Chemical Strategy for Weed Management in Sugar Beet

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Abstract

The growing population of the world and the needs related to nutrition and food supply for human societies has led farmers and crop producers to increase production and minimize the limiting factors of crop production. Among these, the management of pests, mainly weeds, is of great importance. One of the significant limiting factors in agricultural production systems is the presence of weeds in main crops and especially the sugar beet. Sugar beet, as an inferior competitor, is very sensitive to biotic and abiotic stresses. Despite all the

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environmental hazards, impact on human health, and challenges related to herbicide residues in the environment, the chemical weed control method is still considered an effective and promising method for controlling weeds. This chapter is devoted to discuss about the chemical strategy for weed management in sugar beet.

Keywords

Environment · Herbicides · Residues · Sugar beet · Weed management

Abbreviation

MS Mass spectrometry

18.1 Introduction

Sugar beet is an important commercial agricultural crop related to sugar production globally, ranked second in sugar production after sugarcane. One of the most critical factors affecting the yield of sugar beet and the quality of produced sugar is weed management. Weeds are one of the leading causes of damage to crops. According to available data, the damage caused by their existence is not less than for pests and plant diseases. This amount of damage in developed countries, semi-developed countries, and developing countries with traditional agricultural systems are 5%, 10%, and 25%, respectively (Harker and O'Donovan 2013). A 50–100% reduction in sugar beet yield has been reported when weeds were not controlled (Deveikyte and Seibutis 2006). Sugar beet competes poorly with weeds from emergence until the leaves shade the ground. To prevent economic damage and reduced yields, weeds should be entirely controlled within 4 weeks after the emergence of sugar beet plants in the field. Subsequently, the weed management program should be continued throughout the growing season (Gerhards et al. 2017).

Sugar beet is very sensitive to weed competition, especially in the early growth stages (Lobmann et al. 2019). Of all the pests associated with sugar beet, weeds are the most severe and critical pest for this crop (Abouziena and Haggag 2016). From the first stages of sugar beet growth, the competition between this plant and the weeds in the field for water, sunlight, and micronutrients in the soil begins (Bruciene et al. 2021). Other disadvantages of the presence of weeds in crops include reducing the quantity and quality of crops, interference in harvest, hosting some pests and plant diseases, threatening human and animal health and increasing production costs. Soltani et al. (2018) assessed the economic damage in sugar beet crops due to the presence of weeds during 2002–2017. They reported an average yield loss of 70% for this crop with approximately US $1.25 billion in the United States. Manual weeding and mechanical methods for controlling sugar beet weeds are very

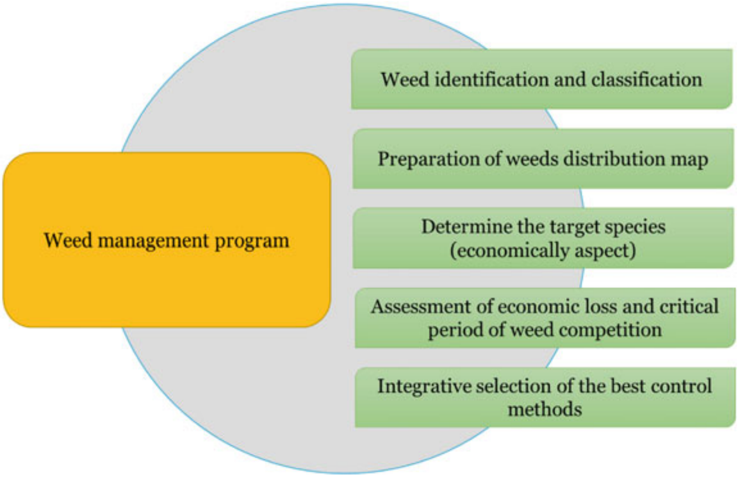

Fig. 18.1 Critical steps to a successful weed management program

expensive and may cause damage to sugar beet seedlings. So, the herbicides application is a more economical practice. Sugar beet cultivated in fields with minor weed infestation and correct agricultural practices only needed post-emergence application of herbicides. However, sugar beet grown in fields with heavy weeds infestation and improper agricultural practices required both the pre-and post-emergence application of herbicides (Cioni and Maines 2010).

Successful weed control in new agricultural systems requires the development of a management plan with considering all the factors affecting the crop and weeds. Critical steps to a successful weed management program are presented in Fig. 18.1.

According to this strategic plan, weed identification and classification is the first step to achieve a successful management plan and needs sufficient knowledge about plant biology and the condition of the field and weed population. Therefore, researchers and farmers should collect, identify, and classify the weeds in the field and evaluate their characteristics, growth cycle, life cycle, biological needs, and competitiveness. The second step involves mapping the distribution of weeds in the field. For this purpose, the field area is divided into smaller sections, and weed density is recorded in each plot. The preparation of this map will help farmers be aware of the status of weeds in the field and how their population changes over the years (Siddiqui et al. 2021; Somerville et al. 2020). Accurate preparation of distribution maps and their monitoring over the growing seasons will help to minimize weed management costs. In the third step, the target species are identified. The target species are weeds whose population is high in the field, or their vegetation structure is the same as the main crop. So, they could cause significant economic damage. Farmers must have a specific plan to control the population of these species and not neglect their existence during the growing season. Assessment of economic loss and critical period of weed competition is one of the other fundamental steps that researchers and farmers should consider (Gantoli et al. 2013). Accurate determination of economic damage will determine the severity of the need for managing weed species. However, this assessment requires scientific data and research projects. The last step in a successful weed management program is the integrative selection of the best control methods, including chemical and non-chemical approaches depending on farmers' available facilities and financial ability. Also, the appropriate information on field weed status, growth characteristics, and their ecological needs (temperature, light, food needs, etc.) are among the most important factors that will critically accompany farmers' management programs.

Depending on the size of the farm and the area under cultivation, access to the latest technologies and new cultivars, and the financial strength of farmers, there are different approaches to weed management in sugar beet. Different methods such as manual weeding, mechanical, cultural, biological, chemical, and integrated weed management methods are the most well-known approaches for weed control in sugar beet and other crops (Mehdizadeh et al. 2018; Hassani et al. 2020). In sugar beet, weed control is necessary to prevent reduced yields, so herbicides are prevalent in all sugar beet farms. It is reported that 70% of the pesticides used in this crop are devoted to herbicides (Marwitz et al. 2012). Due to the risks of excessive use of herbicides for the environment and human health, and the possibility of weed resistance, none of these solo methods is sufficient to control sugar beet weeds. Therefore, it is necessary to implement an integrated weed management system, primarily using reduced doses of herbicides as an effective control method (Kaya and Buzluk 2006). However, reduced amounts of herbicides in sugar beet should be performed when the weeds are most sensitive to herbicides. In most weeds, this stage is the cotyledon stage (Petersen 2004). Nowadays, herbicide splitting, the combination of different herbicides, and integrated weed management are the main methods to reduce the herbicide dose (Cioni and Maines 2010). According to Daneshian et al. (2013), the application of a mixture of Betanal progress AM and sethoxydim herbicides along with manual weeding 100% of sugar beet weeds. Ganbari Birgani et al. (2007) evaluated the control of sugar beet broadleaf weeds in combination with Betanal progress and Safari herbicides and cultivation. They reported that the combination of cultivation and herbicides reduced the density of the weeds by 41% as compared to the solo chemical method. Melander et al. (2005) reported that the application of reduced amounts of herbicides and mechanical methods reduced total herbicide use and increased the yield of sugar beet in Turkey. This chapter is devoted to evaluate the chemical strategy for weed management in sugar beet.

18.2 Problematic Weeds in Sugar Beet

As a short and low-growing crop, sugar beet is highly affected by weeds. For this reason, weeds are the most critical factor limiting the growth, development, and yield of this crop in agricultural systems (MacLaren et al. 2020). Numerous plant species are known as weeds associated with sugar beet production worldwide, the most important of which are presented in Table 18.1. The abundance of broadleaf weeds is higher than other weeds, and they have a more significant share of competition with sugar beet (Soltani et al. 2018). Weeds cause problems for agricultural products in the following cropping seasons due to the production of abundant seeds and the distribution of these seeds in arable soils. On the other hand, weeds pose a severe challenge to the weed management program (Chauhan 2020). A wide range of weeds can be found in sugar beet products that could be classified in different ways. One of the best classification factors is based on plant morphology. Therefore, sugar beet weeds could be divided into broad-leaved and narrow-leaved (grassy) species. However, more than 70% of problematic weeds in sugar beet is devoted to broad-leaved weeds (Lobmann et al. 2019).

18.2.1 Broad Leaf Weeds

These kinds of weeds have wide leaves with netlike veins, and their seedlings emerge with two leaves. More than 70% of the sugar beet weeds are broadleaf weeds (Heidari et al. 2007). As shown in Table 18.1, the most abundant and important broadleaf weeds of sugar beet have belonged to Brassicaceae, Chenopodiaceae, Amaranthaceae, and Asteraceae families. Typically, different types of control methods can be used for these weeds. However, selective herbicides are one of the most effective options to manage these plants in products such as sugar beet (Jhala et al. 2021).

18.2.2 Grasses (Narrow Leaf Weeds)

Although the economic losses associated with narrow-leaved weeds in broadleaf crops such as sugar beet are not significant, several narrow-leaved species of the Poaceae family are found on sugar beet farms. One of the challenges associated with using herbicides to control narrow-leaved weeds is related to the resistance of these plant species to herbicides. Accordingly, the application of other weed management methods with an integrated approach can be practical (Storkey et al. 2021).

18.2.3 Parasitic Weeds

A limited group of weeds called parasitic weeds is found in some agricultural products, such as sugar beet. Due to the severity of economic losses of this group of weeds, their rapid management is of particular importance. Cuscuta spp. is one of the most important parasitic weeds in sugar beet fields (Saric-Krsmanovic et al. 2017). Hoseyni et al. (2018) reported 90.63–100% control of *Cuscuta campestris* in response to application of Propyzamide herbicide in sugar beet fields. In the case of these weeds, the use of herbicides along with a combination of other control methods

Table 18.1 Problematic weeds associated with sugar beet

Scientific name	Family name	Common name	Morphology
Brassica napus	Brassicaceae	Wild buckwheat	Broad-leaved
Chenopodium album	Chenopodiaceae	Common lambsquarters	Broad-leaved
Amaranthus powellii	Amaranthaceae	Powell amaranth	Broad-leaved
Amaranthus retroflexus	Amaranthaceae	Redroot pigweed	Broad-leaved
Kochia scoparia	Amaranthaceae	Kochia	Broad-leaved
Beta vulgaris	Chenopodiaceae	Sea beet	Broad-leaved
Ambrosia artemisiifolia	Asteraceae	Common ragweed	Broad-leaved
Anagallis arvensis	Primulaceae	Ain el-gamal	Broad-leaved
Polygonum lapathifolium	Polygonaceae	Pale persicaria	Broad-leaved
Cirsium arvense	Asteraceae	Canada thistle	Broad-leaved
Convolvulus arvensis	Convolvulaceae	Field bindweed	Broad-leaved
Veronica persica	Plantaginaceae	Persian speedwell	Broad-leaved
Portulaca oleracea	Polygonaceae	Common purslane	Broad-leaved
Galium aparine	Rubiaceae	Goosegrass	Broad-leaved
Helianthus annuus	Asteraceae	Common sunflower	Broad-leaved
Brassica nigra	Brassicaceae	Kaber mustard	Broad-leaved
Chamomilla suaveolens	Asteraceae	Pineappleweed	Broad-leaved
Matricaria chamomilla	Asteraceae	False chamomile	Broad-leaved
Sinapis arvensis	Brassicaceae	Wild mustard	Broad-leaved
Polygonum persicaria	Polygonaceae	Ladysthumb	Broad-leaved
Physalis spp.	Solanaceae	Groundcherries	Broad-leaved
Sonchus arvensis	Asteraceae	Perennial sow-thistle	Broad-leaved
Polygonum aviculare	Polygonaceae	Knotgrass	Broad-leaved
Polygonum spp.	Polygonaceae	Smartweeds	Broad-leaved
Abutilon theophrasti	Malvaceae	Velvet leaf	Broad-leaved
Datura stramonium	Solanaceae	Jimsonweed	Broad-leaved
Lamium purpureum	Lamiaceae	Red dead-nettle	Broad-leaved
Solanum sarachoides	Solanaceae	Hairy nightshade	Broad-leaved
Solanum tuberosum	Solanaceae	Potato	Broad-leaved
Fumaria officinalis	Fumariaceae	Common fumitory	Broad-leaved
Stellaria media	Caryophyllaceae	Common chickweed	Broad-leaved
Viola arvensis	Violaceae	Field pansy	Broad-leaved
Galeopsis tetrahit	Lamiaceae	Common hemp-nettle	Broad-leaved
Matricaria inodora	Asteraceae	Scentless mayweed	Broad-leaved
Thlaspi arvense	Brassicaceae	Field pennycress	Broad-leaved
Vicia sativa	Fabaceae	Common vetch	Broad-leaved
Sisymbrium irio	Brassicaceae	London rocket	Broad-leaved
Helianthus annuus	Asteraceae	Common sunflower	Broad-leaved
Salsola kali	Amaranthaceae	Saltwort	Broad-leaved
Euphorbia helioscopia	Euphorbiaceae	Libbein	Broad-leaved
Cichorium pumilum	Asteraceae	Shikoria	Broad-leaved
Ammi majus	Apiaceae	Common bishop	Broad-leaved
Rumex dentatus	Polygonaceae	Sheep sorrel	Broad-leaved

(continued)

Table 18.1 (continued)

Scientific name	Family name	Common name	Morphology
Avena fatua	Poaceae	Wild-oat	Grassy
Echinochloa crus-galli	Poaceae	Barnyardgrass	Grassy
Poa annua	Poaceae	Annual meadow-grass	Grassy
Agropyron repens	Poaceae	Common couch	Grassy
Setaria glauca	Poaceae	Yellow foxtail	Grassy
Setaria faberi	Poaceae	Giant foxtail	Grassy
Setaria spp.	Poaceae	Foxtail	Grassy
Setaria viridis	Poaceae	Green foxtail	Grassy
Sorghum halepense	Poaceae	Johnsongrass	Grassy

can lead to successful control of these plants and reduce the severity of field contamination in next growing seasons.

18.3 Chemical Weed Management

Herbicides today play a pivotal role in weed management and are widely used due to their high efficiency and economic advantage. One of the most widely used, easily applicable, flexible, and effective weed management methods in most crops is chemical method and the use of herbicides or bioherbicides (Kunz et al. 2016; Mushtaq et al. 2020; Mehdizadeh and Mushtaq 2020). Especially for crops such as sugar beets that have low competitiveness, the use of herbicides to prevent yield loss is critical (Jhala et al. 2021). The success of chemical herbicides in controlling weeds depends mainly on the time of application, application doses, and method of application. According to the herbicide application time, there are three different types of herbicides for controlling weeds (Fig. 18.2). The primary purpose of using herbicides is to reduce production costs and human resources, use labor for more critical farm affairs, increase the product's quantity and quality, and improve weed control and better utilization of agro-ecosystems. One of the other aspects of chemical weed control is the use of biochemical compounds derived from plants with allelopathic properties. Dadkhah (2013) assessed the allelopathic impact of sugar beet on *Portulaca oleracea* and reported that the seedling growth of this weed was significantly affected by the extract of sugar beet.

Accordingly, due to the presence of the main crop, there are more restrictions on the use of appropriate herbicides in the post-emergence application. So that the main crop should not be damaged while controlling weeds.

18.3.1 Herbicides Used in Sugar Beet

Generally, few selective herbicides such as desmedipham, chloridazon, clopyralid, phenmedipham, ethofumesate, and metamitron have been introduced to control

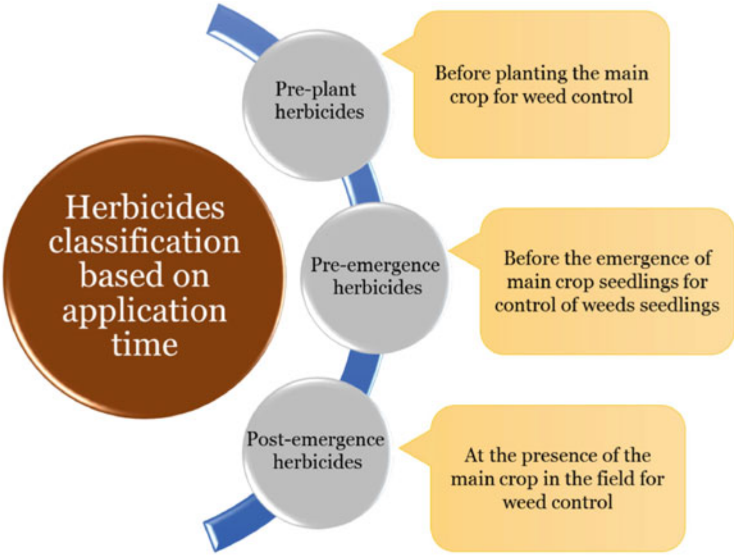

Fig. 18.2 Herbicides classification based on application time

weeds in sugar beet fields (Wilson 1999; Adamczewski et al. 2019). Due to the wide range of weeds related to the sugar beet plant and, on the other hand, the limitations of the selective herbicides for this crop, it is common to use a combination of some herbicides as tank mixes to control sugar beet weeds.

Today's use of pre-plant herbicides is very restricted due to their high persistence and toxicity and the negative impacts on human health and the safety of the agroecosystem (Ayivi et al. 2021; Zimmerman et al. 2021). On the other hand, the use of pre-emergence herbicides in sugar beet fields is only about 10% of the herbicides used in this crop, and in fact, the significant share is related to post-emergence herbicides (Deveikyte et al. 2015). Some circumstances such as rainfall severity and duration, soil moisture, soil physicochemical properties, and microorganism's population in the soil could be affected the efficacy of post-emergence herbicides. Some successful chemical control cases for weed management in sugar beet are presented in Table 18.2.

18.3.1.1 Combination of Herbicides

The combination of herbicides could enhance the control efficacy of a wide range of weed in different crops. Typically, the combination of different herbicides that are compatible in terms of mixing can affect a wide range of weeds in cropping systems due to having several different modes of action. A tank mixture of some different herbicides was successfully performed for weed management in the United States (Carlson et al. 2008). Rasha (2010) reported a significant reduction in weed biomass due to the application of Betanal progress (135 g a.i/fed) combined with Fusilade Super (94.75 g a.i./fed). Rapparini (2008) evaluated the effect of combined

Table 18.2 Herbicides used in sugar beet

Herbicide	Dose	Result	References
Glyphosate	3 L ha^{-1}	100% weed control efficacy	Bezhin et al. (2015)
Phenmedipham	960 g a.i ha^{-1}	Significant weed control	Hamouzová et al. (2013)
Ethofumesate 6.5% + metamitron 28% + phenmedipham 6.5%	2.5 kg/fed	84.5% reduction in total weeds	Abd El-Hamed (2019)
Acetochlor 84% EC	0.75 L/fed	51% reduction in total weeds	Abd El-Hamed (2019)
Betasana-trio	0.9 L fed^{-1}	Completely eliminate the broad-leaved weeds associated with sugar beet	Abd El-Lateef et al. (2021)
Betanal MaxxPro	0.5 L fed^{-1}	Completely eliminate the narrow-leaved weeds associated with sugar beet	Abd El-Lateef et al. (2021)
Desmedipham + phenmedipham + ethofumesate	616.5 g a.i ha^{-1}	90.93% control of *Chenopodium album*	Chitband et al. (2014)
Chloridazon	1300 g a.i ha^{-1}	90.47% control of *Amaranthus retroflexus*	Chitband et al. (2014)
Clopyralid	240 g a.i ha^{-1}	89.67% control of *Portulaca oleracea*	Chitband et al. (2014)
Desmedipham + phenmedipham + triflusulfuron + clopyralid	45 g + 45 g + 4.4 g + 26 g a.i ha^{-1}	78.4% reduction in weed biomass	Armstrong and Sprague (2010)
Glyphosate	840 g a.i ha^{-1}	99.8% reduction in weed biomass	Armstrong and Sprague (2010)

(continued)

Table 18.2 (continued)

Herbicide	Dose	Result	References
Phenmedipham 6.5% + metamitron 28% + ethofumesate 6.5%	2 kg a.i ha^{-1}	96.8 and 59.8% reduction in *Medicago polymorpha* and *Phalaris minor* biomass, respectively	Mahmoud and Soliman (2012)
Acetochlor	0.75 L/fed	51.3 and 47.3% reduction in *Medicago polymorpha* and *Phalaris minor* biomass, respectively	Mahmoud and Soliman (2012)
Desmedipham plus phenmedipham plus ethofumesate	0.23 + 0.23 + 0.23 kg a.i ha^{-1}	Maximum reduction in weed biomass	Abdullahi and Ghadiri (2004)
Goltix + betanal progress	Recommended doses	Best control results for *Chenopodium album* and *Amaranthus retroflexus*	Zargar et al. (2010)
Betanal Expert of	1.7–2.1 L ha^{-1}	Efficient control for *Salvia reflexa*	Chetin et al. (2008)
Ethofumesate + phenmedipham + desmedipham	1.12 g a.i ha^{-1}	45% reduction in Kochia control	Sbatella et al. (2019)
Betanal progress	877 g a.i ha^{-1}	Resulted in lowest weed density and weed dry matter	Anabestani and Armin (2017)
Propyzamide	1500 g a.i ha^{-1}	Significant control of field dodder	Saric-Krsmanovic et al. (2017)
Desmedipham + phenmedipham at	0.045 + 0.045 kg a.i ha^{-1}	Control of *Chenopodium album* and *Amaranthus* spp.	Dale et al. (2006)
Glyphosate	0.84 kg a.i ha^{-1}	Provided 89% weed control in sugar beet	Wilson and Sbatella (2011)
Pendimethalin	3.6–4.8 kg a.i ha^{-1}	Provided 82% grass and 56% broadleaved weed control	Yagoob et al. (2021)

herbicides desmedipham + phenmedipham + ethofumesate and found high efficiency (95% control) of this combination on annual dicotyledonous weeds in sugar beet. Deveikyte and Seibutis (2008) reported significant management of *Chenopodium album* L., *Tripleurospermum perforatum*, *Polygonum aviculare* L., and *Thlaspi arvense* L. due to the application of phenmedipham + desmedipham + ethofumesate mixed herbicides. Significant control of broad-leaved weeds and sugar beet yield improvement was reported by Majidi et al. (2011).

In some cases, considering genetically modified crops or herbicides-tolerant varieties reduces the limitations associated with using a tank mixture of some different herbicides and thus prevents their occurrence of side effects in agricultural ecosystems. The introduction of sugar beet varieties with high tolerant levels to glyphosate herbicide was one of these approaches for effective management of broad-leaved weeds in this crop (Khan 2010). Bezhin et al. (2015) reported 90% weed control efficacy in sugar beet using the tank mixture of pre-emergence application of 1.0 L ha^{-1} Goltix Gold, followed by 2–4 post-emergent applications of 1 L ha^{-1} Goltix Gold +1.5 L ha^{-1} Betanal Expert.

18.3.1.2 Reduced Doses

Given the environmental risks associated with the use of herbicides, it seems necessary to provide practical tactics to reduce these hazards. In general, a significant portion of herbicides used to control weeds reaches places other than the herbicide's site of action. Accordingly, the concentration of the recommended doses is usually considered to be higher than the actual required level. From an environmental point of view, there is no need for maximum weed control to achieve optimal crop yield. So, the recommended and registered doses of herbicides could be shifted to the application of reduced doses. One of these strategies is to reduce the dose of herbicides compared to the recommended doses (Hamill et al. 2004; Benedetti et al. 2020). In other words, by using reduced doses of herbicides, we can prevent the adverse effects of herbicide residues while achieving an acceptable level of weed control (Kudsk 2008). On the other hand, the use of reduced doses of herbicides can play a role in reducing weed resistance (Beckie and Kirkland 2003; Norsworthy et al. 2012). The essential component in applying reduced doses of herbicides is to prevent the reduction of herbicide efficiency in the control of target weeds. Kahramanoglu and Uygur (2010) reported that reducing metribuzin doses from 525 g a.i ha^{-1} (recommended dose) to 183.7 g a.i ha^{-1} was still significantly provided 90% wild mustard control. Bostrom and Fogelfors (2002) reported the satisfactory control of weeds by reducing 50% recommended herbicide doses. The application of reduced doses could achieve acceptable results in weeds control if used in combination with other weed management methods. 70% reduced doses of Atlantis herbicide, and a combination of sunflower and sorghum water extracts resulted in a 90% reduction in weed dry weights (Razzaq et al. 2012).

18.3.2 Herbicide Residues

Monitoring and evaluation of chemical pesticides in the environment are essential components of sustainable agriculture in agro-ecosystems. The issue of herbicide residues should be considered in terms of food security, human health, animal and microorganism's safety, prevention of the damage to non-target crops, etc. (Mehdizadeh et al. 2021). One of the most critical approaches to chemical weed management is maximum weed control without damaging or reducing yield for the main crop. Generally, different plants have different levels of resistance or tolerance to herbicides. Based on this, plants can be divided into resistant, tolerant, and sensitive crops. Resistance level or sensitivity of a plant to a particular herbicide depends on many factors, including the formulation and chemical composition of the herbicide, herbicide application time, herbicide half-life and persistence, herbicide concentration, herbicide mode of action, soil physicochemical properties, plant biology, etc. Sugar beet crops need extensive use of herbicides to control weeds; however, it has a relatively high sensitivity to herbicide residues.

Today, various methods such as instrumental analysis (chromatography (GC, HPLC, TLC), mass spectrometry (MS)), and bioassay methods are used to assess herbicide residues in agricultural ecosystems (Mehdizadeh 2014; Mehdizadeh et al. 2016; Janaki et al. 2018). Crops such as sugar beet, oil seed rape, and tomato, due to their high sensitivity to herbicide residues, have a high potential for selection as biological indicators to track and evaluate the residues of these toxins in agricultural soils (Mehdizadeh 2016, 2019). Matte et al. (2021) evaluated the mobility and persistence of pyroxasulfone herbicide in soil by using some sensitive crops such as lettuce, cucumber, sorghum, sugar beet, and tomato as bioindicators. Very low concentrations of rimsulfuron herbicide residues were successfully assessed using a bioassay method using sugar beet as a sensitive crop (Mehdizadeh and Gholami-Abadan 2018). Mehdizadeh et al. (2017) used a high-performance liquid chromatography along with bioassay methods to evaluate the residues of two sulfonylurea herbicides and reported appropriate results due to the use of HPLC and bioassay for analyzing these herbicides residues in different soils.

18.3.3 Sensitivity of Sugar Beet to Persistent Herbicides

Herbicides with high or moderate persistence in the soil environment could adversely affect sensitive crops in the field or non-target following plants in crop rotation (Greenland 2003). Typically, these kinds of herbicides have a relatively long half-life, and the residues from their degradation can affect plants and microorganisms in the soil (Zaller et al. 2021). There are many factors involved in herbicide residues and their adverse effects on different plants. However, the most important influencing factors are the physiochemical properties and concentration of using the herbicide and the biology of the plant exposed to direct concentrations of the herbicide or its residues over time. Accordingly, it is not unreasonable to expect that different crops show different responses to a particular herbicide. Tandon and

Pal (2021) found no adverse effect of ethofumesate herbicide 2.0 kg ha^{-1} on sugar beet. However, this herbicide with different concentrations could influence the other crops.

Sugar beet is known as one of the most sensitive crops to herbicide residues. Mehdizadeh and Gholami-Abadan (2018) reported the high susceptibility of sugar beet to the trace concentration of rimsulfuron herbicide. According to their study, the root biomass was more sensitive than for shoot. Carneiro et al. (2019) reported a significant reduction in the yield of sugar beet due to the application of tembotrione at the rate of 100.8 g a.i ha^{-1}. The total fresh biomass and carotenoid content of sugar beet were significantly reduced by applying 288 g a.i ha^{-1} mesotrione (Pintar et al. 2020). Dale et al. (2006) evaluated the effects of different herbicides on sugar beet and weed biomass. They reported 44% sugar beet injury due to the application of Desmedipham + phenmedipham + ethofumesate at the rate of 0.03 kg ha^{-1}.

18.4 Future Prospect

Today, crop producers employ a diversity of weed management techniques such as chemical, mechanical, cultural, biological, and integrated weed management (Cheboi et al. 2021). These methods aim to reduce weed damage and to deplete the weed seed bank in crop ecosystems. Given the critical challenges such as ensuring human health and the environment, preventing soil degradation and pollution of water resources, weed resistance, and superweeds creation, the need to review and innovate in weed management methods in the future is absolutely essential (Chauhan et al. 2017). Artificial and robotic control techniques with minimum interference with soil, sensory, computer and information techniques, precision agriculture approaches, expanding the new effective bio-herbicide formulations, genetic engineering, and biotechnology, and considering biological method and allelopathy as environmentally friendly perspective in weed control, could be developed as new prospects for weed management in agricultural systems (Shaner and Beckie 2014; Westwood et al. 2018; Dayan 2019; Mehdizadeh and Mushtaq 2020).

18.5 Conclusion

As discussed before, weeds are among the most critical limiting factors in crop production systems. Damage due to the weed presence in agricultural lands becomes more severe when the crop has lower competitiveness than weeds. Therefore, weed control is one of the most fundamental prerequisites required to achieve acceptable crop yields. Among the various weed management methods, chemical techniques and the application of herbicides play a pivotal role. They are widely used due to their high efficiency, flexibility, easily applicable, and economic advantage. Accordingly, various herbicides have been developed for weed management and are available to farmers worldwide. Despite the relative success of chemical weed management, several challenges such as threatening human health, animals, microorganisms, and the environment, pollution of water and soil resources, and the emergence of weed resistance phenomena have arisen concerning the increasing use of herbicides. Therefore, the side effects of herbicides used in agricultural ecosystems should be evaluated. On the other hand, the researchers should focus on reducing herbicides by using environmentally friendly alternative methods such as robotic, sensory, and computer techniques, expanding precision agriculture and bio-herbicide approaches, biotechnology, and genetic engineering.

References

Abd El-Hamed GM (2019) Performance of some sugar beet (*Beta vulgaris* L.) cultivars under annual weed control condition. J Plant Prod 10(9):739–750. https://doi.org/10.21608/jpp.2019.54481

Abd El-Lateef EM, Mekki BB, Abd El-Salam MS, El-Metwally IM (2021) Effect of different single herbicide doses on sugar beet yield, quality and associated weeds. Bull Natl Res Cent 45:21. https://doi.org/10.1186/s42269-020-00476-9

Abdullahi F, Ghadiri H (2004) Effect of separate and combined applications of herbicides on weed control and yield of sugar beet. Weed Technol 18(4):968–976. https://doi.org/10.1614/WT-03-142R2

Abouziena HF, Haggag WM (2016) Weed control in clean agriculture: a review. Planta Daninha 34 (2):377–392. https://doi.org/10.1590/S0100-83582016340200019

Adamczewski K, Matysiak K, Kierzek R, Kaczmarek S (2019) Significant increase of weed resistance to herbicides in Poland. J Plant Prot Res 59(2):139–150. https://doi.org/10.24425/jppr.2019.129293

Anabestani V, Armin M (2017) Reduction of Phenmedipham + Desmedipham + Ethofumesate herbicides dosage based on application timing in sugar beet. J Crop Ecophysiol 10(4):823–838

Armstrong JJQ, Sprague CL (2010) Weed management in wide- and narrow-row glyphosate-resistant sugarbeet. Weed Technol 24(4):523–528. https://doi.org/10.1614/WT-D-10-00033.1

Ayivi R, Ibrahim S, Colleran H, Silva R, Williams L, Galanakis C, Fidan H, Tomovska J, Siddiqui SA (2021) COVID-19: human immune response and the influence of food ingredients and active compounds. Bioact Compd Health Dis 4(6):100. https://doi.org/10.31989/bchd.v4i6.802

Beckie HJ, Kirkland KJ (2003) Implication of reduced herbicide rates on resistance enrichment in wild oat (*Avena fatua*). Weed Technol 17:138–148. https://doi.org/10.1614/0890-037X(2003)017[0138:IORHRO]2.0.CO;2

Benedetti L, Rangani G, Ebeling Viana V, Carvalho-Moore P, Merotto A Jr, Rabaioli CE, Antonio de AL, Roma-Burgos N (2020) Rapid reduction of herbicide susceptibility in jungle rice by recurrent selection with sublethal dose of herbicides and heat stress. Agronomy 10(11):1761. https://doi.org/10.3390/agronomy10111761

Bezhin K, Santel HJ, Gerhards R (2015) Evaluation of two chemical weed control systems in sugar beet in Germany and the Russian Federation. Plant Soil Environ 61(11):489–495. https://doi.org/10.17221/482/2015-PSE

Bostrom U, Fogelfors H (2002) Response of weeds and crop yield to herbicide dose decision-support guidelines. Weed Sci 50(2):186–195. https://doi.org/10.1614/0043-1745(2002)050[0186:ROWACY]2.0.CO;2

Bruciene I, Aleliunas D, Sarauskis E, Romaneckas K (2021) Influence of mechanical and intelligent robotic weed control methods on energy efficiency and environment in organic sugar beet production. Agriculture 11:449. https://doi.org/10.3390/agriculture11050449

Carlson AL, Luecke JL, Khan MFR, Dexter AG (2008) Survey of weed control and production practices on sugarbeet in Minnesota and eastern North Dakota. North Dakota State University, 2007 Sugarbeet research and extension reports 38:40–63

Carneiro GDOP, Bontempo AF, Guimarães FAR, Rodrigues dos Reis M, Silva DV, Souza MF, Lins HA (2019) Carryover of tembotrione and atrazine in sugar beet. Cienc Investig Agrar 46(3):319–324. https://doi.org/10.7764/rcia.v46i3.2006

Chauhan BS (2020) Grand challenges in Weed Management. Front Agron 1:3. https://doi.org/10.3389/fagro.2019.00003

Chauhan BS, Matloob A, Mahajan G, Aslam F, Florentine SK, Jha P (2017) Emerging challenges and opportunities for education and research in weed science. Front Plant Sci 8:1537. https://doi.org/10.3389/fpls.2017.01537

Cheboi PK, Siddiqui SA, Onyando J, Kiptum CK, Heinz V (2021) Effect of ploughing techniques on water use and yield of rice in Maugo small-holder irrigation scheme. Kenya Agric Eng 3(1):110–117. https://doi.org/10.3390/agriengineering3010007

Chetin AD, Borodin AA, Chmeleva LE (2008) Lanceleaf sage and other problem weeds in sugar beet crops. Sakharnaya Svekla 6:26–27

Chitband AA, Ghorbani R, Rashed MH, Abbaspoor MA, Abbasi R (2014) Evaluation of broadleaf weeds control with selectivity of post-emergence herbicides in sugar beet (*Beta vulgaris* L.). Not Sci Biol 6(4):491–497. https://doi.org/10.1583/nsb649457

Cioni F, Maines G (2010) Weed control in sugarbeet. Sugar Technol 12:243–255. https://doi.org/10.1007/s12355-010-0036-2

Dadkhah A (2013) Allelopathic effect of sugar beet (*Beta vulgaris*) and eucalyptus (*Eucalyptus camaldulensis*) on seed germination and growth of Portulaca oleracea. Russ Agric Sci 39(2):117–123. https://doi.org/10.3103/S1068367413020043

Dale TM, Renner KA, Kravchenko AN (2006) Effect of herbicides on weed control and sugar beet (*Beta vulgaris*) yield and quality. Weed Technol 20(1):150–156. https://doi.org/10.1614/WT-04-278R1.1

Daneshian J, Najari Z, Mavi FL (2013) Investigating of integrated weed management on sugar beet (*Beta vulgaris*) yield in Miandoab. Iran J Weed Sci 8:41–53. (In Persian)

Dayan FE (2019) Current status and future prospects in herbicide discovery. Plan Theory 8:341. https://doi.org/10.3390/plants8090341

Deveikyte I, Seibutis V (2006) Broadleaf weeds and sugar beet response to phenmedipham, desmedipham, ethofumesate and triflusulfuron-methyl. Agron Res 4:159–162

Deveikyte I, Seibutis V (2008) The influence of postemergence herbicides combinations on broad-leaved weeds in sugar beet. Zemdirbyste-Agriculture 53(3):43–49

Deveikyte I, Sarunaite L, Seibutis V (2015) Evaluation of pre- and Postemergence herbicide combinations for broadleaved weeds in sugar beet. In: Price A, Kelton J, Sarunaite L (eds) Herbicides, agronomic crops and weed biology. IntechOpen. https://doi.org/10.5772/61437

Ganbari Birgani D, Hosseinpour M, Shimi P, Noghabi MA (2007) Integrated weed control of sugar beet in Dezful and Boroujerd. Iran J Crop Sci 8:283–299. (In Persian)

Gantoli G, Ayala VR, Gerhards R (2013) Determination of the critical period for weed control in corn. Weed Technol 27(1):63–71. https://doi.org/10.1614/WT-D-12-00059.1

Gerhards R, Bezhin K, Santel H (2017) Sugar beet yield loss predicted by relative weed cover, weed biomass and weed density. Plant Prot Sci 53:118–125. https://doi.org/10.17221/57/2016-PPS

Greenland RG (2003) Injury to vegetable crops from herbicides applied in previous years. Weed Technol 17(1):73–78. https://doi.org/10.1614/0890-037X(2003)017[0073:ITVCFH]2.0.CO;2

Hamill AS, Weaver SE, Sikkema PH, Swanton CJ, Tardif FJ, Ferguson GM (2004) Benefits and risks of economic vs. efficacious approaches to weed management in corn and soybean. Weed Technol 18:723–732. https://doi.org/10.1614/WT-03-166R

Hamouzová K, Jursík M, Zábranský P (2013) Effect of different weather conditions on selectivity of post-emergence herbicides in sugar beet. Listy Cukrovarnicke a Reparske 129(7–8):224–228

Harker KN, O'Donovan JT (2013) Recent weed control, weed management, and integrated weed management. Weed Technol 27(1):1–11. https://doi.org/10.1614/WT-D-12-00109.1

Hassani M, Hemmati Gezaz H, Behfar H, Abdollah Pour S (2020) Construction and evaluation of flame weeding to remove weed in corn and sugar beet rows. J Res Weed Sci 3(4):436–450. https://doi.org/10.26655/JRWEEDSCI.2020.4.3

Heidari GH, Dabbagh Mohammadi Nasab A, Javanshir A, Rahimzadeh Khoie F, Moghaddam M (2007) Influence of redroot pigweed (*Amaranthus retroflexus* L.) emergence time and density on yield and quality of two sugar beet cultivars. J Food Agric Environ 5:261–266. https://doi.org/10.1234/4.2007.1183

Hoseyni SM, Najafi H, Sani B, Mozafari H (2018) Role of new herbicides in dodder (*Cuscuta campestris*) control in sugar beet (*Beta vulgaris*) fields. Appl Ecol Environ Res 16(4):5117–5125. https://doi.org/10.15666/aeer/1604_51175125

Janaki P, Bhuvanadevi S, Dhananivetha M, Murali AP, Chinnusamy C (2018) Persistence of Quizalofop ethyl in soil and safety to ground nut by ultrasonic Bath extraction and HPLC-DAD detection. J Res Weed Sci 1(2):63–74. https://doi.org/10.26655/jrweedsci.2018.9.1

Jhala AJ, Beckie HJ, Peters TJ, Culpepper AS, Norsworthy JK (2021) Interference and management of herbicide-resistant crop volunteers. Weed Sci 69(3):257–273. https://doi.org/10.1017/wsc.2021.3

Kahramanoglu I, Uygur FN (2010) The effects of reduced doses and application timing of metribuzin on redroot pigweed (*Amaranthus retroflexus* L.) and wild mustard (*Sinapis arvensis* L.). Turk J Agric For 34:467–474. https://doi.org/10.3906/tar-0905-17

Kaya R, Buzluk Ş (2006) Integrated weed control in sugar beet through combinations of tractor hoeing and reduced dosages of a herbicide mixture. Turk J Agric For 30:137–144

Khan MFR (2010) Introduction of glyphosate-tolerant sugar beet in the United States. Outlooks Pest Manage 21:38–41. https://doi.org/10.1564/21feb10

Kudsk P (2008) Optimising herbicide dose: a straightforward approach to reduce the risk of side effects of herbicides. Environmentalist 28:49–55. https://doi.org/10.1007/s10669-007-9041-8

Kunz C, Sturm D, Vanrholt D, Walker F, Gerhards R (2016) Allelopathic effects and weed suppressive ability of cover crops. Plant Soil Environ 62:60–66. https://doi.org/10.17221/612/2015-PSE

Lobmann A, Christen O, Petersen J (2019) Development of herbicide resistance in weeds in a crop rotation with acetolactate synthase-tolerant sugar beets under varying selection pressure. Weed Res 59:479–489. https://doi.org/10.1111/wre.12385

MacLaren C, Storkey J, Menegat A, Metcalfe H, Dehnen-Schmutz K (2020) An ecological future for weed science to sustain crop production and the environment. A review. Agron Sustainable Dev 40:24. https://doi.org/10.1007/s13593-020-00631-6

Mahmoud MS, Soliman FS (2012) Chemical weed control in sugar beet. Alex Sci Exchange J 33(4):341–350. https://doi.org/10.21608/asejaiqjsae.2012.3171

Majidi M, Heidari G, Mohammadi K (2011) Management of broad- leaved weeds by combination of herbicides in sugar beet production. Adv Environ Biol 5(10):3302–3306

Marwitz A, Ladewig E, Märländer B (2012) Impact of herbicide application intensity in relation to environment and tillage on earthworm population in sugar beet in Germany. Eur J Agron 39:25–34. https://doi.org/10.1016/j.eja.2012.01.005

Matte WD, Oliveira RS Jr, Constantin R, Mendes RR, Padovese LB, Tseng TM (2021) Bioindicators selection to monitoring pyroxasulfone mobility and persistence in soil. J Res Weed Sci 4(2):142–150. https://doi.org/10.26655/JRWEEDSCI.2021.2.1

Mehdizadeh M (2014) High performance liquid chromatographic determination of an asymmetrical Triazine herbicide from soil. Int J Farming Allied Sci 3:1201–1205

Mehdizadeh M (2016) Effect of pesticide residues on agricultural food production; a case study: sensitivity of oilseed rape to Triasulfuron herbicide soil residue. MOJ Food Process Technol 2:1–2. https://doi.org/10.15406/mojfpt.2016.02.00054

Mehdizadeh M (2019) Sensitivity of oilseed rape (*Brassica napus* L.) to soil residues of imazethapyr herbicide. Int J Agric Environ Food Sci 3(1):46–49. https://doi.org/10.31015/jaefs.2019.1.10

Mehdizadeh M, Gholami-Abadan F (2018) Negative effects of residual herbicides on sensitive crops: impact of Rimsulfuron herbicide soil residue on sugar beet. J Res Weed Sci 1:1–6. https://doi.org/10.26655/jrweedsci.2018.6.1

Mehdizadeh M, Mushtaq W (2020) Biological control of weeds by allelopathic compounds from different plants: a BioHerbicide approach. In: Egbuna C, Sawicka B (eds) Natural remedies for pest, disease and weed control. Academic Press, Cambridge, pp 107–117. https://doi.org/10.1016/B978-0-12-819304-4.00009-9

Mehdizadeh M, Alebrahim MT, Roushani M, Streibig JC (2016) Evaluation of four different crops' sensitivity to sulfosulfuron and tribenuron methyl soil residues. Acta Agric Scand B-Soil Plant Sci 66:706–713. https://doi.org/10.1080/09064710.2016.1212919

Mehdizadeh M, Alebrahim MT, Roushani M (2017) Determination of two sulfonylurea herbicides residues in soil environment using HPLC and phytotoxicity of these herbicides by lentil bioassay. Bull Environ Contam Toxicol 99:93–99. https://doi.org/10.1007/s00128-017-2076-8

Mehdizadeh M, Asadi GA, Delobel A (2018) Biological control potential of *Spermophagus sericeus* Geoffroy, 1785 (Coleoptera: Chrysomelidae) against field bindweed as the first report from Iran. J Res Weed Sci 1:40–47. https://doi.org/10.26655/jrweedsci.2018.6.5

Mehdizadeh M, Mushtaq W, Siddiqui SA, Ayadi S, Kaur P, Yeboah S, Mazraedoost S, DKA A-T, Tampubolon K (2021) Herbicide residues in agroecosystems: fate, detection, and effect on non-target plants. Rev Agric Sci 9:157–167. https://doi.org/10.7831/ras.9.0_157

Melander B, Rasmussen IA, Bàrberi P (2005) Integrating physical and cultural methods of weed control-examples from European research. Weed Sci 53:369–381. https://doi.org/10.1614/WS-04-136R

Mushtaq W, Mehdizadeh M, Siddiqui MB, Ozturk M, Jabran K, Altay V (2020) Phytotoxicity of above-ground weed residue against some crops and weeds. Pak J Bot 52(3):1–10. https://doi.org/10.30848/PJB2020-3(40)

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60(1):31–62. https://doi.org/10.1614/WS-D-11-00155.1

Petersen J (2004) A review on weed control in Sugarbeet. In: Inderjit (ed) Weed biology and management. Springer, Dordrecht, pp 467–483. https://doi.org/10.1007/978-94-017-0552-3_23

Pintar A, Stipicevic S, Svecnjak Z, Baric K, Lakic J, Sraka M (2020) Crop sensitivity to mesotrione residues in two soils: field and laboratory bioassays. Chil J Agric Res 80(4):496–504 http://dx.doi.org/https://doi.org/10.4067/S0718-58392020000400496

Rapparini G (2008) New Betarens in the system of postemergence weed control. Sakharnaya Svekla 8:18–20

Rasha GMA (2010) Improving the efficiency of some herbicides in weed control in sugar beet by some adjuvants. M.Sc. Thesis, Fac. Agric. Cairo Univ., Egypt. Saric-Krsmanovic M, Bozic D, Radivojevic L, Gajic Umiljendic J, Vrbnicanin S (2018) response of alfalfa and sugar beet to field dodder (*Cuscuta campestris* Yunck.) parasitism: physiological and anatomical approach. Can J Plant Sci 99:199–209. https://doi.org/10.1139/cjps-2018-0050

Razzaq A, Cheema ZA, Jabran K, Hussain M, Farooq M, Zafar M (2012) Reduced herbicide dosed used together with allelopathic sorghum and sunflower water extracts for weed control in wheat. J Plant Prot Res 52(2):281–285. https://doi.org/10.2478/v10045-012-0045-0

Saric-Krsmanovic MM, Bozic DM, Radivojevic LM, Umiljendic JSG, Vrbnicanin SP (2017) Effect of *Cuscuta campestris* parasitism on the physiological and anatomical changes in untreated and herbicide-treated sugar beet. J Environ Sci Health B 52(11):812–816. https://doi.org/10.1080/03601234.2017.1356167

Sbatella GM, Adjesiwor AT, Kniss AR, Stahlman PW, Westra P, Moechnig M, Wilson RG (2019) Herbicide options for glyphosate-resistant kochia (*Bassia scoparia*) management in the Great Plains. Weed Technol 33(5):658–663. https://doi.org/10.1017/wet.2019.48

Shaner DL, Beckie HJ (2014) The future for weed control and technology. Pest Manag Sci 70(9):1329–1339. https://doi.org/10.1002/ps.3706

Siddiqui SA, Blinov AV, Serov AV, Gvozdenko AA, Kravtsov AA, Nagdalian AA, Raffa VV, Maglakelidze DG, Blinova AA, Kobina AV, Golik AB, Ibrahim SA (2021) Effect of selenium nanoparticles on germination of Hordéum Vulgáre barley seeds. Coatings 11(7):862. https://doi.org/10.3390/coatings11070862

Soltani N, Dille JA, Robinson DE, Sprague CL, Morishita DW, Lawrence NC, Kniss AR, Jha P, Felix J, Nurse RE, Sikkema PH (2018) Potential yield loss in sugar beet due to weed interference in the United States and Canada. Weed Technol 32:749–753. https://doi.org/10.1017/wet.2018.88

Somerville GJ, Sønderskov M, Mathiassen SK, Metcalfe H (2020) Spatial modelling of within-field weed populations; a review. Agronomy 10:1044. https://doi.org/10.3390/agronomy10071044

Storkey J, Helps J, Hull R, Milne AE, Metcalfe H (2021) Defining integrated weed management: a novel conceptual framework for models. Agronomy 11:747. https://doi.org/10.3390/agronomy11040747

Tandon S, Pal SL (2021) Residue kinetics of ethofumesate in texturally diverse soils of sugar beet crop under field conditions. J Chem:5566787. https://doi.org/10.1155/2021/5566787

Westwood JH, Charudattan R, Duke SO, Fennimore SA, Marrone P, Slaughter DC, Swanton C, Zollinger R (2018) Weed management in 2050: perspectives on the future of weed science. Weed Sci 66(3):275–285. https://doi.org/10.1017/wsc.2017.78

Wilson RG (1999) Response of nine sugarbeet *(Beta vulgaris*) cultivars to post-emergence herbicide applications. Weed Technol 13:25–29. https://doi.org/10.1017/S0890037X00044857

Wilson RG, Sbatella GM (2011) Late-season weed control in glyphosate-resistant Sugarbeet. Weed Technol 25(3):350–355. https://doi.org/10.1614/WT-D-10-00057.1

Yagoob AM, Zaroug MSA, Dafaallah ABB (2021) Efficacy and selectivity of pendimethalin for weed control in sugar beet (*Beta vulgaris* L.), Gezira state, Sudan. J Res Weed Sci 4(1):16–28. https://doi.org/10.26655/JRWEEDSCI.2021.1.2

Zaller JG, Weber M, Maderthaner M, Gruber E, Takács E, Mörtl M, Klátyik S, Győri J, Römbke J, Leisch F, Spangl B, Székács A (2021) Effects of glyphosate-based herbicides and their active ingredients on earthworms, water infiltration and glyphosate leaching are influenced by soil properties. Environ Sci Eur 33:51. https://doi.org/10.1186/s12302-021-00492-0

Zargar M, Najafi H, Zand E, Mighani F (2010) Study of integrated methods for management of red-root pigweed and lamb-squarters in single- vs. twin-row sugar beet. Proceedings of 3rd Iranian Weed Science Congress. Vol 2: Key papers, weed management and herbicides. Babolsar, Iran, February. pp. 654–657

Zimmerman T, Siddiqui SA, Bischoff W, Ibrahim SA (2021) Tackling airborne virus threats in the food industry: a proactive approach. Int J Environ Res Public Health 18(8):4335. https://doi.org/10.3390/ijerph18084335