**ABSTRACT**

Sugar is an essential commodity and an integral part of the food chain which is the cheapest source of energy. It plays a vital role in the development of taste, texture, colour and keeps baked goods soft and moist. Sugar beet ranks second as a sugar producing crop in the world. Weeds in beet crops reduce the yield in the field level as well as make the harvesting and processing difficult. The weed seeds in soil bank are detrimental as they germinate in subsequent crop cultivation. Weed control failure causes severe yield loss in sugar beet. However, several weed control measures along with herbicides provide a significant increase of average yield in sugar beet. It has become necessary to reduce the use of them in order to protect the human health as well as the other living organisms. For this reason, alternative ways of controlling weeds are being practiced all over the world. The efficient way of reducing the use of herbicides with the revaluation of agronomic techniques is replacing herbicide treatments. Thereby weed control combines herbicidal and non-herbicidal methods in an integrated manner. Basically, integrated weed control approach provides a potential reduction in weed population. However, this system is not efficient to manage weeds in larger-scale sugar beet production.

**Keywords:** Weed management, sugar beet, herbicide, sugar crop

1 **Introduction**

Sugar beet (*Beta vulgaris* L.) is ranked as the second important sugar crop all over the world next to sugarcane (*Saccharum officinarum* L.) which belongs to the family Chenopodiaceae (Brar et al., 2015). Sugar beet is a temperate crop and its root contains a high amount of sucrose (Paul et al., 2019). Its life duration is short (5–6 months) and contains a high concentration of sucrose (14–20%) compared to sugarcane as sugarcane’s life duration is long (12–14 months) with the low amount of sucrose (10–12%) (Ahmad et al., 2012; Paul et al., 2018). About 30% for human consumption sugar of the world is contributed by the sugar beet crop (Bairagi et al., 2013).

Weeds are noticed as one of the major yield obstructive factors (Oerke, 2006). Sugar beet is a slow-growing crop early in the season and thus in the field it seems to be a poor competitor with weeds (May, 2003). If immediate control measures are not employed in the sugar beet field, a severe competition occurs in the crop growing period thus resulted in full crop damage (Cioni and Maines, 2010; Kropff and Spitters, 1991). Particularly effective weed control is required up to the first 60 days after emergence which is the critical period of sugar beet (Gerhards et al., 2017). It has been reported that sugar beet root yields can be reduced by 26–100% when competition from annual weeds that are uncontrolled which emerges at 8 weeks of sowing or at 4 weeks of the crop attainment the 2-leaf phase (Rosso et al., 1996; Schweizer and Dexter, 1987). Scott et al. (1979) stated that weeds might decrease yields by about 1.5% Day-1 for the following 6 weeks when the sugar beet crop at the 4 to 6-leaf phase and therefore, weed removal from sugar beet crops is essential until the 8-leaf stage (Gerhards et al., 2017).

In the sugar beet field, herbicides application have been started from early 1950s as preliminary approach of weed control, although hoeing and hand weeding are still used in many areas in the world (Schweizer and Dexter, 1987). The limited use of herbicides has become a requirement in the 1990s to address ecological contamination and subsequently
Table 1. Common, scientific and family names of the most important problematic weeds in sugar beet†

| Common name                      | Scientific name                          | Family name       |
|----------------------------------|------------------------------------------|-------------------|
| Powell amaranth                  | *Amaranthus powellii* S. Wats.           | Amaranthaceae     |
| Common amaranth, redroot pigweed | *Amaranthus retroflexus* L.              | Amaranthaceae     |
| Common ragweed                   | *Ambrosia artemisiifolia* L.             | Asteraceae        |
| Wild-oat                         | *Avena fatua* L.                         | Poaceae           |
| Rape, wild buckweed             | *Brassica napus* L.                      | Brassicaceae      |
| Common lambsquarters, fat-hen    | *Chenopodium album* L.                   | Chenopodiaceae    |
| Canada thistle, creeping thistle | *Cirsium arvense* (L.) Scop.             | Asteraceae        |
| Field bindweed                   | *Convolvulus arvensis* L.                | Convolvulaceae    |
| Jimsonweed, thorn-apple          | *Datura stramonium* L.                   | Solanaceae        |
| Barnyardgrass, cockspur          | *Echinochloa crus-galli* (L.) Beauv.     | Poaceae           |
| Common couch, quackgrass, twitch| *Elymus repens, Agropyron repens*        | Poaceae           |
| Common clave, goosegrass         | *Galium aparine* L.                      | Rubiaceae         |
| Common sunflower                 | *Helianthus annuus* L.                   | Asteraceae        |
| Kochia                           | *Kochia scoparia* (L.) Schrad            | Amaranthaceae     |
| Pineappleweed                    | *Chamomilla suaveolens*                  | Asteraceae        |
| False chamomile, mayweed         | *Matricaria camomilla*                   | Asteraceae        |
| Pale persicaria                  | *Polygonum lapathifolium*                | Polygonaceae      |
| Ladysthumb, redshank             | *Polygonum persicaria*                   | Polygonaceae      |
| Groundcherries                   | *Physalis* spp.                          | Solanaceae        |
| Annual meadow-grass              | *Poa annua* L.                           | Poaceae           |
| Knotgrass, prostrate knotweed    | *Polygonum aviculare* L.                 | Polygonaceae      |
| Smartweeds, polygonum            | *Polygonum* spp.                         | Polygonaceae      |
| Common purslane                  | *Portulaca oleracea* L.                  | Polygonaceae      |
| Giant foxtail                    | *Setaria faberi* Herrm.                  | Poaceae           |
| Yellow foxtail                   | *Setaria glauca* (L.) Beauv.             | Poaceae           |
| Foxtail, bristle-grass           | *Setaria* spp.                           | Poaceae           |
| Green foxtail, green bristle-grass| *Setaria viridis* (L.) Beauv.            | Poaceae           |
| Charlock, wild mustard           | *Sinapis arvensis* L.                    | Brassicaceae      |
| Hairy nightshade                 | *Solanum sarachoides* Sendtner           | Solanaceae        |
| Potato                           | *Solanum tuberosum* L.                   | Solanaceae        |
| Perennial sow-thistle            | *Sonchus arvensis* L.                    | Asteraceae        |
| Johnsongrass                     | *Sorghum halepense* (L.) Pers.           | Poaceae           |
| Common chickweed                 | *Stellaria media* (L.) Vill.             | Caryophyllaceae   |
| Field pansy, field violet        | *Viola arvensis* Murr.                   | Violaceae         |
| Velvet leaf                      | *Abutilon theophrasti* Medic             | Malvaceae         |

† Source: Modified from May and Wilson (2006)

Table 2. Effect of tillage in the preceding crops on the weed species occurrence in sugar beet†

| Soil cultivation                     | Preceding crop                  | Weeds                                                                 |
|--------------------------------------|---------------------------------|----------------------------------------------------------------------|
| Conventional tillage (>20–25 cm)     | Sunflower, maize, soybean       | *Abutilon theophrasti, Amaranthus* spp., *Ammi majus, Chenopodium album, Cyperus rotundus, Cirsium arvense, Cynodon dactylon, Datura stramonium, Echinochloa crus-galli, regrowth of sunflower, Polygonum spp., Salsola Kali, Sorghum halepense, Xanthium strumarium* |
| Minimum tillage (15–20 cm)           | Wheat, sunflower, soybean       | *Alopecurus myosuroides, Amaranthus* spp., *Ammi majus, Chenopodium spp., Cirsium arvense, Cynodon dactylon, Fallopia convolvulus, Lolium spp., Phalaris spp., Polygonum aviculare, Sinapis spp.* |
| Direct drilling                       | Wheat, sunflower, maize, soybean| *Agropyron repens, Alopecurus myosuroides, Cirsium arvense, Convolvulus spp., Equisetum spp., Fallopia convolvulus, Phalaris spp., Picris echioides, Poa spp., Sorghum halepense* |

† Source: Modified from Cioni et al. (1998)
to protect human fitness. By replacing herbicides with the adjustment of different management practices and limiting the herbicide doses, the decrease of the use of herbicides can be achieved. Thus, in the integrated weed management, weed control involved in a chemical method including other non-chemical approaches (Cioni and Maines, 2010). Therefore, the real weed management is very important for sustaining sugar beet production to mitigate sugar demand.

2 Weeds of sugar beet

There are 60 weed species detected as major infesting species among 250 weed species in sugar beet crop in the world. Of which approximately 70% are broad-leaved and 30% are grass weeds (May and Wilson, 2006). The dicot weeds are more destructive compared to monocots (Zoschke and Quadranti, 2002; Roos and Brink, 1996). The most important dicot weeds of sugar beet growing areas from the families of Chenopodiaceae, Asteraceae, Brassicaceae, and Polygonaceae. Annual grasses are usually less competitive than annual broad-leaved (Schweizer and May, 1993). The most common annual broad-leaved weeds are Amaranthus retroflexus, Chenopodium album, Matricaria recutita, Polygonum aviculare, Fallopia (Polygonum) convolvulus, Sinapis arvensis and Stellaria media; annual grasses are Echinochloa crus-galli, Poa annua and Setaria viridis. Chenopodium album, a species under to the same family of sugar beet, is one of the common weeds in this crop. The common name, scientific name and family names of the most important problematic weeds in sugar beet are listed in Table 1.

3 Effect of weed on sugar beet yield

Weeds are the major enemies in sugar-beet cultivation in many countries in the world including Bangladesh. The sugar beet crop is relatively susceptible to the competition of weeds due to its slow initial growth. Weed has significant effect on yield of sugar beet. The mixed weed populations greatly reduced sugar beet yield to the extent that about 99% in control plots as compared to weed free plots (Tekleselassie and Yirefu, 2013). Besides, a yield loss of 50 and 75% occurred when weeding was delayed for 60 and 90 DAS. According to Salehi et al. (2007), weed infestation reduced beet yield by 92.9% and 61.2% in 1999 and 2000, respectively, as compared to weed free throughout the growth period. Compared to weed-free check the weed infestation decreased sugar yield considerably due to weed infestation and a decrease of sugar yield in season-long weed infestation was 84.87% and 62.1% in 1999 and 2000, respectively. The crop yield lost up to 100% due to severe weed-crop competition under limiting weed control or without control (Kropff and Spitters, 1991).

4 Effect of weed on sugar beet quality

Weed-beet competition does not affect impure substances such as potassium, sodium and amino nitrogen in sugar beet juice. Above ground weed biomass production influenced individual beet root weight. According to Longden (1989), there was no correlation found between weed-beet population and the sucrose concentration as well as potassium, sodium, amino nitrogen or invert sugars. However, a strong correlation found between root and sugar yields with weed-beet population. With the increasing densities of weed beet, root and sugar yields were gradually decreased. A negative relationship between weed-beet density and sugar yield was observed by Longden (1989), which shown that the higher the weed-beet density the lower the sugar yield. Seadh et al. (2013) reported that weed control treatment significantly influenced on total soluble sugar (TSS)%, sucrose% and apparent purity% in beet juice over weedy check.

5 Weed control in sugar beet

5.1 Cultural control

5.1.1 Crop rotation

Weed control should be considered over the whole rotation instead of a single crop to ensure the protection of one weed species in the field. The weed control through crop rotation schedule is imperative because of its minimum cost, highest effectiveness and without or minimum environmental risk. Mono- and dicotyledonous species should be included in the weed management programs where the crop less similar to weed species or where weed control is easy for example it is easier to control Cuscuta spp. (Common dodder) crops-growing, such as maize, sorghum, soybean, wheat, can give a noble support to crack the problem (Cioni and Maines, 2010). Crop rotation can influence the growth of sugar beet by controlling the intensity of weed infestation and suppress the weed spectrum in the field (Cioni and Maines, 2010; Koocheki et al., 2009). Crop rotation influence the stability of beet yield and quality was reported by Götzte (2017).

5.1.2 Cover crop or mulching

Addition of cover crops into a sugar beet rotation is very typical (25% of sugarbeet area) in some countries (Merkes et al., 2001). In autumn, cover crops struggle with weeds for water, space, light, and nutrients and subsequently suppress weeds during their growth periods (Brust et al., 2014; Kunz et al., 2016) and as
mulch in spring (Campiglia et al., 2015). Commonly used cover crop species in sugar beet fields are mustard (Sinapis alba L.), phacelia (Phacelia tanacetifolia Benth.) and radish (Raphanus sativus var. oleiformis (Stokes) Metzg.) (Petersen, 2004). By these rapid growing cover crops weed suppression is effectively occurred in field as light intensity reduced (Auler, 1998). Additionally, allelopathic properties of, some cover crops can suppress the weeds by releasing allelopathic ingredients into the environment (Kelton et al., 2012; Kunz et al., 2016). Secondary metabolites, glucosinolates are the representative of the family Brassicaceae (Fenwick et al., 1983). Isothiocyanates as degradation materials from glucosinolates are biologically active and can hamper weed sprouting (Al-Khatib et al., 1997). Though, this issue is important while the cover crops incorporated into the soil to prepare green manure (Petersen et al., 2001).

5.1.3 Tillage
Weed flora present in sugar beet farms can be changed by the reduction of tilling depth in the soil during land preparation. Cioni et al. (1998) observed that weed species configuration in sugar beet field varies due to different tillage system (conventional tillage, minimum tillage and direct drilling) of previous crops. The impact of tillage on weed flora configuration was not detected in case of annual weeds which are very problematic to control in sugar beet, while Polygonaceae, Gramineae and perennials were preferred by minimum tillage (Table 2). The minimum tillage could lead to increase in not only perennials and gramineae but also the Compositeae weed species (Table 3)

5.2 Mechanical control
Mechanical control removes weeds substantially by uprooting, chopping up the whole plants or untying weed stems and leaves from their roots. The unintentional spread of perennial weeds, through splitting up and dispersal roots, rhizomes, stolons and tubers which will again produce up into a new weed is another drawback (Cioni and Maines, 2010). To allow the use of cultivation equipment, wide distances between sugar beet rows is required. Based on the growth phase of the crops some precise farming tools should be used to escape crop injury in the field. For high effectiveness and crop care, the timing of mechanical farming is very important. For example, damp soil conditions never permit the use of hoeing machines even the effectiveness is reduced due to regrowth of the weeds in this condition. Harrows as mechanical weeder can be used also in the rows and harrows must not be used between emergence of the coleoptile from the seed and 2-leaf stage of the sugar beet. There are certain tools used in hoeing machines which remove weeds from the sugar beet rows namely finger weeder or a torsion weeder (Petersen, 2004). As a consequence, removal of weed by hand is quiet essential. Based on the weed outbreak and field situations there are about 70-300 hr ha⁻¹ are required to effectively removal weeds in the row by hand. Hand weeding is very costly in case of industrial countries although now-a-days hand weeding is partial to very precise weed problems (e.g., weed beets). Hand weeding is fairly common in countries wherever labor is inexpensive than the use of herbicides (e.g., Turkey and the countries of the former Soviet Union) (Petersen, 2004). Most of the sugar beet growing countries tractor-mounted hoes is very vital to destroy weeds between sugar beet rows. Tractor hoes are used where herbicides have been sprayed in bands over the rows or to control difficult weeds in case of perennials or some weeds are too far advanced to be properly controlled by the herbicide (Cioni and Maines, 2010). Tractor hoes works greater in arid land as the soil is friable and as less re-rooting of the weeds while sharp tine weeder work properly when the soil is wet. The weeds can easily eliminate under moist conditions from the soil although monocot weeds can easily re-root under wet conditions (Jones et al., 1996).

5.3 Chemical control
Broad leaved weed species are the utmost competitive annual weeds. During midsummer, these weeds frequently raise to a height 2-3 times than that of sugar beet. In crop field, weed control is done by herbicides because chemical control is efficient and easily applicable (Lodovichi et al., 2013). Tank mixes of various herbicides are usually used to offer a wide range of weed control (May and Wilson, 2006). Chemical method of weeds control is the most vital ways of weed management in sugar beet farm (Table 4).

5.3.1 Pre-sowing and pre-emergence herbicides
Pre-sowing and pre-emergence herbicides are presently suggested in sugar beet fields to weed control. The pre-sowing is the non-selective contact herbicides that are recommended to destroy weeds before the crop appears while pre-emergence is the remaining soil-applied herbicides which are applied pre or post sowing. Non-selective herbicides prior to sugar beet germination, the main advantage of is that almost all the appeared weed species, including weed beet, are controlled. Paraquat, glyphosate and glufosinate-ammonium are the main contact herbicides that are used round the world (Cioni and Maines, 2010). Soil applied residual herbicides decrease the number of weeds which appear with the crop and it often sensitizes fighters to succeeding post-emergence sprays (Duncan et al., 1982; Cioni et al., 1991; Zanin et al., 1996). Pre-emergence herbicides
Table 3. Spreading of weed species related to the time duration of minimum tillage

| Biological group | Species                  | Years of minimum tillage |
|-----------------|--------------------------|--------------------------|
|                 |                          | 1st | 2nd | 3rd |
| Geophyte        | *Agropyron repens*      | 0   | 0   | ++  |
|                 | *Cirsium arvense*       | +   | 0   | +++ |
| Hemicryptophyte | *Picris echioides*      | 0   | 0   | +++ |
|                 | *Taraxacum officinale*  | 0   | 0   | ++  |
| Therophyte      | *Alopecurus myosuroides*| ++  | ++  | +++ |
|                 | *Coryza canadensis*     | 0   | 0   | ++  |
|                 | *Daucus carota*         | 0   | 0   | +   |
|                 | *Lolium multiflorum*    | 0   | 0   | ++  |
|                 | *Poa annua*             | +   | ++  | ++  |
|                 | *Senecio vulgaris*      | +   | 0   | ++  |
|                 | *Sonchus spp.*          | +   | +   | +++ |
|                 | *Veronica persica*      | +   | +   | ++  |

† Source: Cioni et al. (1998); § 0 = not present, + = only presence, ++ = low spread, +++ = medium spread, ++++ = high spread

reduce weed population, complement subsequent post-emergence uses as well as offer certain flexibility with timing and choice of post-emergence treatments and so they are vital for the common of sugar beet growers (May and Hilton, 1985; Ansaloni, 1990). The increased consistency and previous post-emergence use of low dose sprays permitted the pre-emergence herbicides for broad-leaved weed management to be applied at lower doses than before used (Cioni, 1997). The common pre-emergence residual broad-leaved herbicides applied in sugar beet crops are chloridazon, clomazone, cycloate, ethofumesate, quinmerac, lenacil, metamitron, and metolachlor. To control grass weeds, herbicides that may be used before sowing are cycloate, dalapon, EPTC, metolachlor, TCA and tri-allate. However, these graminicides, particularly dalapon and TCA, though usually inexpensive, that are abundant less probable to reason crop injury, have been changed in many countries by judicious post-emergence graminicides (May and Wilson, 2006).

5.3.2 Post-emergence herbicides

Post-emergence herbicides are used for controlling weeds mainly for broad-leaved and grasses. A large amount of products and tank mixes are existing in post-emergence herbicides for control broad-leaved weeds such as chloridazon, clopyralid, ethofumesate, lenacil, metamitron, desmedipham, endothal phenmedipham and triflusulfuron-methyl (May and Wilson, 2006). Cioni and Maines (2010) reported that since sugar beet herbicides have enough residual activity to control the weeds although tank mixes of various herbicides are frequently used to deliver a broad range of weed control. Increase the efficacy of herbicides the spray additives are used to improve the contact of spray droplets on sugar beet leaves. When weeds and crop both have waxy leaves then spray additives are advantageous, especially under dry conditions. Adding an oil additive is recommended in many countries as post-emergence treatments although the main spray additives used in sugar beet crops are established on mineral or vegetable oils, tal-low amines and wetters. Most of the post-emergence graminicide should be applied at a comparatively later phase of crop growth to offer adequate time to growth based on target (Cioni and Maines, 2010). Post-emergence herbicide could be applied in a low-volume and low-dose for controlling of broad-leaved weeds (Candolo, 1988; Muchembled, 1989; Balsari, 1996) while conventional doses of active ingredient are reduced by two-thirds. Balsari and Airoldi (1993) noticed that a upright spray was ensured by the little spray volumes shared with nozzles that produced relatively fine spray droplets to exposure of plants that apparently an economic weed control to the growers. Spraying to cotyledon-stage weeds is vital for the success of the method. So, in European countries the micro-rate system is widely acceptable (Cioni and Maines, 2010).

5.4 Biological weed control

Biological weed control is a process of controlling weed by the use of microorganisms to suppress weed in the crop field. Biological control of weeds is done by traditional method and augmentative (bio-herbicide). The traditional method introduced external control agents while augmentative approach indicates the manipulation of microorganism that already exists in the ecosystem. Smith (1986) noticed some fungal pathogens of weeds namely; Col-
Table 4. Herbicides used in sugar beet production and their effects on sugar beet and weeds†

| Herbicide                  | Mode and site of action                                      | Sugar beet and weed injury symptoms                                                                 |
|----------------------------|-------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| **Pre-plant, applied post-emergence to weed before crop emergence** |                              |                                                                                                        |
| Glufosinate-ammonium      | Inhibition of glutamine synthetase                          | Plant foliage, especially new growth will turn yellow then brown                                       |
| Glyphosate               | Inhibition of EPSP synthetase                               |                                                                                                        |
| **Pre-plant incorporated, pre-emergence** |                              |                                                                                                        |
| Cycloate                 | Lipid synthesis inhibition                                  | General stunting, crinkled, fused leaves. Shortened leaf mid-vein                                      |
| Ethofumesate             | Inhibition of cell division by a reduction of photosynthesis and respiration |                                                                                                        |
| Lenacil                  | Photosynthesis inhibition                                   | Initial yellowing of leaf vein, injured plant tissue turns brown                                        |
| Metolachlor              | Shoot inhibition                                            | Initial yellowing of leaf margin, affects older leaves, injured plant tissue turns brown                |
| Metamitron, Chloridazon  | Photosynthesis inhibition                                   | Inhibition of root growth, stunting of the shoot, epinasty and anthocyanin-coloration of the leaves    |
| Quinmerae                | Auxin activity. This in turn stimulates the production of ethylene |                                                                                                        |
| **Post-emergence**       |                              |                                                                                                        |
| Clethodim, Fluazifop-P,  | ACCase inhibition                                           | Yellowing (chlorosis), browning of leaves emerging from grass whorl                                   |
| Propaquizafop, Quizalofop-P | ALS-AHAS inhibition                                | General stunting, yellowing of leaves at the growing point                                            |
| Triflusulfuron-methyl     | Carotenoid biosynthesis inhibition                         | Blanching of leaves. Susceptible species emerge but are devoid of pigmentation                        |
| Clomazone                | Growth regulator—synthetic auxin                            | Stem elongation, twisting, leaf cupping                                                               |
| Clopyralid               | Photosynthesis inhibition                                   | Initial yellowing or brown spotting on leaves, browning of leaf margins                               |
| Chloridazon, Lenacil,    | Inhibition of cell division by a reduction of photosynthesis and respiration |                                                                                                        |
| Metamitron, Phenmedipham |                                                                         |                                                                                                        |
| Ethofumesate             | Inhibition of the Hill-reaction (affects assimilation ability of the plant) |                                                                                                        |
| Desmedipham              | Inhibition of the Hill-reaction (affects assimilation ability of the plant) |                                                                                                        |

† Source: Modified from May and Wilson (2006)

*letotrichum gloesporioides* spp. *aeschnomene* for control of *Aeschnomene virginica* in rice and soybean, several fungi, bacteria and viruses are potential bio-herbicides. Some fungal pathogens also showing potentiality to management of *Abutilon theophrastii*, *Chenopodium album*, *Datura stramonium*, *Echinochloa crus-galli* and *Sorghum halepense* in sugar beet field (Cioni and Maines, 2010). A biologically active natural product is the great source of lead molecules to develop pharmaceutical, insecticidal and fungicidal products. Commercial herbicides and natural phytotoxins show a remarkable degree of similarity. Most of the cases as sources of natural products of herbicides the microbial sources are used in the herbicidal industry (Duke et al., 1996). Although hundreds of compounds have been patented but only two, bialaphos and phosphinothricin are successfully popularized. The chemically manufactured Glufosinate (form of phosphinothricin), works directly on plants while bialaphos need to be converted metabolically into phosphinothricin by plants (Lydon and Duke, 1999). In sugar beet fields currently biological control or natural phytotoxins strategies are used to control weeds. Cioni and Maines (2010) noticed that weed control in sugar beet crops might be promising in the longer period using bio-herbicides.
6 Herbicide resistance in sugar beet

Most of the selective sugar beet herbicides have some influence on sugar beet growth where initial symptom shows on the leaves. Therefore, this lack of selectivity reduces yield in sugar beet (Petersen, 2004). Genetic modification technology (genetic engineering) that is tolerant to broad-spectrum herbicides that can change the short spectrum herbicides presently in use, has allowed the production of sugar beet. The two broad-spectrum herbicides namely glyphosate and glufosinate are showed tolerance to genetically modified sugar beet varieties (Marlander, 2005). Genetically improved herbicide tolerant sugar beet enhanced early season crop vigour which increases the crops capability to capture sunlight, increase the struggle with weeds and improve sucrose yield (Wilson and Smith, 1999). Due to reduction of phytotoxicity of herbicide in plants the crop yield increased up to 15% thus reduces expenses by about 15% (Kniss et al., 2003; May, 2003). Intensive use of more than one herbicide resilient crop might cause problems regarding outcrossing of resistance, choice of herbicide tolerant weeds and volunteer crops, surface water contamination, a move in weed flora, and injury to non-target plants by application herbicide drift (Hurle and Petersen, 2000; Petersen et al., 1998). Therefore to address the mentioned problems management techniques is required before herbicide resistant cultivars are extensively cultivated (Petersen, 2004).

7 Reducing the use of herbicides

7.1 Integrated weed management

It is a systematic approach of weed control involving the application of strategies, principles, practices, methods and materials in an integrated, compatible, environmentally sound and economic way to achieve optimum crop production. Conferring to Endure’s definition, IPM (Integrated Pest Management) is a justifiable measure to manage pests through applying all techniques (cultural, biological and chemical) in a way that reduces economic, environmental and health hazards. Locally it is adapted because they contribute to reducing dependency on pesticide in crop production (Cioni and Maines, 2010). The real agronomic need is only to defend the crop during the critical stage of weed competition where weedable to cause yield losses and after which weed competition will no longer decrease crop yield (Zimdahl, 1988). Covarelli and Onofri (1998) reported that sugar beet field should be saved weed free from 15 to 40 days after germination. Herbicide fate, persistence and weed control timing should be chosen accordingly. More or less fifty to seventy percent yield loss occurred in sugar beet when weeding was delayed from 60 to 90 days after sowing. IWMS must be applied to reduce crop-weed competition, enhance crop production and net returns. To attain goals thresholds for target weeds and weed population necessity to be understood. There are many thoughts to be allowed in mind when causal threshold values including the impact of weeds on the yield and quality of the crop (Cousens, 1986). Therefore, the forecast of the effects of given weed population would assist the sugar beet growers in making assessments on the best level of weed control efforts in their crop fields.

7.2 Post-emergence additives spraying

The activity of active ingredients of a pesticide or herbicide can be modified by additives. These additives can ensure reduction of drift, uniform distribution, enhance effectiveness and increase safety use. Depending on composition and action mechanism the additives can be differentiated as surfactants and sprays (anionic, cationic, non-ionic, amphoteric), stabilizers (emulsifiers, dispersing agents, anti-flocculation, compatibility enhances), solvents, oils (paraffinic and vegetable), deposit enhancers (adhesives and film formers), foaming and antifoaming and buffering agents. There are plenty of experimental evidences reported on additives in phytotherapy (Mantey et al., 1989; Gauvrit, 1994; Müller et al., 2001). The opportunity to change the higher toxic products and increase the biotic action of some mixtures employed exploiting seed oil (e.g. rapeseed oil) and buffering agents (pH optimizers) were reported by Tugnoli et al. (2003). Organosiliconic surfactants contained at least 98% triloxane composite augmented triflusulfuron-methyl action haste and herbicide activity by approximately 11% on target weeds (Chiot and Lanza, 2008).

7.3 Intermittent spraying

Herbicide flow sprays maintaining a short duration break is known as intermittent or sporadic spray technique. Benefit of this recurring spread is occurred from active ingredient dispersal system in cuticles of crop as well as permit getting a short distance between drops (Bukovac and Petracek, 1993). Hence applying spray sporadically the drops are distributed homogeneously on the leaves and maintain more distance compared to traditional method. This new spray method has been established to decrease herbicide and pesticide dispersion by the cuticle of the leaves. This system gave the same recital in comparison with the standard method on different weeds for example Alopecurus myosuroides, Capsella bursapastoris and Veronica spp. with strong reduced (−48%) herbicide dose (Falchieri et al., 2008).
8 Conclusions

Production of food for ever increasing population is the most challenging work, whereas weeds show severe competition with the crops for various growth resources. Weeds cause root yield loss in sugar beet by 26–100%. Moreover crop yields are reduced by weeds nearly 1.5% per day. Besides reduction in yield, weeds also reduces the quality of produces and acts as alternate host for disease causing organisms and insect-pests. Though manual method of weed control is very common, it is cost intensive. Herbicides when applied alone may have limitation of resistance development and shift in weed flora etc. although it is economical. Hence, various weed management practices need to be integrated in an appropriate manner during critical period of crop-weed competition.

Research on herbicide mixtures, post-emergence herbicides, management of parasitic weeds, weedy rice, weed competitive crop cultivars with acceptable yield potential, weed management in changing climate scenario and conservation agriculture, effect of herbicides on soil microorganisms, etc. need to be strengthened. Therefore, use of high efficacy herbicides in combination with cultural or mechanical method that means integrated weed management is effective and economical.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Ahmad S, Zubair M, Iqbal N, Cheema NM, Mahmood K. 2012. Evaluation of sugar beet hybrid varieties under Thal-Kumbi soil series of Pakistan. International Journal of Agriculture and Biology 14:605–608.

Al-Khatib K, Libbey C, Boydston R. 1997. Weed suppression with brassica green manure crops in green pea. Weed Science 45:439–445. doi: 10.1017/S0043174500093139.

Ansaloni R. 1990. Risultati prove sperimentali 1989. II. Giornale del Bieticoltore 2:18–20. doi: 10.1007/s12355-010-0036-2.

Auler T. 1998. Unkrautunterdrückung mit Sinapis alba L, als Bodendecker. Dissertation Universitüt, Hohenheim, Germany.

Bairagi A, Paul SK, Kader MA, Hossain MS. 2013. Yield of tropical sugarbeet as influenced by variety and rate of fertilizer application. Pakistan Sugar Journal 28:13–20.

Balsari P. 1996. Soluzioni tecniche innovative per la distribuzione degli erbicidi. Terra e Vita 18:23–28.

Balsari P, Airoldi G. 1993. Sistemi di polverizzazione e trasporto del liquido. In: Macchine per la distribuzione dei fitofarmaci e per il controllo delle malerbe nelle colture erbacee.

Brar NS, Dhillon BS, Saini KS, Sharma PK. 2015. Agronomy of sugarbeet cultivation - A review. Agricultural Reviews 36:184–197. doi: 10.5958/0976-0745.2015.00022.7.

Brust J, Clauepin W, Gerhards R. 2014. Growth and weed suppression ability of common and new cover crops in Germany. Crop Protection 63:1–8. doi: 10.1016/j.cropro.2014.04.022.

Bukovac MJ, Petracek PD. 1993. Characterizing pesticide and surfactant penetration with isolated plant cuticles. Pesticide Science 37:179–194. doi: 10.1002/ps.2780370212.

Campiglia E, Radicetti E, Mancinelli R. 2015. Cover crops and mulches influence weed management and weed flora composition in strip-tilled tomato (Solanum lycopersicum). Weed Research 55:416–425. doi: 10.1111/wre.12156.

Candolo G. 1988. Diserbo chimico: obiettivo volumi ridotti.

Chiot G, Lanza N. 2008. Silwet: tensioattivo organosiliconico non-ionico per agrofarmaci di recente registrazione in Italia. Alcune esperienze sperimentali in Europa. Atti Giornate Fitopatologiche 1:369–376.

Cioni F. 1997. Pre-emergence dose rate reduction in spring and autumnal sugar beet sowing. In: Proceedings of the 60th IIRB Congress. Cambridge.

Cioni F, Ansaloni R, Bettini G. 1991. Diserbo chimico, risultati sperimentali 1990. II Giornale del Bieticoltore 2:11–14.

Cioni F, Guizelis A, Meriggio P, Vicari A, Villarias JL. 1998. Role de la betterave a sucre dans les strategies de controle des mauvaises herbes dans les assolement des regions de la mediterranee. In: Proceedings of the 61 IIRB Congress. Brussels.

Cioni F, Maines G. 2010. Weed control in sugarbeet. Sugar Tech 12:243–255. doi: 10.1007/s12355-010-0036-2.
Cousens R. 1986. Theory and reality of weed control thresholds. Plant Protection Quarterly 2:13–20.

Covarelli G, Onofri A. 1998. Effects of timing of weed removal and emergence in sugar beet. Montpellier, France: Proceedings of 6th EWRS Mediterranean symposium, Montpellier, France.

Duke SO, Abbas HK, Amagasa T, Tanaka T. 1996. Phytotoxins of microbial origin with potential for use as herbicides 35:82–113.

Duncan DN, Meggitt WF, Penner D. 1982. Basis for increased activity from herbicide combinations with ethofumesate applied on sugar beet (Beta vulgaris). Weed Science 30:195–200.

Falchieri D, Lolli M, Romagnoli L, Vianciani M, Brandi M. 2008. Una tecnica di applicazione a getto intermittente per trattamenti a dosi/ha fortemente ridotte: risultati nel diserbo di grano e sorgo e nella difesa antiperonosporica della vite. atti delle giornate fitopatologiche 2:65–72.

Fenwick GR, Heaney RK, Mullin WJ. 1983. Glucosinolates and their breakdown products in food and food plants. Critical Reviews in Food Science and Nutrition 18:123–301. doi: 10.1080/10408398209527361.

Gauvrit C. 1994. Les huiles en phytosanitaire: le cas des herbicides. Phytoma: La Défense des végétaux 458:37–42.

Gerhards R, Bezhin K, Santel H. 2017. Sugar beet yield loss predicted by relative weed cover, weed biomass and weed density. Plant Protection Science 53:118–125. doi: 10.17221/57/2016.

Götze P. 2017. Impact of Specialised Sugar Beet Crop Rotations on Soil Fertility Parameters and on Yield and Yeld Stability of Sugar Beet. Wittenberg: PhD thesis, University of Halle Wittenberg, Wittenberg.

Hurler K, Petersen J. 2000. Cultivation of herbicide resistant crops: weed management and environmental aspects. Braunschweig: Proceedings: The Biosafety Results of Field Tests of Genetically Modified Plants and Microorganisms- 5th International Symposium, Braunschweig.

Jones PA, Blair AM, Orson JH. 1996. Mechanical damage to kill weeds. Copenhagen, Denmark: Proceedings of the 2nd International Weed Control Congress, Copenhagen, Denmark.

Kelton J, Price AJ, Mosjidis J. 2012. Allelopathic weed suppression through the use of cover crops. In: Price AJ (Ed), Weed Control. INTECH Open Access Publisher, Rijeka.

Kniss AR, Wilson RG, Burgener PA, Feuz DM. 2003. Economic analysis of herbicide tolerant sugar beet. San Antonio, Texas: Proceedings of the 1st Joint IIRB-ASSBT Congress, San Antonio, Texas.

Koocheki A, Nassiri-Mahallati M, Alimoradi L, Ghorbani R. 2009. Effect of cropping systems and crop rotations on weeds. http://dx.doi.org/10.1051/agro/2008061 29. doi: 10.1051/agro/2008061.

Kropff M, Spitters C. 1991. A simple model of crop loss by weed competition from early observations on relative leaf area of the weeds. Weed Research 31:97–106.

Kunz C, Sturm DJ, Varnholt D, Walker F, Gerhards R. 2016. Allelopathic effects and weed suppressive ability of cover crops. Plant, Soil and Environment 62:60–66. doi: 10.17221/612/2015.

Lodovichi M, Blanco AM, Chantre GR, Bandoni JA, Sabbatini MR, Vigna M, López R, Gigón R. 2013. Operational planning of herbicide-based weed management. Agricultural Systems 121:117–129.

Longden PC. 1989. Effects of increasing weed-beet density on sugar-beet yield and quality. Annals of Applied Biology 114:527–532.

Lydon J, Duke SO. 1999. Inhibitors of glutamine biosynthesis. Marcel Dekker, New York, USA.

Mantey FA, Nalewaja JD, Szelezniake F. 1989. Esterified seed oils with herbicides. volume 2. Florida, USA: CRC Press Boca Raton, Florida, USA.

Marlander B. 2005. Weed control in sugar beet using genetically modified herbicide-tolerant varieties – A review of the economics for cultivation in Europe. Journal of Agronomy and Crop Science 191:64–74. doi: 10.1111/j.1439-037X.2004.00135.x.

May JM, Hilton JG. 1985. Reduced rates of pre-emergence herbicides (1982–1984. 77th Report of the Norfolk agricultural station.

May JM, Wilson RG. 2006. Weed and weed control. In: Draycott, A.P. (Ed), Sugar beet. In: A Draycott, editor. Sugar beet. London, UK: Blackwell, London, UK. p. 359–386.

May MJ. 2003. Economic consequences for uk farmers of growing GM herbicide tolerant sugar beet. Annals of Applied Biology 142:41–48. doi: 10.1111/j.1744-7348.2003.tb00227.x.

Merkes R, Muggele H, Sauer M, Krah M. 2001. Produktionstechnik zu zuckerriiben - kostensenkung, umweltschonung. Nachhaltigkeit Zuckerindustrie 128:804–811.
Muchembled C. 1989. Possible ways of reducing the water volumes and phytosanitary products for weed control in sugar-beet growing. Proceedings of the 52th IIRB Congress. Bruxelles.

Müller T, Brancq B, Milius A, Okori N, Vaille C, Gauvrit C. 2001. Selfemulsifying ethoxylates of rapeseed oil and methylated rapeseed oil as novel adjuvants for herbicides. Proceedings 6th international symposium on adjuvants for agrochemicals, Amsterdam.

Oerke EC. 2006. Crop losses to pests: Centenary review 144:31–43.

Paul SK, Jori RA, Sarkar MAR, Hossain M, Paul SC. 2019. Performance of tropical sugar beet (Beta vulgaris L.) as influenced by year of harvesting. Archives of Agriculture and Environmental Science 4:19–26. doi: 10.26832/24566632.2019.040103.

Paul SK, Paul U, Sarkar MAR, Hossain MS. 2018. Yield and quality of tropical sugar beet as influenced by variety, spacing and fertilizer application. Sugar Tech 20:175–181. doi: 10.1007/s12355-017-0545-3.

Petersen J. 2004. A Review on Weed Control in Sugarbeet. In: Inderjit (Ed), Weed Biology and Management. Kluwer Academic Publishers.

Petersen J, Belz R, Walker F, Hurle K. 2001. Weed suppression by release of isothiocyanates from turn-rape mulch. Agronomy Journal 93:37–43. doi: 10.2134/agronj2001.93137x.

Petersen J, Sorten H, Einfuhrung K. 1998. Konsequenzen für die unkrautbekämpfung. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, Sonderheft 14:365–372.

Roos H, Brink A. 1996. Optimierung von produktiligenschaften durch formulierungsentwicklung am beispiel rübenherbicide. Mitteilungen aus der Biologischen Bundesanstalt für Land-und Fortwirtschaft 321.

Rosso F, Meriggi P, Paganini U. 1996. Barbabietola da zucchero: tecniche operative per il controllo delle erbe infestanti. Terra e Vita 14:365–372.

Salehi F, Esfandiari H, Rahimian Marshadi H. 2007. Critical period of weed control in sugar beet in shahrekord region. Iranian Journal of Weed Science 2:1–12.

Schweizer EE, Dexter AG. 1987. Weed control in sugarbeet (Beta vulgaris) in north america. Review of Weed Science 3:11–33.

Schweizer EE, May MJ. 1993. Weeds and weed control. In: Cooke DA and Scott RK (Eds), The Sugar Beet Crop. Chapman & Hall.

Scott RK, Wilcockson SJ, Moisey FR. 1979. The effects of time of weed removal on growth and yield of sugar beet. The Journal of Agricultural Sciences 93:693–709.

Seadh SE, Attia NA, Said EM, El-Maghraby SS, Ibrahim MEM. 2013. Productivity and quality of sugar beet as affecting by sowing methods, weed control treatment and nitrogen fertilizer levels. Pakistan Journal of Biological Science 16:711–719.

Smith RJ. 1986. Biological control of northern jointvetch (Aeschynomene virginica) in rice (Oryza sativa) and soybeans (Glycine max – A researcher’s view. Weed Science 34:17–23.

Tugnoli V, Cioni F, Vacchi A. 2003. The use of additives in weed and disease control of the sugarbeet. San Antonio, Texas: Proceedings of the 1st Joint IIRB-ASSBT Congress, San Antonio, Texas.

Wilson RG, Smith JA. 1999. Crop production with glyphosate tolerant sugarbeet. General Meeting of American Society of Sugar Beet Technology 30.

Zanin G, Gasparetto MA, Zuin MC. 1996. Caratteristiche morfologiche delle foglie ed efficacia degli erbici. Terra e Vita 18:6–9.

Zumdahl RL. 1988. The concept and application of the critical weedfree period: In: Altieri MA, Liebmann M (Eds), Weed management in agroecosystems: Ecological approaches. CRC Press, Boca Raton, FL, USA.

Zoschke A, Quadranti M. 2002. Integrated weed management: Quo vadis. Weed Biological Manga 1:1–10. doi: 10.1046/j.1445-6664.2002.00039.x.