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Systems for control of the weeds in indeterminate tomatoes (*Solanum lycopersicum* L.)

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Abstract

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Tomatoes are a major vegetable crop of significant economic value. The effective weed control has a key role in the growth, development, and productivity of tomato plants. This study aims to investigate a weed control system for tomatoes through the use of herbicides. In 2020-2021, on the experimental field of Agricultural University – Plovdiv, Bulgaria, a field experiment with the tomato variety Opal F_1, was performed. The experiment was performed by randomized block design in four replicates. The experience variants include: 1. Untreated control – without the use of herbicides and without hoeing; 2. Economic control – timely removal of weeds by hoeing, without the application of herbicides; 3. Dual Gold 960 EC (960 g/l *s-metolachlor*) + Targa Super 5 EC (50 g/l *quizalofop-p-ethyl*) in rates of 1.20 l ha^{-1} + 1.75 l ha^{-1}; 4. Dual Gold 960 EC + Sencor 70 WG (700 g/kg *metribuzin*) in rates of 1.20 l ha^{-1} + 0.60 g ha^{-1} ; 5. Stomp New 330 EC (330 g/l *pendimethalin*) + Targa Super 5 EC in rates of 4.00 l ha^{-1} + 1.75 l ha^{-1} ; 6. Stomp New 330 EC + Sencor 70 WG in rates of 4.00 l ha^{-1} + 0.60 g ha^{-1}. The dominant weeds in the field were *Portulaca oleracea* L. and *Amaranthus retroflexus* L. Apart from them, there were also *Solanum nigrum* L., *Sonchus oleraceus* L., *Sorghum halepense* (L.) Pers. developed from rhyzomes, etc. Under experimental conditions, application of the Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) system showed the highest efficacy against *Portulaca oleracea* L. – 87.5%, *Amaranthus retroflexus* L. – 80.0%, *Solanum nigrum* L. – 75.0%, and *Sonchus oleraceus* L. – 80.0%. High efficacy against these weeds was also reported at the Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}). At the variant with Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) and Stomp New 330 EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) was reported one hundred percent efficacy against *Setaria viridis* (L.) P.Beauv. Highest herbicidal efficacy against *Sorghum halepense* (L.) Pers. developed from rhizomes – 98.8% was reported after treatment with Stomp New 330 EC + Targa Super 5 EC. In the conditions of experience, the highest yield of tomatoes, Opal F1, was received at Economic control – 6702.5 kg da^{-1}, followed by Stomp New 330 EC + Sencor 70 WG – 6530.3 kg da^{-1}, and Dual Gold 960 EC + Sencor 70 WG – 6262.5 kg da^{-1}. There is no statistically proven difference in yield between Economic control, Stomp New 330 EC + Sencor 70 WG, and Dual Gold 960 EC + Sencor 70 WG.

Keywords: tomatoes; herbicides; weeds; efficacy; yield

Introduction

Tomato (*Solanum lycopersicum* L.), is one of the most important vegetable crops, both globally and in Bulgaria (Meza et al., 2013; MZH, 2023). Tomatoes fruits contain macro-and microelements, antioxidantands and vitamins (A and C), which support the health of humans. (Adalid et al., 2004; Luthria et al., 2006; Borguini and Da Silva Torres, 2009; Nour et al., 2013). In Bulgaria, the cultivation of tomatoes in open fields proceeds in three directions – early, mid-early, and late production. A major limiting factor for tomato plants, especially in field conditions, providing serious competition for water, nutrients, light, and space is weed vegetation. Weeds cause indirect damage, as many species are hosts for diseases, pests, and some nematodes (Kalinova et al., 2012; Amare et al., 2015).

Weed control in the first four weeks is critical for many vegetable crops, including tomatoes (Holm, 1956). Marana et al. (1983) calculated that the critical period of weed competition is 30-40 days after sowing. Later, D'Antoni et al. (2012) confirmed that tomato yield significantly decreased, when the crop had spent thirty or more days of coexistence with perennial weeds. The authors found that the critical density, mainly affecting the yield, is between 100 and 180 perennial weeds/m^2.

The presence of weeds reduces the yield by 70 % depending, and the duration of the competition (Govindra et al., 1986). Bakht and Khan (2014) also found that poor weed management can reduce tomato yields by up to 70%. Crop yield losses from severe weed infestation can increase to 95% (Adigun, 2002). According to Nurse et al. (2006), at a weed density of 5 plants/m^2, tomato yield is reduced by up to 60%. In 2019, Qasem (2019) also confirms that the weed competition with tomatoes for the growing season reduced marketable fruit yield by 58.6%.

Depending on the latitudes and the presence of weed seeds in the soil, different weed associations develop in tomato fields. In Zaragoza, Spain, the most abundant weed species in tomato fields are *Cyperus rotundus* L., *Portulaca oleracea* L., *Chenopodium album* L., and *Digitaria sanguinalis* (L.) Scop. (Anzalone et al., 2010). In Faisalabad, Pakistan, the most common weed species are *Phalaris minor*, *Avaena sativa*, *Chinopodium album*, and *Sinapis arvensis* (Awan et al., 2018).

In Zimbabwe, the dominant weeds in tomatoes fields are *Galinsoga parviflora*, *Setaria verticillata*, *Eleusine indica*. The least dominant weeds are *Acanthospermum hispidum*, *Leucas martinicensis*, *Portulaca oleracea*, and *Cynodon dactylon* (Chipomho et al., 2018).

The most problematic weeds in tomato fields of the mountainous regions of DR Congo, are *Commelina benghalensis*, *Galinsoga quadriradiata*, *Commelina diffusa*, *Galinsoga parviflora*, *Bidens pilosa*, *Oxalis debilis*, and *Digitaria velutina* (Aganze et al., 2020).

Along with the grass weeds, broadleaf weed species are a serious problem in growing tomatoes. In some fields, these weeds dominate the grass species. In Jordan, tomatoes are weeded by *Amaranthus blitoides* S. Wats., *Amaranthus retroflexus* L. *Chenopodium album* L., *Chenopodium murale* L., *Ammi majus* L., *Convolvulus arvensis* L., *Cynodon dactylon* (L.) Pers., *Beta vulgaris* L., *Cyperus rotundus* L., *Eruca sativa* Mill, *Heliotropium europeum* L., *Malva sylvestris* L., *Orobanche ramosa* L., *Portulaca oleracea* L., *Setaria verticillata* (L.) P. Beauv., *Sinapis arvensis* L., *Lactuca serriola* L., *Sisymbrium bilobum* (C. Koch) Grossh., *Tribulus terrestris* L. Despite the great variety of weeds, the dominant species are only *Amaranthus retroflexus* (23 plant/m^2) and *Chenopodium murale* (12 plant/m^2) (Qasem, 2019).

In Ontario, the difficulty for controlling weeds in tomatoes is *Abutilon theophrasti* Medic., *Amaranthus retroflexus* L., and *Chenopodium album* L. (Robinson et al., 2006).

Weed control in tomatoes can be carried out by manual weeding, solarization, and the use of different types of mulch (Kumar et al., 2003; Mauromicale et al., 2005; Anzalone et al., 2010; Moreno et al., 2011; Campiglia et al., 2015; Qasem, 2019; Agarwal et al., 2022; Hu et al., 2023).

Successful weed management can also be achieved through a combination of different methods. For example, Yu et al. (2021) recommend plastic-mulched tomato combined with the application of herbicides in bands over the planting holes, after transplanting or by precisely applied herbicides, to the individual planting holes before transplanting.

One of the main methods of weed control in conventional vegetable production is chemical. Studies by various scientists on the application of herbicides show the following. Robinson et al. (2004) determine the tolerance of several processing tomatoes (*Lycopersicon esculentum* Mill.) cultivars to postemergence applications of thifensulfuron-methyl at 6 and 12 g a.i. ha^{-1}. The authors found that a pre-plant incorporated treatment of s-metolachlor (1600 g a.i. ha^{-1}) plus metribuzin (375 g a.i. ha^{-1}), followed by thifensulfuron-methyl (6 g a.i. ha^{-1}) provided greater than 90% control of triazine-tolerant common lamb's-quarters (*Chenopodium album* L.).

On the forty-second day after treatment, fomesafen 840 g ha^{-1} provides acceptable control against annual grass, common purslane, and redroot pigweed (Mohseni-Moghadam and Doohan, 2017).

It was found that clomazone at doses ranging from 120 to 840 g ha^{-1} used alone, did not provide full-season biologically effective control over 80% againts *Abutilon theophrasti*, *Chenopodium album*, and *Solanum ptycanthum* in tomatoes (Nurse et al., 2006).

According to McGiffen & Masiunas (1991) metribuzin controlled *Abutilon theophrasti,* but not *Solanum ptycanthum*, whereas pyridate controlled *Solanum ptycanthum,* but not *Abutilon theophrasti*. A combination of metribuzin+pyridate controlled both weeds, but caused tomato injury four weeks after application. Bentazon does not control the weeds and does not injury the crop. Acifluorfen controlled both *Solanum ptycanthum* and *Abutilon theophrasti*.

The use of pendimethalin (1.32 kg a.i. ha^{-1}) in a mixture with metribuzin (0.37 kg a.i. ha^{-1}) and trifluralin (0.96 kg a.i.

ha^{-1}) in a mixture with metribuzin (0.37 kg a.i. ha^{-1}) provides from 80 to 99% of weed control and reducing over 85% of the labor involved in hand weeding (Ulises, 1994).

Dayton et al. (2017) recommend the use of metam-sodium and s-metolachlor to control the yellow nutsedge and common purslane in polyethylene-mulched tomatoes.

The application of soil or foliar herbicide used alone, does not always provide sufficiently effective weed control. Therefore, this study aims to investigate weed control systems in tomatoes.

Materials and Methods

In the period of 2020 – 2021, a field plot trial with the tomato cultivar Opal F_1 was conducted. Opal F_1 is a Bulgarian indeterminate hybrid tomato variety. Compared to other tomato varieties, Opal F_1 is characterized as more resistant to high temperatures and retains its leaf mass for a longer time (Danailov, 2012). The experiment was situated in the experimental field of the Department of "Horticulture", at the Agricultural University of Plovdiv, Bulgaria. The experiment included the following treatments: 1. Untreated control – without the use of herbicides and without hoeing; 2. Economic control – timely removal of weeds by hoeing, without the application of herbicides; 3. Dual Gold 960 EC (960 g/l s-metolachlor) + Targa Super 5 EC (50 g/l quizalofop-p-ethyl) in rates of 1.20 l ha^{-1} + 1.75 l ha^{-1}; 4. Dual Gold 960 EC + Sencor 70 WG (700 g/kg metribuzin) in rates of 1.20 l ha^{-1} + 0.60 g ha^{-1} ; 5. Stomp New 330 EC (330 g/l pendimethalin) + Targa Super 5 EC in rates of 4.00 l ha^{-1} + 1.75 l ha^{-1} ; 6. Stomp New 330 EC + Sencor 70 WG in rates of 4.00 l ha^{-1} + 0.60 g ha^{-1} . The trial was performed by the randomized block design in four replications. Each experimental plot is 9.6 m² in size and contains of 30 plants. The application with Dual Gold 960 EC and Stomp New 330 EC was done a day before planting. On the thirtieth day after planting was done application with Targa Super 5 EC and Sencor 70 WG. The treatment was done via electrical backpack sprayer SOLO (model 417) with the size of the working solution for soil herbicides 300 l ha^{-1}, and foliar herbicides 250 l ha^{-1} .

The sowing of seed was done on 1-5 June, in Styrofoam containers with 104 cells. The planting was done on 1-5 July (fourth-sixth true leaf), in two-row strips on high bed-furrow surface, according to a schema – 100 + 60/40 cm. The plants were grown with the attachment of a structure and single-stem formation, with the removal of the vegetative top after the formation of the fifth inflorescence.

The experimental area was naturally infested with *Portulaca oleracea* L., *Amaranthus retroflexus* L., *Convolvulus arvensis* L., *Sorghum halepense* (L.) Pers., developed from rhyzomes, *Solanum nigrum* L. The biological efficacy was reported on the fourteenth and twenty-eighth day after the treatment (DAT) of the soil herbicide, and the tenth and twentieth day after the treatment with the foliar herbicides (DATFH). The efficacy against the weeds was evaluated by the 10-score visual scale of EWRS. The selectivity of the studied herbicides was evaluated on the seventh, fourteenth, and twenty-one, day after treatments by the 9-score visual scale of EWRS (at score 1 – there is no damage on the crop, and at score 9 there is complete destruction of the crop).

During growing season, biometric measurements were performed twice – on the 20th day and on the 40th day after planting (plant height, leaf number, leaf area (cm^2). The reported indicators were processed with the software package SPSS 17 – module two-factor analysis of variance for Windows 8. The difference between evaluated treatments was statistically analyzed by ONE WAY ANOVA, by using Duncan's multiple range test. Statistical differences were considered proved at $p < 0.05$.

Results and Discussion

During both experimental years, the weed infestation was presented by weeds belonging to three biological groups. The presenters of the late-spring weeds were *Portulaca oleracea* L., *Amaranthus retroflexus* L., *Solanum nigrum* L., *Sonchus oleraceus* L., and *Setaria viridis* (L.) P. Beauv. The presenter from the perennial group of weeds was *Sorghum halepense* (L.) Pers., developed from rhizomes as well as the root-sprouted species *Convolvulus arvensis* L. The dominant weeds on the field were *Portulaca oleracea* L. and *Amaranthus retroflexus* L.

As a result of hoeing in economic control, all available weeds are timely removed. The weed control during the vegetation is almost 100%.

Average for the period on the fourteenth DAT, the highest efficacy against *P. oleracea* L. was reported after application of Stomp New 330 EC (4.00 l ha^{-1}) ranging from 87.5% to 88.8%. The results showed that with Dual Gold 960 EC (1.20 l ha^{-1}), the effectiveness against *P. oleracea* L. was from 76.9% to 77.5% (Table 1).

The control of *P. oleracea* L with Stomp New 330 EC, on the twenty-eighth day after treatment was again higher. The biological efficiency against the same weed in the variants with Stomp New 330 EC was from 78.8% to 80.0%. The weed control with Dual Gold 960 EC was unsatisfactory from 70.0% to 71.3%. The results show that the biological efficiency of soil herbicides from the fourteenth to the twenty-eighth day decreased. Variants containing pendimethalin were more effective in controlling *P. oleracea* L. than s-metolachlor. Anyszka, et al. (2011) proves the high efficiency of pendimethalin-containing products – Stomp Aqua 455 CS and Stomp 330 EC in onion. For efficiency weed control in tomatoes, Sandhu et al. (1993) recommended the use of pendimethalin at 0.75 kg, metribuzin at 0.37-0.5 kg/ha, fluchloralin at 1.2 kg, and fluchloralin and pendimethalin + hoeing once. Reddy et al. (1999) found that alone application or mixtures of 1.5 kg a.i. ha^{-1} pendimethalin and 2.0 kg a.i. ha^{-1} metolachlor, does not provide satisfactory weed control. For effective weed control and better growth and yield of tomatoes, the authors recommend herbicide application at their full dose, when supplemented with once hand weeding.

The efficacy against *P. oleracea* L. on the tenth day after treatment of foliar herbicides, was highest for the treatment with Stomp New 330 EC + Sencor 70 WG – 80.0%. Almost the same efficacy of 77.5% was registered for Dual Gold 960 EC + Sencor 70 WG. After the application of Dual Gold 960 EC + Targa Super 5 EC, and Stomp New 330 EC + Targa Super 5 EC registered weed control was 68.8% and 72.5%, respectively. In contrast to the tenth DATFH, on the twentieth DATFH, on average for the experimental period, the systems containing metribuzin the efficacy against *P. oleracea* L. was increased compared with systems containing quizalofop-p-ethyl. The reason is the spectrum of action of the herbicide Targa Super 5 EC – only against grass weeds (Hălmăgean et al., 1993; Penkov et al., 2000). On average for the two years, on the fourth reporting date, the highest control of *P. oleracea* L. was reported for the systems Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}), and Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}). The efficiency for both variants against weed was the same – 87.5%. After the application of Stomp New 330 EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}), the biological efficacy against *P. oleracea* L. was 69.4%. At Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}), the biological efficacy is lowest – 64.4% (Table 1).

In 2020, on the first reporting date, the biological efficacy of the studied herbicides against *A. retroflexus* L. was highest after application of Stomp New 330 EC – from 90.0% to 95.0%, compared to Dual Gold 960 EC – 75.0 %. In 2021, on the fourteenth day after treatment, the control against *A. retroflexus* L. was highest again at variants with Stomp New 330 EC – 85.0% and 92.5%. Dual Gold 960 EC provides 75.0% efficacy against *A. retroflexus* L. was reported. On the twenty-eighth day after treatment, on average for the period, the highest control was reported at Stomp New 330 EC (4.00 l ha^{-1}), ranging from 81.9% to 85.0%. Throughout the experimental period, a reduction in the herbicidal effect was observed from the fourteenth to the twenty-eighth day after the application of soil products (Table 2).

Table 1. Biological efficacy (%) of herbicide systems against *Portulaca oleracea* L.

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	78.8	72.5	70.0	65.0	75.0	70.0	67.5	63.8	76.9	71.3	68.8	64.4
4. Dual Gold 960 EC + Sencor 70 WG	80.0	70.0	80.0	90.0	75.0	70.0	75.0	85.0	77.5	70.0	77.5	87.5
5. Stomp New 330 EC + Targa Super 5 EC	90.0	85.0	75.0	70.0	85.0	75.0	70.0	68.8	87.5	80.0	72.5	69.4
6. Stomp New 330 EC + Sencor 70 WG	92.5	80.0	85.0	90.0	85.0	70.0	75.0	85.0	88.8	78.8	80.0	87.5

Table 2. Biological efficacy (%) of herbicide systems against *Amaranthus retroflexus* L.

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	75.0	70.0	60.0	55.0	75.0	65.0	55.0	52.5	75.0	67.5	57.5	53.8
4. Dual Gold 960 EC + Sencor 70 WG	75.0	70.0	70.0	75.0	75.0	65.0	65.0	70.0	75.0	67.5	67.5	72.5
5. Stomp New 330 EC + Targa Super 5 EC	95.0	85.0	80.0	75.0	92.5	78.8	70.0	65.0	93.8	81.9	75.0	70.0
6. Stomp New 330 EC + Sencor 70 WG	90.0	82.5	80.0	85.0	85.0	75.0	75.0	75.0	87.5	85.0	77.5	80.0

The average results for control of *A. retroflexus* L., on the tenth DATFH, show that the uses of Stomp New 330 EC + Sencor 70 WG provide efficacy of 77.5%. Almost the same control against weed was reported for Stomp New 330 EC + Targa Super 5 EC – 75.0%. The lowest efficacy of the tenth DATFH was registered for Dual Gold 960 EC + Targa Super 5 EK – 57.5%. At the last reporting date, systems containing Sencor 70 WG show the highest results for control of *A. retroflexus* L. On average for both years of the study, on the twentieth DATFH, the highest efficacy against *A. retroflexus* L. was reported after treatment with Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) system – 80.0%, followed by Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) – 72.5%. The weakest weed control – 53.8% was reported after application of Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) (Table 2).

Regarding with control of *S. nigrum* L., the studied herbicides show that on the fourteenth day, on average for the period, the highest efficacy against this weed of 90.0% was obtained at the variants containing pendimethalin. For successful control of weeds in tomatoes, grown for industrial processing, Siviero and Marasi (2002) recommend the combination of Stomp (pendimethalin) + Ronstar (oxadiazone) + Sencor (metribuzin). The lowest efficacy against *S. nigrum* L. on the first reporting date – only 72.5% was obtained at variants containing s-metolachlor. The biological efficacy on the twenty-eighth day decreases, the highest one was for Stomp New 330 EC – from 80.7% to 85.0%. Limited control to *S. nigrum* L. was obtained for Dual Gold 960 EC – from 62.5% to 65.0% (Table 3). Gaynor et al. (1993) found that metolachlor, applied before planting tomatoes, leads to 88.0% control of *Solanum ptycanthum,* and against some annual grasses.

Average for the two years of research on the twentieth DATFH, the highest control against *S. nigrum* L. was reported at Stomp New 330 EC + Sencor 70 WG – 75.0%. After treatment with Dual Gold 960 EC + Sencor 70 WG and Stomp New 330 EC + Targa Super 5 EC, the weed control was the same -73.8% which is very close to variant six (Table 3).

In 2020, on the first reporting date, the biological efficacy of the studied herbicides against *S. oleraceus* L. was the highest in variants, containing pendimethalin. The application of Stomp New 330 EC (4.00 l ha^{-1}) provides 90.0% efficacy against *S. oleraceus* L. After application of Dual Gold 960 EC (1.20 l ha^{-1}), the reported weed control was from 50.0% to 52.5%. In 2021, on the fourteenth DAT, the reported efficacy was approximately the same as the previous year – 85.0% whit Stomp New 330 EC, and lower with Dual Gold 960 EC – from 40.0% to 45.0% (Table 4).

Table 3. Biological efficacy (%) of herbicide systems against *Solanum nigrum* L.

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	75.0	65.0	60.0	55.0	70.0	60.0	57.5	55.0	72.5	62.5	58.8	55.0
4. Dual Gold 960 EC + Sencor 70 WG	70.0	65.0	70.0	75.0	75.0	65.0	70.0	72.5	72.5	65.0	70.0	73.8
5. Stomp New 330 EC + Targa Super 5 EC	90.0	85.0	80.0	72.5	90.0	85.0	70.0	75.0	90.0	85.0	75.0	73.8
6. Stomp New 330 EC + Sencor 70 WG	90.0	85.0	75.0	80.0	90.0	85.0	70.0	70.0	90.0	80.7	72.5	75.0

Average for the period on the twenty-eighth DAT, the highest herbicidal control against *S. oleraceus* L. was reported after treatment with Stomp New 330 EC – 80.7%, and the lowest at Dual Gold 960 EC – 36.3%. The results to the twenty-eighth DAT show that the soil herbicide Stomp New 330 EC was more effective against *S. oleraceus* L., compared with Dual Gold 960 EC.

The application of the vegetative herbicide Sencor 70 WG after treatment with Dual Gold 960 EC increases the control against *S. oleraceus* L. Average for the period on the tenth DATFH, the reported efficacy at variant four was 67.5% (Table 4). The herbicidal control was highest at variant six – 76.9%, and the most limited was at variant three – 30.0%. Average for the experimental period at the twentieth DATFH, the highest control against *S. oleraceus* L. was reported at metribuzin variants. After the application of Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) the efficacy was 80.0%, and after Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}), it was 73.8%. Dobrzański et al. (1989) also found a positive effect in the control of broadleaved weeds from the application of soil herbicide, and during the growing season spraying with metribuzin. For satisfactory control of annual broadleaved weeds in tomatoes, the authors recommend Goal 2E (oxyfluorfen) at 1 l ha^{-1}, in tank mixtures in combination with Sencor (metribuzin) at 0.25 kg ha^{-1}. The lowest control of *S. oleraceus* – 22.5%, on the twentieth DATFH, was reported in Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}).

Under the experimental conditions, the most sensitives weed to Stomp New 330 EC and Dual Gold 960 EC, was *S. viridis* (L.) P. Beauv. On average for the period, on the fourteenth and twenty-eighth DAT, one hundred percent efficacy was reported. Abdel-Gadir et al. (2009) found that the application of s-metolachlor in sorghum leads from satisfactory to excellent control (65-100%) of grasses and poor to satisfactory control (0-66%) of deciduous weeds. According to Khan and Hassan (2003), the application of s-metolachlor (Dual Gold 960 EC) leads to 90.0 % control of a large proportion of common weeds in onions, cauliflower, okra, peas, potatoes, sunflower, sugarcane, and maize.

On the tenth DATFH, 100% control against *S. viridis* (L.), P. Beauv. was reported after the application of Dual Gold 960 EC + Targa Super 5 EC and Stomp New 330 EC + Targa Super 5 EC. Dual Gold 960 EC + Sencor 70 WG and Stomp New 330 EC + Sencor 70 WG provide 90.0% and 87.5% efficacy against weed.

Average for the experimental period on the twentieth DATFH, 100% control against *S. viridis* (L.), P. Beauv. was reported after the application of Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}), and Stomp New 330

Table 4. Biological efficacy (%) of herbicide systems against *Sonchus oleraceus* L.

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	50.0	38.8	35.0	25.0	40.0	35.0	25.0	20.0	45.0	36.9	30.0	22.5
4. Dual Gold 960 EC + Sencor 70 WG	52.5	40.0	70.0	75.0	45.0	32.5	65.0	72.5	48.8	36.3	67.5	73.8
5. Stomp New 330 EC + Targa Super 5 EC	90.0	82.5	75.0	70.0	85.0	75.0	70.0	65.0	87.5	78.8	72.5	67.5
6. Stomp New 330 EC + Sencor 70 WG	90.0	85.0	75.0	80.0	85.0	76.3	78.8	80.0	87.5	80.7	76.9	80.0

Table 5. Biological efficacy (%) of herbicide systems against *Setaria viridis* (L.) P. Beauv.

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	100	100	100	100	100	100	100	100	100	100	100	100
4. Dual Gold 960 EC + Sencor 70 WG	100	100	90.0	85.0	100	100	90.0	85.0	100	100	90.0	85.0
5. Stomp New 330 EC + Targa Super 5 EC	100	100	100	100	100	100	100	100	100	100	100	100
6. Stomp New 330 EC + Sencor 70 WG	100	100	90.0	85.0	100	100	85.0	80.0	100	100	87.5	82.5

EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}). In the other two variants, the control against *S. viridis* (L.), P. Beauv. was 85.0% for Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}), and 82.5% for Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) (Table 5).

Convolvulus arvensis L. is one of the chemically resistant weeds in tomatoes. On the fourteenth and twenty-eighth DAT, at all variants with herbicides, there were no registered efficacy. Vasilakoglou et al. (2013) also reported that *C. arvensis* L. is one of the most serious and difficult to control weeds in *Solanum tuberosum* L. The *C. arvensis* L. not only competes with tomato plants for the main vegetation factors, but this weed is also a host of *Alternaria solani* (Akhtar et al., 2011). On the tenth DATFH, the efficacy of 2.5% was reported only at systems including Dual Gold 960 EC + Sencor 70 WG and Stomp New 330 EC + Sencor 70 WG. For the other two systems, the registered efficacy was 0%. Unsatisfactory efficacy was also reported at the twentieth DATFH. The system Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) showed 5.0% control against *C. arvensis* L, and Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) – 3.8%. After treatment with Dual Gold 960 EC (1.20 l ha-1) + Targa Super 5 EC (1.75 l ha^{-1}) and Stomp New 330 EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}), the reported efficacy was 0% (Table 6).

The biological efficacy of fourteenth and twenty-eighth DAT against *Sorghum halepense* (L.) Pers. developed from rhizomes was zero percent. The same result was registered in the control of *C. arvensis* L. The reason is that to the twenty-eighth DAT on the field were applied only the soil herbicides – Stomp New 330 EC and Dual Gold 960 EC.

The efficacy against *S. halepense* (L.) Pers. developed from rhizomes on the third reporting date, significantly increases. The reason was the use of the herbicide Targa Super 5 EC. On the tenth DATFH, the highest herbicidal efficacy against *S. halepense* (L.) Pers. developed from rhizomes was reported at system Dual Gold 960 EC + Targa Super 5 EC – 93.2% and at system Stomp New 330 EC + Targa Super 5 EC – 96.3%. In the herbicide system involving Sencor 70 WG, the reported efficacy was 2.5% at variant four, and 5.0% at variant six. At twentieth DATFH, on average for the period, the highest efficacy was obtained after treatment with Stomp New 330 EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) – 98.8%, followed by Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) – 96.5%. At Dual Gold 960 EC + Sencor 70 WG and Stomp New 330 EC + Sencor 70 WG the reported efficacy was 2.5% and 7.5%, respectively (Table 7).

As a result of the visual observations for the selectivity of the studied herbicides, no visible manifestations of

Table 6. Biological efficacy (%) of herbicide systems against *Convolvulus arvensis* L.

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	0	0	0	0	0	0	0	0	0	0	0	0
4. Dual Gold 960 EC + Sencor 70 WG	0	0	5.0	7.5	0	0	0	0	0	0	2.5	3.8
5. Stomp New 330 EC + Targa Super 5 EC	0	0	0	0	0	0	0	0	0	0	0	0
6. Stomp New 330 EC + Sencor 70 WG	0	0	5.0	10.0	0	0	0	0	0	0	2.5	5.0

Table 7. Biological efficacy (%) of herbicide systems against *Sorghum halepense* (L.) Pers. developed from rhyzomes

Variants/Year	2020				2021				Average			
	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)	DAT (14)	DAT (28)	DATFH (10)	DATFH (20)
1. Untreated control	0	0	0	0	0	0	0	0	0	0	0	0
2. Economic control	100	100	100	100	100	100	100	100	100	100	100	100
3. Dual Gold 960 EC + Targa Super 5 EC	0	0	92.5	95.0	0	0	93.8	98	0	0	93.2	96.5
4. Dual Gold 960 EC + Sencor 70 WG	0	0	5.0	5.0	0	0	0	0	0	0	2.5	2.5
5. Stomp New 330 EC + Targa Super 5 EC	0	0	95.0	97.5	0	0	97.5	100	0	0	96.3	98.8
6. Stomp New 330 EC + Sencor 70 WG	0	0	5.0	5.0	0	0	5.0	10.0	0	0	5.0	7.5

Table 8. Plant height (PH), Leaf number (LN) and Leaf area (LA) on the 20th day after planting

Variants / Years and indicators	2020	2021	Average	2020	2021	Average	2020	2021	Average
	PH (cm)	PH (cm)	PH (cm)	LN $plant^{-1}$	LN $plant^{-1}$	LN $plant^{-1}$	LA (cm^2)	LA (cm^2)	LA (cm^2)
Untreated control	27.6 [b]	26.2 [b]	26.9 [b]	7.7 [b]	7.3 [b]	7.5 [b]	1363.5 [b]	1295.3 [b]	1329.4 [b]
Economic control	36.8 [a]	34.9 [a]	35.9 [a]	9.7 [a]	9.2 [a]	9.5 [a]	1643.5 [a]	1561.1 [a]	1602.3 [a]
Dual Gold 960 EC	36.2 [a]	34.4 [a]	35.3 [a]	9.4 [a]	8.9 [a]	9.2 [a]	1568.4 [a]	1490.0 [a]	1529.2 [a]
Stomp New 330 EC	35.8 [a]	34.0 [a]	34.9 [a]	8.9 [a]	8.4 [a]	8.7 [a]	1547.3 [a]	1469.9 [a]	1508.6 [a]

[a] Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$). The statistical analysis of the results for each separate year is performed by using the data from each replication. The statistical analyses average for the period is done by using the data from each experimental year.

phytotoxicity on tomatoes, Opal F_1, were found. Under the conditions of the experiment, on the seventh, fourteenth, and twenty-first day after treatment, at all variants with herbicides was reported a score of 1 by the visual scale of EWRS – there is no damage to the crop.

Apart from the biological efficacy and selectivity during the two years of the experiment, the influence of the studied herbicide systems on plant height, leaf number, leaf area, and total yield was established also.

The results of biometric measurements, performed on the twentieth day after planting, (Table 8 and Table 9), were unidirectional for the experimental period. The values of the reported indicators at all investigation variants were higher in 2020, compared with 2021.

During this stage of plant development, the plant height was highest at economic control – average 35.9 cm, followed by a variant Dual Gold 960 EC – average 35.3 cm. There is no mathematically proven difference between economic control, Dual Gold 960 EC, and Stomp New 330 EC. A mathematical difference between untreated control and the other three variants is proven (Table 8).

On average for the two years, on the twentieth day after planting, the leaf number was lowest in plants from untreated control – 7.5. In plants from the other three variants, the leaf number was from 8.7 to 9.5, as the differences between them were no proof (Table 8).

An important indicator of the vegetative manifestations of plants is the size of the leaf area. The plants from the economic control, in which regular hoeing was carried out during the vegetation, form the largest leaf area – average 1602.3 cm^2. After the application of Dual Gold 960 EC, a larger leaf area was reported than the application of Stomp New 330 EC, respectively, 1529.2 cm^2 and 1508.6 cm^2, and the difference is unproven. A statistically proven difference exists only between untreated control and the other three variants (Table 8).

On the fortieth day after planting, on average for the period, the highest values of plant height, leaf number, leaf area were reported in economic control respectively – 66.7 cm, 14.7, 3604.3 cm^2 (Table 9). Of the investigated herbicide systems, the highest results of plant height, leaf number, and leaf area were obtained after application with Stomp New 330 EC + Sencor 70 WG, respectively, 63.2 cm, 13.4, and 3156.5 cm^2. There is no statistically proven difference between these two variants. The lowest values of the biometric indicators were reported at the untreated control.

During the period 2020 – 2021, the impact of the investigation herbicide systems on the yield of tomatoes was studied. The reported yield of each variant was compared with the yield of economic control. Carrying out regular

Table 9. Plant height (PH), Leaf number (LN) and Leaf area (LA) on the 40th day after planting

Variants / Years and indicators	2020	2021	Average	2020	2021	Average	2020	2021	Average
	PH (cm)	PH (cm)	PH (cm)	LN plant^{-1}	LN plant^{-1}	LN plant^{-1}	LA (cm^2)	LA (cm^2)	LA (cm^2)
1. Untreated control	49.5 ^{d}	47.1 ^{d}	48.3 ^{d}	10.7 ^{c}	10.2 ^{c}	10.5 ^{c}	2132.3 ^{c}	2025.7 ^{c}	2079.0 ^{c}
2. Economic control	68.4 ^{a}	65.0 ^{a}	66.7 ^{a}	15.0 ^{a}	14.3 ^{a}	14.7 ^{a}	3696.7 ^{a}	3511.9 ^{a}	3604.3 ^{a}
3. Dual Gold 960 EC + Targa Super 5 EC	60.7 ^{bc}	57.7 ^{bc}	59.2 ^{bc}	12.3 ^{b}	11.7 ^{b}	12.0 ^{b}	2896.9 ^{b}	2752.1 ^{b}	2824.5 ^{b}
4. Dual Gold 960 EC + Sencor 70 WG	63.8 ^{abc}	60.6 ^{abc}	62.2 ^{abc}	13.4 ^{b}	12.6 ^{b}	13.0 ^{b}	3045.6 ^{b}	2893.3 ^{b}	2969.5 ^{b}
5. Stomp New 330 EC + Targa Super 5 EC	62.8 ^{abc}	59.6 ^{abc}	61.2 ^{abc}	12.9 ^{b}	12.3 ^{b}	12.6 ^{b}	2989.7 ^{b}	2840.1 ^{b}	2914.9 ^{b}
6. Stomp New 330 EC + Sencor 70 WG	64.8 ^{ab}	61.6 ^{ab}	63.2 ^{ab}	13.7 ^{ab}	13.0 ^{ab}	13.4 ^{ab}	3237.4 ^{ab}	3075.5 ^{ab}	3156.5 ^{ab}

[a] Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$). The statistical analysis of the results for each separate year is performed by using the data from each replication. The statistical analyses average for the period is done by using the data from each experimental year.

Table 10. Tomato yield (kg da^{-1})

Variants/Years	2020	2021	Average
1. Untreated control	2939.3 [e]	2692.3 [e]	2815.8 [e]
2. Economic control	6874.4 [a]	6530.6 [a]	6702.5 [a]
3. Dual Gold 960 EC + Targa Super 5 EC	6125.1 [cd]	5818.9 [cd]	5972.0 [cd]
4. Dual Gold 960 EC + Sencor 70 WG	6423.1 [abc]	6101.9 [abc]	6262.5 [abc]
5. Stomp New 330 EC + Targa Super 5 EC	6232.8 [bc]	5921.2 [bc]	6077.0 [bc]
6. Stomp New 330 EC + Sencor 70 WG	6697.7 [ab]	6362.9 [ab]	6530.3 [ab]

[a] Means with different letters are with proved differences according to Duncan's Multiple Range test ($p < 0.05$). The statistical analysis of the results for each separate year is performed by using the data from each replication. The statistical analyses average for the period is done by using the data from each experimental year

tillage helps to keep the crop free of weeds, improves soil aeration, improves its moisture retention capacity, and activates microbiological activity. In this regard, on average for the experimental period, the economic control reported the highest standard yield – 6702.5 kg da^{-1} (Table 10). Ahmed and Kandeel (1991) confirmed that the optimal garlic yield is obtained when the crop is dug up.

From the studied systems with herbicides, the highest yield was obtained after application of Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) – 6530.3 kg da^{-1}, followed by Dual Gold 960 EC (1.20 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}) – 6262.5 kg da^{-1}. There is no proven difference in yield between economic control, Stomp New 330 EC + Sencor 70 WG and Dual Gold 960 EC + Sencor 70 WG. As the dominant weeds in the field are *Portulaca oleracea* L. and *Amaranthus retroflexus* L., the high yields in both systems involving metribuzin, can be explained by the efficacy against both weeds (Table 1 and Table 2). The increase of tomato yield after metribuzin administration has been demonstrated by other researchers (Singh and Twpathi, 1988; Nath and Sharma, 2000; Sinha et al., 2000).

The yield of Stomp New 330 EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) – 6077.0 kg da^{-1} and Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) – 5972.0 kg da^{-1} was proven to be lower than the economic control. However, the yields obtained from these two variants exceed the untreated control. The increase in yield after the use of herbicides has also been found in drilled onion and tobacco (Trojak-Goluch and Solarska, 2010; Anyszka et al., 2011). In both years, the lowest yield was reported at the untreated control – an average of 2815.8 kg da^{-1}.

Conclusions

Under experimental conditions, on 20 DATFH application of the Stomp New 330 EC (4.00 l ha^{-1}) + Sencor 70 WG (0.60 g ha^{-1}), system showed the highest efficacy against *Portulaca oleracea* L. – 87.5%, *Amaranthus retroflexus* L. – 80.0%, *Solanum nigrum* L. – 75.0%, and *Sonchus oleraceus* – 80.0%. At the variant with Dual Gold 960 EC (1.20 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}) and Stomp New 330 EC (4.00 l ha^{-1}) + Targa Super 5 EC (1.75 l ha^{-1}), was reported one hundred percent efficacy against *Setaria viridis* (L.) P. Beauv. Highest efficacy against *Sorghum halepense* (L.) Pers. developed from rhizomes – 98.8%, was reported after treatment with Stomp New 330 EC + Targa Super 5 EC. In the conditions of experience, the highest yield of tomatoes, Opal F1, was received at Economic control – 6702.5 kg da^{-1}, followed by Stomp New 330 EC + Sencor 70 WG – 6530.3 kg da^{-1}, and Dual Gold 960 EC + Sencor 70 WG – 6262.5 kg da^{-1}. There is no statistically proven difference in the yield between Economic control, Stomp New 330 EC + Sencor 70 WG, and Dual Gold 960 EC + Sencor 70 WG.

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