Chapter 3

Evaluation of Pre- and Postemergence Herbicide Combinations for Broadleaved Weeds in Sugar Beet

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Additional information is available at the end of the chapter

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Abstract

Lithuania sugar beet growers have few herbicide options available for weed management. Six field trials were conducted at the Institute of Agriculture, Lithuania, in order to evaluate the effects of chemical weed management in sugar beet. Treatments included untreated and hand-weeded control and several rates of phenmedipham plus desmedipham plus ethofumesate, phenmedipham, ethofumesate, triflusulfuron, chloridazon, and metamitron. Pre- and postemergence and only postemergence applications similarly affected weed control. Phenmedipham plus desmedipham plus ethofumesate was more effective for controlling weeds when applied in combination with metamitron, triflusulfuron, and chloridazon. The significantly lowest efficacy for weed control was phenmedipham combined with ethofumesate and metamitron as compared to the phenmedipham plus desmedipham plus ethofumesate. Reducing the doses of phenmedipham plusdesmedipham plus ethofumesate from 114+89+140 g a.i. ha^{-1} to 91+71+112 g a.i. ha^{-1} and 68+53+84 g a.i. ha^{-1} in mixture with triflusulfuron resulted in the increase of weed biomass. Full (45 g a.i. ha^{-1}) and reduced doses (30 g a.i. ha^{-1}) of triflusulfuron with phenmedipham plus desmedipham plus ethofumesate similarly affected weeds. The herbicides investigated did not have any negative influence on sugar beet productivity and quality.

Keywords: Weeds, herbicides combination, sugar beet

1. Introduction

Weed competition is one of the major factors which limit sugar beet production in the world [1]. Weed–crop interactions are based on competition for water, nutrients, and light and allelopathic effects may also play a small role. In sugar beet weed interference, all these factors are important too, but light is of prime importance. Weeds may also interfere with harvest operations, making the process less efficient [2]. Due to the fact that a lot of weeds can grow above the sugar beet canopy and reduce the amount of photosynthetic radiation reaching the crop, these weeds are stronger competitors compared to smaller weeds [3, 4]. In a weed free crop stand, photosynthesis in sugar beet is more efficient and nutrient accumulation in the sugar beet root is higher [5]. Left uncontrolled, weeds may reduce yield, interfere with harvest, reduce the value of the crop, and increase future weed problems. The yield of sugar beet roots and sucrose can be severely decreased by weeds, the extent of the decrease being dependent upon competitive ability, weed density, and the length of time that weeds compete with the crop. The total potential losses from weeds would be between 26 and 100% of the potential crop yield [6-8].

Sugar beet is very sensitive to weed competition from the early stages of growth [9, 10]. Sugar beet is not competitive with emerging weeds until it has at least 8 true leaves [7]. Therefore, effective control of weeds at early stages seems to be more important than that at later developed stages [10]. The length of weed-free period affected yield of sugar beet very markedly [11]. When sugar beet and weeds grow together 30 days after emergence of sugar beet, the root yield is decreased up to 45% [12]. As control of weeds is delayed, the yield lost may be decreased by 1.5% for each day the crop is left unweeded, although sugar beet has some ability to recover from an early check [13]. Understanding the emergence characteristics of weeds can be helpful in determining the optimum time to apply postemergence herbicide [11].

Weed control in sugar beet is accomplished with herbicides, mechanical tillage, cultural practices, and hand labor. Control of weeds with herbicides is generally more profitable than allowing weeds to compete with the crop. Herbicides play an important role for weed control in sugar beet production [14, 15]. For high efficacy of chemical method, the timing of application is very important. Weeds have to be small (cotyledon stage) to ensure successful weed control [16]. The doses of herbicides could be reduced by applying at the early growth stage of the weeds, when the first seed leaves start to appear [14, 15]. The application of lower doses leads to reduction of negative impact of herbicides on environment and cuts expenditures for beet production [17].

In recent years, the use of preplant-applied herbicides has declined and use of postemergence herbicides has increased. The most popular active ingredients are phenmedipham, desmedipham, ethofumesate, metamitron, triflusulfuron-methyl, lenacil, clopyralid, and chloridazon [7, 18]. The range of weed species controlled by each herbicide is also limited and so mixtures of herbicides are applied [7, 15, 19, 20]. Sugar beet is applied by tank-mix herbicides combinations several times after crop emergence [15, 21, 22]. Mixtures of postemergence, broad-spectrum herbicides have to be applied to control the wide range of weed species in sugar beet crops [23, 24].

Field experiments were carried out in 2004–2005 and 2010–2012 on arable fields located at the Institute of Agriculture in Central Lithuania. The objective of this study was to evaluate the efficacy of different herbicide mixtures used in recommended and reduced doses on broad-leaved weeds applied pre- and postemergence in sugar beet. Treatments included preemergence application of chloridazon (Pyramin Turbo, 520 g ai l^{-1}) and metamitron (Goltix SC, 700 g ai l^{-1}) and postemergence application of the mixtures of phenmedipham plus desmedipham plus ethofumesate (Betanal Expert, 274 g ai l^{-1}) with chloridazon, metamitron, triflusulfuron-methyl (Caribou, 500 g ai kg^{-1}), ethofumesate (Nortron, 500 g ai l^{-1}), and of the mixtures of phenmedipham (Betasana, 160 g ai l^{-1}) with ethofumesate, metamitron, mineral oil, and of the mixtures of phenmedipham (Kontakt SC, 320 g ai l^{-1}) with ethofumesate, metamitron, rapeseed oil, and of the mixtures of phenmedipham (Betasana) with ethofumesate, metamitron, raps oil. Soil texture was loam consisting of 14.5–17.7% clay, 34.8–39.9% silt, 44.7–51.1% sand. Humus content amounted to 1.6–2.4%, and pH – 6.1–6.9. The field was fertilized with nitrogen, phosphorus, and potassium at the ratio of 105–120:80–120:120–170 kg ha^{-1}. Mineral fertilizers were incorporated into the soil during cultivation. Sugar beet was planted with 45 cm row space, at a density of 15 plants m^{-2}. The herbicides were tank-mixed and applied postemergence at three different dates. The first application was done at the early cotyledon stage of weed growth. Subsequent applications were applied when the next weed flush emerged or 10–17 days after the first flush. The plot size was 2.5 m x 10 m. The herbicides in the experiment were broadcast-applied. The amount of water was 200 l ha^{-1}. Weed dry weight was measured two times: four weeks after herbicide application and before harvest. At the time of assessment a quadrat of 0.20 m x 1.25 m was randomly thrown in each plot. Weed control was assessed by visually estimating the % control relative to the ground cover and vigor of each weed species in the untreated plots. Weed samples were dried at 105°C for 24 h and weighed. Weed density and dry weight data were transformed to $\sqrt{x+1}$. The data were analyzed with ANOVA and LSD test.

2. Weed flora in sugar beet

In much sugar beet growing areas, dicot weeds of the families Chenopodiaceae, Asteraceae, Brassicaceae, and Polygonaceae are of major importance. The monocots are less important compared to dicot weeds [2, 5]. Broadleaf weeds often grow to a height two to three times that of sugar beet by mid-summer. Annual broad-leaved weeds are usually more competitive than annual grasses [25].

The botanical surveys of species were conducted before herbicide application. Overall, 24 weed species were found. The number of weeds found in 2004–2005 and 2010–2012 was from 41 to 108 weeds m^{-2}. In 2011 and 2012, the germination of weeds was lowest in sugar beet; the weed number was 41 and 49 m^{-2}, respectively. Weeds abundantly germinated in 2005, the number of weeds was 108 and 106 m^{-2}, respectively. The dominant weed species in all years were *Chenopodium album* L. (from 11 to 62 weed m^{-2}), *Lamium purpureum* L. (from 3 to 30 weed m^{-2}), *Stellaria media* (L.) Vill. (from 2 to 40 weed m^{-2}), *Viola arvensis* Murray (from 2 to 18 weed m^{-2}), and *Thlaspi arvense* L. (from 1 to 14 weed m^{-2}). In Latvia, the most frequent species of annual dicots in sugar beet were: *Tripleurospermum perforatum* (Merat.) M. Lainz, *Chenopodium album, Fallopia convolvulus* (L.) Löve, *Capsella bursa-pastoris* (L.) Medik, and *Stellaria media* [26]. *Chenopodium album* was the dominant weed species from the 19–24 species indentified. This species accounted for 10–58% of the total weeds documented. Accroding to literature on the population dynamics of a common arable weed, *Chenopodium album*, and its interactions with an arable crop, sugar beet, where *Chenopodium album* and other weeds may also be a considerable problem [7]. Our research data revealed that *Galium aparine* L., *Veronica arvensis* L., and

Erysimum cheiranthoides L. were present at a low frequency (Figure 1). Other weeds such as *Tripleurospermum perforatum Fumaria officinalis* L., *Fallopia convolvulus*, *Lapsana communis* L., *Polygonum aviculare* L., *Polygonum persicaria* L., *Capsella bursa-pastoris*, *Sinapis arvensis* L., *Euphorbia helioscopia* L., *Myosotis arvensis* (L.) Hill, *Chaenorhinum minus* (L.) Lange., *Centaurea cyanus* L., *Silene pratensis* (Rafn) Godr., *Anagalis arvensis* L., *Myosurus minimus* L., and *Galeopsis tetrahit* L. were less common species. These species germinated in only a few years of the study.

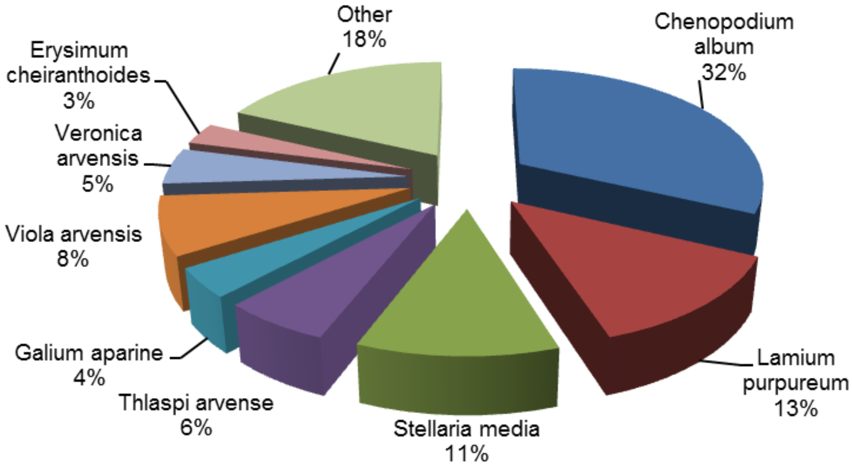

Figure 1. Weed species in sugar beet before herbicide application data averaged over 2004–2012

3. Sensitivity of weeds to phenmedipham, desmedipham, ethofumesate, metamitron, chloridazon, and triflusulfuron combinations at preemergence application

Weed control in crops is mainly based on the use of herbicides because they are efficient and easily applied [27]. Weed control is one of the most difficult agricultural arrangements in sugar beet growing because of low crop interference with weeds [11]. After herbicide use, significant changes in weed flora were noted in terms of abundance and share of some weed species on total weed community [28, 29]. Herbicides for control of dicots can only be used until the crop starts to develop true leaves and their efficacy decreases as the weeds grow [30].

Weed control programs in sugar beet include both pre- and postemergence herbicide treatments [31]. The effectiveness of preemergence residual herbicides decreases with reductions in rainfall or soil moisture content [32]. Preemergence application of soil herbicides is used limitedly because it strongly depends on soil moisture [33]. Therefore, less than 10% of the total sugar beet crop is treated with preemergence herbicides. The remaining 90% depends solely on a selection of postemergence herbicides to maintain season-long weed control [34].

The advantage of soil applied residual herbicides is that they reduce the number of weeds that emerge with the crop and often sensitize survivors to subsequent postemergence sprays. When

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residual herbicides are used after sowing, they must be applied to the soil surface before sugar beet seedlings emerge or crop damage may result. Preemergence herbicides are important for the subsequent postemergence applications and provide some flexibility with timing and selection of postemergence treatments [35].

The main preemergence residual broad-leaved weed control herbicides used on sugar beet crops are chloridazon and metamitron. Chloridazon is a pyridazinone herbicide with pre-emergence and postemergence activity. This herbicide is usually applied prior to emergence of beet and weeds, and may also be applied postemergence to control common lambsquarters in combination with other herbicides [36]. Metamitron is a 1, 2, 4-triazinone herbicide which is absorbed predominantly by the roots, but also the leaves. This herbicide is applied predrilling incorporated, pre- and postemergence. Metamitron is applied in tank-mix with other herbicides postemergence [37].

Our research data revealed that the efficacy of herbicides varied from 35.0 to 100% (Table 1,2). In 2010, the efficacy of herbicides was higher than in 2011 because the growing season of 2010 started later than normal and the spring. rainfall was higher than the perennial average Total amount of rain was significantly higher and amounted to 20 and 80%, respectively, as compared to long-term average. In April and May of 2011, dry weather prevailed. The amount of precipitation was 42 and 90% of that as the long-term average, respectively. Air temperature, soil moisture, and relative humidity affected herbicide efficacy [38].

Treatment	Efficacy in 1 month after DAA, %				
	CHEAL	POLCO	STEME	LAMPU	EPHHE
Weedy check	0	0	0	0	0
Metamitron, 2100 g a.i. ha^{-1} – predrilling (T_0); Metamitron, 700 g a.i. ha^{-1} – $T_{1,}$T2; Raps oil, 0.5 l ha^{-1} – T0, T1, T3	98.5b	89.0b	100.0a	98.3b	98.8b
Metamitron, 1400 g a.i. ha^{-1} –T_1; Metamitron, 1050 g a.i. ha^{-1} – T_2, T_3; Raps oil, 0.5 l ha^{-1} – T_0,T_1, T_3	100.0a	95.3a	99.8a	99.5a	100.0a
Metamitron + phenmedipham + ethofumesate, 1400+160+35 g a.i. ha^{-1} – T_1; Metamitron + phenmedipham + ethofumesate, 1050+160+35 g a.i. ha^{-1} – T_2, T_3; Raps oil, 0.5 l ha^{-1} – T_0,T_1, T_3	100.0a	99.8a	100.0a	100.0a	100.0a

Note. The means followed by the same letter within a line are not significantly different according to Fisher's Protected LSD test (P<0.05).

Table 1. Effect of the herbicide combinations on weeds in sugar beet, 2010

The tank mixture of metamitron at 1050 g ai ha^{-1} or 1400 g ai ha^{-1} with phenmedipham at 160 g ai ha^{-1} and ethofumesate at 35 g ai ha^{-1} and raps oil at 0.5 l ha^{-1} sigificantly reduced *Chenopo-*

dium album (CHEAL), *Fallopia convolvulus* (POLCO), *Lamium purpureum* (LAMPU), and *Euphorbia helioscopiai* (EPHHE) as compared with pre- and postemergence application of metamitron (Table 1). The higher efficacy (95.3–100.0%) on weeds was achieved when metamitron at 1050 g ai ha^{-1} or 1400 g ai ha^{-1} with raps oil at 0.5 l ha^{-1} was applied postemergence.

In 2011, in dry years, the efficacy of metamitron alone was lower (35.0–62.5%) than when in combination with other herbicides (Table 2). Preemergence application of metamitron provided significantly lower efficacy on *Chenopodium album*, but significantly higher efficacy on *Galium aparine* (GALAP) than postemergence application of this herbicide. In other studies, metamitron controlled *Chenopodium album* up to two weeks after application thoroughly. One month after application *Chenopodium album* regenerated [38]. The combination of metamitron with phenmedipham plus desmedipham plus ethofumesate plus raps oil resulted excellent control of weeds (>96%).

Treatment	Efficacy in 1 month after DAA, %				
	CHEAL	POLCO	STEME	GALAP	VIOAR
Weedy check	0	0	0	0	0
Metamitron, 2100 g a.i. ha^{-1} – predrilling (T_0); Metamitron, 700 g a.i. ha^{-1} – $T_{1,}$T2; Raps oil, 0.5 l ha^{-1}, T0, T1, T3	56.3de	43.8bc	48.8bc	56.3b	37.5b
Metamitron, 1400 g a.i. ha^{-1} –T_1; Metamitron, 1050 g a.i. ha^{-1} – T_2, T_3; Raps oil, 0.5 l ha^{-1} – T_0,T_1, T_3	62.5bc	42.5bc	43.8cd	46.3c	35.0b
Metamitron + phenmedipham plus tthofumesate, 1400+160+35 g a.i. ha^{-1} –T_1; Metamitron + phenmedipham + ethofumesate, 1050+160+35 g a.i. ha^{-1} – T_2, T_3; Raps oil, 0.5 l ha^{-1}, T_0,T_1, T_3	98.0a	98.5a	100.0a	97.8a	96.8a

Note. The means fallowed by the same letter within a line are not significantly different according to Fisher's Protected LSD test (P<0.05).

Table 2. Effect of the herbicide combinations on weeds in sugar beet, 2011

Herbicides can interact with each other in tank-mixed and can cause damage or reduce crop populations [35]. The visual crop injury symptoms included deformation and yellowing of leaves, growth reduction, and thinning (Figure 2). Statistical analysis of the data on visual injury showed that the effect of year with treatments was significant. The visual injury in metamitron-treated plots ranged from 64% of preemergence and 0% of postemergence when herbicides were applied at low doses (Table 3). Sugar beet recovered from metamitron injury even at high doses [39]. Other studies also have reported no or less injury of sugar beet plants with the application of herbicides at reduced doses compared to full dose application [40]. No visible symptoms of phytotoxicity on sugar beet plants were noticed after postemergence metamitron and this herbicide tank-mixed with phenmedipham plus desmedipham plus ethofumesate plus raps oil application. The phytotoxicity of herbicides decreased with time. To avoid injury, growth depressions, or leaf damage of sugar beet plants, herbicide use has to be carefully adjusted especially to the prevailing weather conditions [41].

Treatment	2010			2011		
	7 DAT	14 DAT	28 DAT	7 DAT	14 DAT	28 DAT
Weedy check	0	0	0	0	0	0
Metamitron, 2100 g a.i. ha^{-1} – predrilling (T_0); Metamitron, 700 g a.i. ha^{-1} – $T_{1,}$T2; Raps oil, 0.5 l ha^{-1}, T0, T1, T3	64.0**	61.3**	61.3**	0	0	0
Metamitron, 1400 g a.i. ha^{-1} –T_1; Metamitron, 1050 g a.i. ha^{-1} – T_2, T_3; Raps oil, 0.5 l ha^{-1}, T_0,T_1, T_3	0	0	0	0	0	0
Metamitron + phenmedipham + thofumesate, 1400+160+35 g a.i. ha^{-1} –T_1; Metamitron + phenmedipham + ethofumesate, 1050+160+35 g a.i. ha^{-1} – T_2, T_3; Raps oil, 0.5 l ha^{-1}, T_0,T_1, T_3	0	0	0	0	0	0

Note. **differences are statistically significant as compared to the control at P<0.01. $T_{1,}$ T_2, T_3, and T_4 - first, second, third, and fourth application.

Table 3. Visual injury on sugar beet treated with pre- and postemergence herbicides

A B

Figure 2. Sugar beet injury from preemergence application of metamitron: (a) yellowing, (b) thining

The infestation of *Chenopodium album* (CHEAL), *Fallopia convolvulus* (POLCO), *Galium aparine* (GALAP), *Stellaria media* (STEME), and *Lapsana communis* (LAPCO) were noted (Table 4). After herbicide application, significant changes were noted in the weed flora. When chloridazon was applied preemergence or postemergence, the herbicidal activity was very high. Preemergence application of chloridazon at 2080 g a.i. ha^{-1} and postemergence application of tank-mixed phenmedipham plus desmedipham plusethofumesate with metamitron resulted in excellent control of *Chenopodium album*, *Fallopia convolvulus*, *Galium aparine*, and *Stellaria media* (99–100%) and provided good control of *Lapsana communis* (91 %).

Treatment	CHEAL	POLCO	GALAP	STEME	LAPCO
Weedy check	259.0b	6.8b	9.9b	6.4b	10.8c
Chloridazon, 2080 g a.i. ha^{-1} – predrilling; Phenmedipham + desmedipham + ethofumesate + metamitron, 91+71+114+700 g a.i. ha^{-1} – T_1, T_2	0.0a	0.01ab	0.0a	0.0a	1.0ab
Phenmedipham + desmedipham + ethofumesate + chloridazon 91+71+112+650 g ha^{-1} a.i. – T_1, T_2, T_3	0.9a	0.0a	0.8ab	0.0a	2.0abc
Phenmedipham + desmedipham + ethofumesate + metamitron, 91+71+112+700 g a.i. ha^{-1} – T_1, T_2, T_3	5.0a	0.1ab	0.4ab	0.0a	0.5a

Note. The means followed by the same letter within a line are not significantly different according to Fisher's Protected LSD test ($P<0.05$).

Table 4. Biomass of prevailing weeds species (g m^{-2}) in sugar beet 1 month after DAA, data averaged over 2004–2005

Postemergence application of chloridazon with phenmedipham plus desmedipham plus ethofumesate resulted in a similar effect on weeds as with the preemergence application. There was no significant difference when comparing both applications. The combination of cloridazon with phenmedipham plus desmedipham plus ethofumesate and metamitron with phenmedipham plus desmedipham plus ethofumesate provided a similar reduction of weed biomass. At the final assessment (3 month after DAA), weed density and biomass decreased compared with first assessment, respectively 42.3 and 25.7% (Table 5).

Treatment	Density, weed m^{-2}		Weed biomass, g m^{-2}	
	1 month after DAA	3 month after DAA	1 month after DAA	3 month after DAA
Weedy check	96.9	55.9	424.7	315.4
Chloridazon, 2080 g a.i. ha^{-1} – predrilling; Phenmedipham + desmedipham + ethofumesate + metamitron, 91+71+114+700 g a.i. ha^{-1} – T_1, T_2	10.6**	3.2*	6.6**	13.1*
Phenmedipham + ethofumesate + chloridazon 91+71+112+650 g ha^{-1} a.i. – T_1, T_2, T_3	5.1**	1.8**	2.3**	1.5*
Phenmedipham + desmedipham + ethofumesate + metamitron, 91+71+112+700 g a.i. ha^{-1} – T_1, T_2, T_3	13.0**	3.2*	11.3**	5.7*

Note. *differences are statistically significant as compared to the control at $P<0.05$, **-at $P<0.01$. T_1, T_2, T_3, and T_4 – first, second, third, and fourth application.

Table 5. Effect of the herbicide combinations on weed density and biomass in sugar beet; data averaged over 2004–2005

The results showed that combination of herbicides significantly affected weed control. A preemergence application of chloridazon at 2080 g a.i. ha^{-1} and two postemergence applications of phenmedipham plus desmedipham plus ethofumesate with metamitron resulted in a similar effect on weeds as a postemergence application of tank-mix of phenmedipham plus desmedipham plus ethofumesate with metamitron and chloridazon. Chloridazon did not influence effectivity. The addition of chloridazon and metamitron similarly affected efficacy of phenmedipham plus desmedipham plus ethofumesate.

4. Combinations of phenmedipham, desmedipham, ethofumesate, metamitron, chloridazon, and triflusulfuron at postemergence application on weeds and sugar beet

Often sugar beets are treated with postemergence herbicides two or more times [16, 20, 28, 40]. Sometimes, more herbicide applications may be necessary [40]. Herbicides are applied at the cotyledon growth stage at 5–14-day intervals [42-45]. The major herbicides are phenmedipham, desmedipham, ethofumesate, chloridazon, metamitron, clopyralid, lenacil, and triflusulfuron-methyl [7, 46-48]. Individual sugar beet herbicides seldom have a wide enough weed control spectrum or residual activity to control all weeds [49], and tank-mixes of different herbicides are commonly used in order to provide a broad spectrum of weed control [35]. The optimization of herbicide application in the sugar beet protection system can be achieved by using mixtures of appropriate components and their selected doses [30, 49]. Mixing compatible herbicides can have benefits such as consumption reduction, increased weed control, economization of the number of applications, release of fewer chemicals into the ecosystem with using their synergistic effects, decrease in residue of herbicide in soil and crops in low concentrations and reduced occurrence of herbicide resistance in weeds [50]. Weed control is often higher from tank-mixed herbicides than from a single herbicide [20, 38, 41, 47, 50, 51]. The herbicides phenmedipham, desmedipham, and ethofumesate are commonly tank-mixed with metamitron, while chloridazon and triflusulfuron are used for broad-leaved weed control in sugar beet [37, 38, 43, 45, 52].

The tank-mix of phenmedipham plus desmedipham plus ethofumesate at 1029 g ai ha^{-1} controlled *Chenopodium album* better than the combination of this herbicide at 822 g a.i. ha^{-1} with triflusulfuron, but the efficacy was lower on *Tripleurospermum perforatum*. Other studies have shown a good control of *Chenopodium album* with phenmedipham plus desmedipham plus ethofumesate [53]. The effect of herbicide treatments on density and biomass of weeds was not significant (Table 6). The addition of triflusulfuron increased the effectiviness of phenmedipham plus desmedipham plus ethofumesate. Results of root yield showed that the combination of herbicides used had no significant effect on root yield as compared to the control.

At the first assessment 1 month after application (DAA), all combinations of herbicides similarly controlled weed density, except where phenmedipham plus desmedipham plus ethofumesate with metamitron and ethofumesate and triflusulfuron were applied (Table 7). At the final

Treatment	Density, weed m^{-2}		Weed biomass, g m^{-2}		Root yield, t ha^{-1}
	1 month after DAA	3 month after DAA	1 month after DAA	3 month after DAA	
Control (cleaned manually)	7.5	1.1	2.1	2.2	75.8
Phenmedipham + desmedipham + ethofumesate, 114+89+140 g a.i. ha^{-1} – T_1, T_2, T_3 (1029 g)	1.3	5.5**	59.0**	70.6**	76.1
Phenmedipham + desmedipham + ethofumesate, 91+71+112 g a.i. ha^{-1} – T_1, T_2, T_3 (822 g); Triflusulfuron, 5 g a.i. ha^{-1} – T_2; 10 g a.i. ha^{-1} – T_3	9.7	4.3**	50.2**	64.1**	75.0

Note. **differences are statistically significant as compared to the control at P<0.01.

T_1, T_2, and T_3 – first, second, and third application.

Table 6. Effect of the herbicide combinations on weeds and sugar beet; data averaged over 2010–2012

assessment, at the 3-month DAA, all treatments resulted in similar effect on weed density. The significantly lowest efficacy on biomass of weeds was the combination of phenmedipham with ethofumesate and metamitron (544+500+700 g a.i. ha^{-1}) and raps oil as compared to the phenmedipham plus desmedipham plus ethofumesate (Control II) and other herbicides treatments. Phenmedipham plus desmedipham plus ethofumesate at 1029 g a.i. ha^{-1} and phenmedipham plus desmedipham plus ethofumesate at 822 g a.i. ha^{-1} with triflusulfuron at 15 g a.i. ha^{-1} decreased weed biomass similarly. The biomass of weeds was significantly lower after application of tank-mixed phenmedipham plus desmedipham plus ethofumesate with metamitron, ethofumesate, and triflusulfuron (319+249+492+10 g a.i. ha^{-1}) as compared to other herbicide combinations. Other studies also have reported that phenmedipham plus desmedipham plus ethofumesate was more effective for controlling weeds by applying in a mixture with metamitron than by applying alone phenmedipham plus desmedipham plus ethofumesate [54, 55]. The combination of herbicides decreased sugar beet root yield as compared to the hand-weeded check (Control I). Similar results were reported elsewhere [34, 49]. Only application of phenmedipham with ethofumesate and metamitron (544+500+700 g a.i. ha^{-1}) and raps oil significantly decreased root yield as compared to control I.

5. Sensitivity of weeds to low rates of phenmedipham, desmedipham, ethofumesate, metamitron, chloridazon, and triflusulfuron

In older systems used for weed control in sugar beets, herbicides were applied at a high, single dose. Herbicides are often applied at rates higher than required for weed control under ideal conditions [44]. A single full-rate of phenmedipham and/or desmedipham controlled weeds better and caused less sugar beet injury than half-rate application [56]. By testing the efficacy

Treatment	Density, weed m^{-2}		Weed biomass, g m^{-2}		Root yield, t ha^{-1}
	1 month after DAA	3 month after DAA	1 month after DAA	3 month after DAA	
Control I (cleaned manually)	1.3	0.9	4.8	2.8	80.6
Control II. Phenmedipham + desmedipham + ethofumesate, 114+89+140 g a.i. ha^{-1} – T_1, T_2, T_3 (1029 g)	16.2	6.4	86.7	96.4	76.8
Phenmedipham + desmedipham + ethofumesate + metamitron, 91+71+112+700 g a.i. ha^{-1} – T_1; Phenmedipham + desmedipham + ethofumesate + ethofumesate, 114+89+140+100 g a.i. ha^{-1} – T_2; Phenmedipham + desmedipham + ethofumesate + triflusulfuron, 114+89+140 +10 g a.i. ha^{-1} – T_3 (319+249+492+10 g)	7.4**	3.5	14.9**	17.1**	77.2
Phenmedipham + ethofumesate + metamitron 160+100+700 g a.i ha^{-1} – T_1; Phenmedipham + ethofumesate 224+150 g a.i. ha^{-1} – T_2; Phenmedipham + ethofumesate 160+250 g a.i. ha^{-1} – T_3 (544+500+700 g) Raps oil 0.5 l ha^{-1} – T_1, T_2, T_3	20.4	10.5	148.0*	249.7**	72.3**
Phenmedipham + desmedipham + ethofumesate, 91+71+112 g a.i. ha^{-1} – T_1, T_2, T_3 (822 g); Trilusulfuron 5 g a.i. ha^{-1} - T_2; 10 g a.i. ha^{-1} – T_3 (15 g)	14.2	6.0	75.2	94.0	75.9

Note. *differences are statistically significant as compared to the control at $P<0.05$, **-at $P<0.01$.

T_1, T_2, and T_3 – first, second, and third application.

Table 7. Effect of the herbicide combinations on weed density and biomass in sugar beet; data averaged over 2011–2012

of a herbicide over a wide range of rates, growers will have better information to determine the appropriate weed management program that maximizes net returns and minimizes loading of herbicides into the environment [57]. Reducing the recommended dose of herbicides is one of the important instruments in weed management systems. Reduced herbicide applications could be achieved either by reducing the dosages or the number of treatments [53]. The exploitation of competitiveness factors might favor the development of reduced herbicide use strategies for sugar beet [9]. Numerous research studies have indicated a few reasons for the potential successful use of reduced dose: 1) registered doses are set to ensure adequate control over a wide spectrum of weed species, weed densities, growth stages, and environmental conditions; 2) maximum weed control is not always necessary for optimal crop yields; and 3) combining reduced doses of herbicides with other management practices, such as tillage or competitive crops, can markedly increase the odds of successful weed control [30, 58]. Another researcher has shown that it is possible to reduce herbicide doses in sugar beet [38, 44, 45, 50, 59, 60]. For example, Goleblowska and Domaradzki [48] reported that a 50% and 67% dose of Betanal Progress + Goltix + Safari and Betanal Progress + Venzar + Safari consistently produced 94–97% weed control. The half dose of herbicides reduced weed biomass significantly [38]. The lower and frequent doses of herbicide reached comparable or better results in comparison with the traditional system of application [34].

The weed spectrum was similar in both years. The results showed that the efficacy of phenmedipham plus desmedipham plus ethofumesate (1029 g a.i. ha^{-1}) was lower on *Chenopodium album* (CHEAL), *Tripleurospermum perforatum* (MATIN), *Polygonum aviculare* (POLCO), *Thlaspi arvense* (THLAR), and *Viola arvensis* (VIOAR) (Table 8). The additions of metamitron (1050 g) and triflusulfuron (15 g) increased efficacy of phenmedipham plus desmedipham plus ethofumesate. Similar cases of metamitron effectivenes have been reported by many authors [59, 61].

Treatment	CHEAL	MATIN	POLAV	THLAR	VIOAR
Control II. Phenmedipham + desmedipham + ethofumesate, 114+89+140 g a.i. ha^{-1} – T_1, T_2, T_3 (1029 g)	33.4b	4.4b	6.3b	1.5b	0.2b
Phenmedipham + desmedipham + ethofumesate, 91+71+112 g a.i. ha^{-1} – T_1, T_2, T_3 (822 g); Trilusulfuron, 5 g a.i. ha^{-1} - T_2; 10 g a.i. ha^{-1} – T_3 (15 g)	12.2ab	1.7ab	2.0ab	0.3ab	0.2ab
Phenmedipham + desmedipham + ethofumesate, 68+53+84 g a.i. ha^{-1} – T_1, T_2, T_3 (615 g); Metamitron 350 g ha^{-1} a.i. – T_1, T_2, T_3 (1050 g)	18.2ab	1.4ab	0.4ab	0.3ab	0.02ab

Note. The means followed by the same letter within a line are not significantly different according to Fisher's Protected LSD test ($P<0.05$).

Table 8. Biomass of prevailing weed species (g m^{-2}) in sugar beet 1 month after DAA; data averaged over 2010–2011

All herbicide treatments had similar effects on weed density, except treatments where combination of phenmedipham plus desmedipham plus ethofumesate (822 g a.i. ha^{-1}) with triflusulfuron were applied (Table 9). The least biomass of weeds was recorded for phenmedipham plus desmedipham plus ethofumesate (1029 g ha^{-1} – full dose). Reducing the doses of phenmedipham plus desmedipham plus ethofumesate by 20% with triflusulfuron and by 40% with metamitron, their efectiviness significantly reduced at final assessment. Metamitron with tank-mixes of phenmedipham plus desmedipham plus ethofumesate had similar effect on weeds compared to triflusulfuron with phenmedipham plus desmedipham plus ethofumesate. Effect of combination herbicides was not significant on sugar beet root yield as compared with control I.

The postemergence trials showed that commercial mixture of phenmedipham plus desmedipham plus ethofumesate (1029 g ha^{-1} – full dose) effectively decreased the biomass of

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Treatment	Density, weed m^{-2}		Weed biomass, g m^{-2}		Root yield, t ha^{-1}
	1 month after DAA	3 month after DAA	1 month after DAA	3 month after DAA	
Control I (cleaned manually)	1.8	1.4	2.5	2.5	83.0
Control II. Phenmedipham + desmedipham + ethofumesate, 114+89+140 g a.i. ha^{-1} – T_1, T_2, T_3 (1029 g)	11.1	5.5	46.8	44.4	82.4
Phenmedipham + desmedipham + ethofumesate, 91+71+112 g a.i. ha^{-1} – T_1, T_2, T_3 (822 g); Trilusulfuron, 5 g a.i. ha^{-1} – T_2; 10 g a.i. ha^{-1} – T_3 (15 g)	7.2	2.2*	21.2	14.0*	81.1
Phenmedipham + desmedipham + ethofumesate, 68+53+84 g a.i. ha^{-1} – T_1, T_2, T_3 (615 g); Metamitron 350 g ha^{-1} a.i. – T_1, T_2, T_3 (1050 g)	8.2	3.5	18.7	14.2*	81.7

Note. *differences are statistically significant as compared to the control at $P<0.05$.

T_1, T_2, and T_3 – first, second, and third application.

Table 9. Effect of the herbicide combinations on weeds and sugar beet; data averaged over 2010–2011

Chenopodium album (CHEAL), *Veronica arvensis* (VERAR), and *Galium aparine* (GALAP), but the differences were not statistically significant. In the treatment where by reducing dose of phenmedipham plus desmedipham plus ethofumesate by 40% with triflusulfuron at 30 and 45 g ha^{-1} was applied, the biomass of *Veronica arvensis* (VERAR) was recorded to be higher as compared to that of full dose of phenmedipham plus desmedipham plus ethofumesate. The herbicide combination did not have significant influence on weight of botanical composition of weed flora.

All herbicide combinations similarly affected weed density, except phenmedipham plus desmedipham plus ethofumesate (615 g a.i. ha^{-1}) with triflusulfuron at 30 g a.i. ha^{-1} (Table 11). In this mixture, dose of phenmedipham plus desmedipham plus ethofumesate were the lowest. When the dose of phenmedipham plus desmedipham plus ethofumesate in a herbicide mixture was reduced by 40% and addition of triflusulfuron at reducing dose by 33% (30 g a.i. ha^{-1}) was used, the effectiveness of phenmedipham plus desmedipham plus ethofumesate was not reduced. At the first assessment (1 month after DAA), different herbicide treatments had no significant effect on biomass of weeds. At the final assessment, triflusulfuron with tank-mixes of phenmedipham plus desmedipham plus ethofumesate had a greater effect on biomass of weeds than phenmedipham plus desmedipham plus ethofumesate. When the dose of phenmedipham plus desmedipham plus ethofumesate in this herbicide combination was reduced by 40% the biomass of weeds significantly decreased as compared to phenmedipham plus desmedipham plus ethofumesate of reducing dose by 20%. Weed control from herbicide combinations of phenmedipham plus desmedipham plus ethofumesate with full dose (45 g

Treatment	CHEAL	MATIN	VERAR	POLCO	GALAP
Phenmedipham + desmedipham plus ethofumesate, 114+89+140 g a.i. ha^{-1} – T_1, T_2, T_3 (1029 g)	0.00a	0.93ab	0.00ab	2.27b	0.00ab
Phenmedipham + desmedipham + ethofumesate, 91+71+112 g a.i. ha^{-1} – T_1, T_2, T_3 (822 g); Trilusulfuron, 10 g a.i. ha^{-1} – T_2; 20 g a.i. ha^{-1} – T_3 (30 g)	0.00a	0.05ab	0.00ab	0.00ab	0.10ab
Phenmedipham + desmedipham + ethofumesate, 68+53+84 g a.i. ha^{-1} – T_1, T_2, T_3 (615 g); Trilusulfuron, 15 g a.i. ha^{-1} – T_2, T_3 (30 g)	0.25c	1.91b	0.66ab	0.00ab	0.07ab
Phenmedipham + desmedipham + ethofumesate, 68+53+84 g a.i. ha^{-1} – T_1, T_2, T_3 (615 g); Trilusulfuron, 10 g a.i. ha^{-1} – T_1; 15 g a.i. ha^{-1} – T_2; 20 g a.i. ha^{-1} – T_3 (45 g)	0.01abc	0.00ab	0.77b	0.00ab	0.10b

Note. The means followed by the same letter within a line are not significantly different according to Fisher's Protected LSD test ($P<0.05$).

Table 10. Biomass of prevailing weeds species (g m^{-2}) in sugar beet 1 month after DAA; data averaged over 2011–2012

a.i. ha^{-1}) of triflusulfuron was the highest. Sugar beet yield was not significantly different between herbicide treatments. All herbicide treatments produced lower sugar beet yields than the hand-weeded check. Similar results were reported elsewhere [49, 62].

Treatment	Density, weed m^{-2}		Weed biomass, g m^{-2}		Root yield, t ha^{-1}
	1 month after DAA	3 month after DAA	1 month after DAA	3 month after DAA	
Control. Phenmedipham + desmedipham + ethofumesate, 114+89+140 g a.i. ha^{-1} – T_1, T_2, T_3 (1029 g)	1.5	3.8	3.6	19.1	74.6
Phenmedipham + desmedipham + ethofumesate, 91+71+112 g a.i. ha^{-1} – T_1, T_2, T_3 (822 g); Trilusulfuron, 10 g a.i. ha^{-1} – T_2; 20 g a.i. ha^{-1} – T_3 (30 g)	0.5	1.0	0.2	4.4	70.2
Phenmedipham + desmedipham + ethofumesate, 68+53+84 g a.i. ha^{-1} – T_1, T_2, T_3 (615 g); Trilusulfuron, 15 g a.i. ha^{-1} – T_2, T_3 (30 g)	6.8*	2.0	3.1	4.2*	70.8
Phenmedipham + desmedipham + ethofumesate, 68+53+84 g a.i. ha^{-1} – T_1, T_2, T_3 (615 g); Trilusulfuron, 10 g a.i. ha^{-1} – T_1; 15 g a.i. ha^{-1} – T_2; 20 g a.i. ha^{-1} - T_3 (45g)	3.2	1.0	1.2	1.2*	69.0

Note. *differences are statistically significant as compared to the control at $P<0.05$.

T_1, T_2 and T_3 – first, second, and third application.

Table 11. Effect of the herbicide combinations on weeds and sugar beet; data averaged over 2011–2012

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6. Conclusion

All herbicide combinations acted similarly on reduction of the following weed species: *Chenopodium album, Thlaspi arvense, Tripleurospermum perforatum, Polygonum aviculare, Veronica arvensis, Stellaria media,* and *Lapsana communis.* Postemergence application of chloridazon with phenmedipham plus desmedipham plus ethofumesate resulted in a similar effect on weeds compared to preemergence applications. The efficacy of phenmedipham plus desmedipham plus ethofumesate was similar in action as compared to that applied in tank-mixes with chloridazon, metamitron, and triflusulfuron. There were no significant differences on weight of weeds. The addition of chloridazon, metamitron, and triflusulfuron controlled weeds similarly. The significantly lowest efficacy on weeds resulted from a combination of phenmedipham with ethofumesate and metamitron as compared to the phenmedipham plus desmedipham plus ethofumesate. Two reduced doses (by 20% and 40%) of phenmedipham plus desmedipham plus ethofumesate in tank-mix had a significant effect on weeds compared to that of all doses of phenmedipham plus desmedipham plus ethofumesate. Full and reduced doses (by 33%) of triflusulfuron with phenmedipham plus desmedipham plus ethofumesate similarly affected weeds. The herbicides investigated did not have any negative influence on sugar beet productivity and quality.

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