more locations that can be cell division mechanisms, enzyme proteins, non-enzyme proteins, etc which are known to be defined as 'sites of action'. It is not because of the genetic changes occurred due to herbicide application that makes a plant herbicide resistant. The survivability of a few plants with natural resistance to the herbicide after its application and their reproduction followed by the exposure of each successive generation to the herbicide results increase in the number of resistance plants as long as they dominate the population of susceptible plants. One major reason for increasing herbicide resistant weed species is use of transgenic plants. The development of transgenic crops throughout the world has solved weed problem and increase yield. In the United States, Brazil, Argentina and Canada, there was a major effect of glyphosate-resistance (GR) crops in the field of agriculture since 1996 (Brookes & Barfoot, 2011). It also solved major weed management problem of that time, the weed resistance evolved to acetolactate synthase (ALS)-inhibiting and protoporphyrinogen oxidase (PPO)- inhibiting herbicides. However, there was also concern about transfer of herbicide resistance through crop to weed gene flow due to the introduction of such GR crops flow (Dale, 1994)(Warwick et al., 1999). The stable introgression of a HR transgene to weedy birdsrape mustard (*Brassica rapa* L) from GR canola (*Brassica napus* L) under field conditions was reported (Warwick et al., 2008). (Zapiola et al., 2008) reported the accidental pollen and propagule transfer from GR ornamental bentgrass (*Agrostis palustris Huds*) to a population of creeping bentgrass (*Agrostis stolonifera* L). Other recent examples of herbicide resistant weeds include goosegrass (*Eleusine indica* L.) population resistant to glufosinate (Jalaludin et al., 2010) (Seng et al., 2010) and tall waterhamp [*Amaranthus tuberculatus* (Moq.) Sauer] resistant to HPPD-inhibating herbicides (Hausman, et al., 2011) (McMullan & Green, 2011).

Overreliance on the herbicides with single mode of action (MOA) is another prime cause of increased resistance among weed species. Despite the frequency of resistance events in the weed population is governed by a number of factors, several reports strongly suggest the over-dependent on a single herbicide (or a group of herbicides with same mode of action) without using any other management practices, as an important cause of herbicide resistance (Heap, 2011). In the orchards where glyphosate had been regularly used for at least 14 consecutive years, there was evident of GR Italian ryegrass [*Lolium perenne* L. *ssp. multiflorum* (Lam.) Husnot] and GR rigid ryegrass (*Lolium rigidum Gaudin*) (Perez-Jones et al., 2005) (Powles et al., 1997). Also, (VanGessel, 2001) (Pollard et al., 2004) stated that continuous application of glyphosate on GR soyabean for 3 and 6 years resulted GR horseweed [*Conyza canadensis*(L.) *Cronq.*] and GR common ragweed (*Ambrosia artemisiifolia* L) respectively. Similarly, glyphosate resistance in Palmer amaranth (*Amaranthus palmeri S. Wats*) and common waterhemp (*Amaranthus rudis Sauer*) were also evident after 4 and 6 years of consecutive glyphosate use (Culpepper, et al., 2006) (Legleiter & Bradley, Glyphosate and multiple herbicide resistance in common waterhemp (Amaranthus rudis) populations from Missouri, 2008). The phenomena is not only limited to herbicides like glyphosate but also other herbicides like chlorsulphuron,, propanil, atrazine and so on. After 5 years of consecutive application, Prickly lettuce (*Lactuca serriola* L) evolved resistance against chlorsulfuron (Mallory-Smith et al., 1990). Wild carrot resistant to 2,4-D(Switzer 1957; common groundsel resistance to atrazine ryan 1970 and barnyardgrass resistance to propanil (Carey et al., 1995) are other examples. (Lebaron, 1991) mentioned that there is no clear relationship between the plants family and genera and their tendency to develop resistance. It has been evident that there is shift of weed population towards a high tolerance level due to the selection under reduced or sub-lethal dose of herbicide over several generations (Manalil et al., 2011).

The resistance development mechanism also depends upon the initial frequency of the resistance trait. It is possible that before any exposure to herbicides, resistant genotypes are present in plant population in varying but low frequencies and increase in the proportion of the resistant genotype within the population results development of resistance. The rapid development of resistance is accounted as a result of differences in initial frequency of gene. As for example such differences caused the resistance to chlorsulfuron after 3-5 years of annual (Thill, et al., 1991) compared to triazine with slower appearance after 6-10 years (Bandeen,

et al., 1982). Other factors such as selection pressure, population dynamics of the weed and genetic characteristics of resistance also cause a weed population to be resistant over time. The presence of modified susceptible individuals which produce progeny with intermediate resistance level is found to cause resistance in certain populations of *Chenopodium album* (Gasquez, 1991). Those progenies of such intermediate biotypes were highly resistant which could only survive moderate triazine doses. Fitness is also responsible to cause resistance on weed species. In comparison to susceptible biotypes of same species, many triazine resistant weeds do not show reduced vigor (Holt, 1990). The reason for the lower photosynthetic potential and reduced fitness of triazine-resistant plants is the lower efficiency of the photosynthetic activity. A number of available evidences and findings indicate that resistant plants necessarily may not be less productive than susceptible plants, however, (Holt, 1990) mentioned that under field conditions, more study is needed to know the relationship between resistant trait and factors determining reproductive success.

3.3 Tactics For Resistance Management

3.3.1 Herbicide sequence and rotation

During the past decade in countries like Canada and Australia, there has been increased in the adoption of herbicide group rotation for the management of resistance. Such herbicide rotation practices have been carried out by less than 50% of farmers in Western Canada in 1998. The adoption rate of herbicide group rotation, attributed largely to site of action labeling on herbicide containers, was 85% by 1998 in Australia (Shaner et al., 1999). By 2003, the rotation of herbicide by site of action has been claimed by 70 (Saskatchewan) to 90 % (Manitoba) of farmers (H. Beckie, unpublished). In a survey questionnaire conducted in Australia (Shaner et al., 1999) and Canada (H. Beckie, unpublished), the method of herbicide sequences and rotation is found to be a most common tactic for herbicide resistance management tactic. The Australian National Glyphosate Sustainability Working Group (2005) recommended that by following a preplant glyphosate application in sequence with tillage or a paraquat-based product, the risk of glyphosate with paraquat for preplant weed control, or using a "double knock" technique can be reduced (Weersink et al., 2005). The evidencences regarding adoption of herbicide group rotation for delaying or preventing weed resistance include

Table 3: Evidence of herbicide group rotation with location

S.N	Herbicide group rotation	Location	Reference
1	Triazine-HR weeds	North America	(Stephenson et al., 1990)
2	Isoproturon-HR littleseed canarygrass (Phalaris minor Retz.)	India	(Singh et al., 1999)
3	ACCase inhibitor-HR wild oat	Canada	(Le´ge`re et al., 2000)
4	ALS inhibitor-HR common cocklebur (Xanthium strumariu.L)	Southern US	(Schmidt et al., 2004)
5	ACCase inhibitor-HR wild oat	Australia	(Gill, Development of herbicide resistance in annual ryegrass populations (Lolium rigidum Gaud.) in the cropping belt of Western Australia, 1995)

3.3.2 Herbicide mixtures

Herbicide mixtures are predicted to delay the resistance in weeds longer than rotations, based on the compounded resistance frequency model (Diggle et al., 2003). The tank mix herbicides was found to delay or manage ALS inhibitor-HR broadleaf weeds in a survey carried out in Western Canada among 1,800 farmers during 2001-2003 (H.Beckie, unpublished data). Increased cost and availability of proper mixing partners that meet the criteria are some challenges to the farmers for adopting herbicides mxtures for resistance management.

Table 4: Effect of different herbicide mixtures on herbicide resistant management.

SN	Mixture	Result	Reference
1	Mixtures with ALS inhibitor	Delayed ALS inhibitor resistance in weeds of rice field(Japan) and field crops (Europe)	(Gressel, 1997) (Itoh et al., 1999)
2	atrazine plus chloracetamide mixtures (for 20 years)	Lower triazine resistance in *Chenopodium* and *Amaranthus sp.* (used in monoculture corn in North America	(Wrubel & Gressel, 1994)
3	Pendimethalin plus propanil	Delayed or manage propanil resistance in jungle rice (*Echinochloa colona* L.) in rice in Central America	(Valverde, Management of herbicide resistant weeds in Latin America: the case of propanil-resistant Echinochloa colona in rice, 1996)
4	Anilofos (or piperophos) plus propanil	Control propanil-HR barnyard grass in rice (U.S)	(Daou & Talbert, 1999)

3.3.3 Herbicide rates

it is evident that a number of herbicides at different places are commonly applied at lower-than the recommended rates with the aim of reducing cost. (Leeson et al., 2004) mentioned that in Western Canada, herbicide application is applied at reduced rates to 28% of cropped land annually. Quantitative resistance has been developed in weeds below due to lower dose or rate of herbicide application than recommended.

Table 5: Effects of herbicide rates on resistance management

SN	HR weeds	Location	References
1	chlortoluron-HR blackgrass	United Kingdom	(Chauvel & Gasquez, Relationships between genetic polymorphism and herbicide resistance within Alopecurus myosuroides Huds, 1994) (Hall et al., 1994)
2	diclofop-HR rigid ryegrass	Australia	(Gressel et al., 1997) (Neve & Powles, 2005)
3	dicamba-HR kochia	North America	(Belles et al., 2005)
4	isoproturon-HR littleseed canarygrass	India	(Malik & Singh, 1995) (Singh et al., 1998)

In order to delay the evolution of major monogene and quantitative resistance, (Gressel, 1995) (Gardner et al., 1998) suggested a tactic of revolving the doses of herbicides. It is not a good resistant management tactic of routine reduced-rate application (Morrison & Friesen, 1996). Non-herbicidal methods of weed control should be followed if herbicides are applied at sub-optimal level. The sub-optimal application of herbicides should not be practiced especially for the significantly or highly out-crossing target weeds such as blackgrass, Lolium spp and koicha, particularly when they occur in large populations (Jasieniuk et al., 1996).

3.3.4 Cropping rotation and delayed planting

Integration of non-herbicide tactics with herbicides such as cropping systems and practices (crop rotation) can be effectively used for

management of resistance development in weeds. One of the best and most influential cultural tactic for managing herbicide resistance in weed is crop rotation (Bourgeois et al., 1997) (Chauvel et al., 2001). There is also facilitation of herbicide reduction or rotation due to practices like crop rotation (Beckie & Gill, 2006). Due to the lack of crop rotation diversity, there was evidence of ACCase and ALS inhibitor resistance in wild oat (Beckie et al., 2004). There are some evidences that suggest the role of delayed planting for control of some herbicide resistant weed species. In Europe, delayed planting is promoted by depleting the seed bank before crop planting to control HR weed grass species such as hood canarygrass (*Phalaris paradoxa* L.), blackgrass and winter wild oat (*Avena ludoviciana* Durieu) (Chauvel et al., 2001). Similarly, (Valverde et al., 2000) mentioned that delayed planting of rice in Central America is used commonly used to reduce the population densities of HR junglerice. Integration of delayed crop planting with other control tactics has been used in Australia to manage HR rigid ryegrass (Gill & Holmes, 1997).

3.3.5 Tillage practices

An important practice to delay or manage HR weeds is the judicious use of tillage in timely basis (Bourgeous et al 1997)(Chauvel et al., 2001). The practice of proper tillage not only breaks the cycle of weed growth in the field reducing the weed infestation in the field, but also helps manage the HR resistant weed population. The impact of tillage and mechanical practices for the management of HR weed population has been reviewed (Owen, 2001). (Orson & Livingston, 1987) mentioned that it has been proved highly effective to manage HR population plowing to bury weed seeds of black grass reducing germination and emergence. There will be consequent increase in the use or application of herbicide use due to reduced tillage. And when, same herbicide with same mode of action is constantly applied in the field of reduced tillage for a prolonged time, there is the chance of resistant development by the particular weed against that herbicide and thus, it is suggested to carry out tillage practices not only from weed population-reduction view but also from decreased-resistance view.

3.3.6 Limiting the herbicide resistance gene spread

The sources of herbicide resistant alleles that are likely to transfer to the herbicide susceptible population include the flow of gene from the HR weed population through the means of pollen or seed movement. Also, as the rate of gene flow exceeds the rate of mutation, there is great reduction in time required t reach a high level of resistance in such circumstances (Jasieniuk et al., 1996). The major gene flow in weed population is probably responsible due to the seed movement (Diggle & Neve, 2001) and it is found to influence HR gene spread more than the pollen flow. A study (Letouze´ & Gasquez, 1999) (Richter & Powles, 1993) suggested that the spread of herbicide resistance via pollen flow is difficult to control, especially at the time when the resistance is endowed by a single, dominant or semidominant gene. The evolution or occurrence of HR weed population due to the seed dispersal can be minimized or controlled by adopting several management practices. Study carried out by (Letouze´ & Gasquez, 1999) mentioned that in Western Canada, the practice of weed sanitation by farmers such as cleaning the tillage and harvesting equipments when moving between fields, covering the grain truck box, applying composted versus fresh manure, mowing or spraying ditches or uncontrolled weed patches have resulted less likely to have HR wild oat compared to those who were less careful. In order to reduce herbicide resistance, practices by farmers such as capture of weed seeds during harvest operation is also important. (Gill, 1996) reported 60-80% removal of seeds of ryegrass in Western Australia, which reduce weed infestation by 73% in the subsequent crop. Weed seed catching or removal is effective for HR weed population management at harvest (Gill & Holmes, 1997), however, the adoption of such practices by farmers is low (Powles S. , 1997). Such practices need to be flourished to limit the flow or spread of seed of HR weed population to the susceptible one so as to manage such HR weeds.

4. Cost of Resistance

The scenario of economically developed nations depict that there is more use of herbicides for the control of weeds existing in the field and among agricultural crops. Since herbicide is the most used pesticide in the world and most of the developed countries use it to reduce the weed infestation, the resistance of herbicide use on weeds cause incur of a great amount of short-term cost to manage the weed population, particularly in absence of new herbicide chemistry. The cost added during the management of HR weed has been explained by through a number of studies. (Mueller et al., 2005) mentioned that there was a net increase in production cost of US$ 28.4 per hectare due to the occurrence of Glyphosate Resistant (GR) horseweed in soybean in the United States. The loss in crop yield, reduced value of land, cost of mechanical and cultural control, reduced price of commodity due to weed-seed contamination, additional expenses of alternate herbicides or cropping systems or both for managing the resistant weeds are some implicits in the measurement cost of herbicide resistant weeds. The management of GR *Palmer amaranth* in Georgia and Arkanas cotton production system incurred an estimated management cost of US $48 per hectare (vencill et al 2011). Similarly, a similar net increase in cost for controlling GR common waterhemp in soyabean was also found (Legleiter et al., 2009) in Missouri. In the same way, (Norsworthy & Oliveira, 2007) stated that the additional cost in Arkansas rice, for controlling propanil- and quinclorac-resistant barnyard grass was estimated US$ 64 per hectare.

5. Limitations to Implement Resistant-Preventing Practices

The growers find easy to use herbicides for weed infestation control rather thinking in a long term sustainable way to minimize herbicide resistant in weeds. The growers are reluctant to adopt measures to reduce the menace of resistant development in the field despite the cost for managing resistant weeds being significant.

One of the major limitation or factor to influence the growers negatively to adopt resistant preventing practices is that farmers expect the availability of new herbicides in the future (Foresman & Glasgow, 2008). (Finnoff et al., 2007), with invasive plant populations, elaborated quantitatively that how the managers who are financially risk averse or cautious are reluctant to adopt measures to prevent because prevention rather eliminating risk, only reduces it. (Frisvold et al., 2009) found that in a survey conducted among 1000 commercial cotton and soyabean growers in the United States, the use of multiple herbicides with different mode of actions (MOAs) by growers was found least adopted despite this being frequently suggested or recommended by the weed scientists as an effective control for herbicide-resistance evolution in weeds. The influencing reason for this is that using herbicides with multiple MOAs can increase current weed-control costs (Hurley et al., 2009), while the benefits of delaying the resistance in weeds gradually increases in the future and are uncertain. Mitigation of herbicide resistance in weeds is believed or perceived by some growers as if it is beyond their control limit and it depends more on natural factors and neighbor's behavior (Llewellyn & Allen, 2006). Further, some growers, according to (Llewellyn et al., 2002), believe that new herbicide chemistries will be developed by the industries and thereby reducing the benefits of resistance management. A number of reasons at farmers 'level persist and are evident in the field time to time that hurdle the implementation of the resistance management practices. Some practices like introduction of HR crops can also help manage resistance in weed population, further effective and sustainable weed management practices must be adopted and implemented to minimize the limitations to resistance-management adoption practices.

6. Conclusions and Recommendations

The phenomena of herbicide resistance among weed species have become havoc in agricultural crops and the herbicidal control adoption of same mode of action for a number of seasons lead to herbicide resistance. There are several mechanisms of herbicide resistance. Some of which include use of transgenic crops, overreliance in the herbicides with single mode of action, selection pressure, fitness, seed bank in the soil, low adoption of cultural and mechanical cropping practices and so on. The herbicide group, ALS inhibitor holds the highest number of active ingredient globally. Wheat is the crop in the world with highest number of herbicide resistant weed species. The single active herbicide atrazine has result the highest number of resistant species worldwide. The resistant development trend after 1980s had transcended sharply and still is in progression.

Every member country should act "hand in globe" so as to reduce the development of resistance. Implementation of herbicide MOA labeling

mechanism for all products of herbicides and conducting awareness campaign is utmost imperative. Reduction of the weed seed bank to minimize weed seed production and their dispersal can be a crucial initiation from farmer level of each nation through diversified sets of programs. Awareness regarding the fact that the invention of new and effective herbicide Mode of Action (MOAs) is hard and the existing herbicide is exhaustible can help users to apply in a judicious and recommended manner without harm to environment. In order to encourage adoption of effective herbicide resistance management practices, government agencies and industries that conserve herbicide MOAs should be provided with incentives. Mitigation of the resistant weeds and creation of a sound farming practice is achievable after the demonstration of benefit-cost analysis of weed management systems so that it can be adopted by progressive farmers easily. Adoption of public private partnership (PPP) for funding and research activities related to herbicide resistance mechanism and its management is crucial. Every member country should act "hand in globe" so as to reduce the development of HR weeds.

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