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Biological thresholds of weeds to seedlingless growing of tomatoes

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Abstract- To establish the weed thresholds of injury to seedlingless growing of tomatoes a field trial was carried out in the conditions of artificial weed infestation, and variants of particular types of weeds with particular density were tested. The trial recorded weed infestation, growth, development and productivity of tomatoes, content of soil humidity and soil nutrients. It was established that at equal number of weeds per area unit, most nitrogen was consumed by *Chenopodium album* L. and *Solanum nigrum* L., phosphorus – *Datura stramonium* **L.**, and potassium – *Solanum nigrum* L., *Chenopodium album* L. and *Echinochloa crus-galli* L. The strongest tomato competitor for water was *Solanum nigrum* L., and the weakest – *Setaria veridis* P.B. The highest injury levels were manifested by *Datura stramonium* L. and *Solanum nigrum* L. and the biological threshold of injury levels for these weeds was 1 per m^2. *Echinochloa crus-galli* L., *Amaranthus retroflexus* L. and *Chenopodium album* L. had lower injury levels, and the biological threshold of injury for them was 2 per m^2. *Setaria veridis* P.B. manifested the lowest injury level. Its biological threshold was 4 per m^2.

Index Terms- Tomatoes, Biological thresholds, Weeds, Injury levels

I. Introduction

To develop plant protection technologies for weed control it is not enough only to include chemical systems of highly effective herbicides and herbicide mixtures and the use of new ways and methods for their application. It is also necessary to establish accurately the weed density and the critical period of competition with the crop when it is appropriate to apply these herbicides. In a number of cases, a good knowledge of the injury thresholds of the individual types of weed to a certain crop makes it possible to avoid one or more sprayings, which is of great significance both economically and ecologically, as it protects the soil and environment from harmful residues.

The injury thresholds and critical periods in the competition between weeds and crops and subject of study for a number of authors. It was established that the biological threshold of injury of johnsongrass to maize is one plant per m^2, and the economical is two plants per m^2, and the weed is most harmful in the period between the third and sixth week after crop emergence [1,2]. The critical period for weed infestation of fat hen to wheat is between the 28th and 42nd day after its emergence [3]. With soya the critical period of weed infestation is between the 15th and 60th day after sowing or the phase of 1st, 3rd triple leaf [4,5]. The competition between weeds and beans is strongest in the period between emergence and second triple leaf of the crop [6]. The weeds have the greatest impact on broad beans in the period 28-30 days after its emergence [7]. The black nightshade has the strongest effect on peas in the period from four to six weeks after sowing [8]. The critical period of competition between the weeds and tomatoes is about 12 days (from 24th to 36th day) after planting the tomatoes [9], and acording other studies the critical period of weed infestation covers the period from 35th to 60th days after tomatoes sowing and its duration depends on the variety [10]. The economical threshold of injury to growing tomatoes for Redroot pigweed is over 1 per m^2, and for cockspur grass it is over 5 per m^2 [11], whereas the biological threshold of injury of black nightshade according to other authors is 0.8 per m^2 of weed plants [12]. In garlic growing, the weeds which developed between the 28th and 49th day of crop emergence affect yield formation the greatest [13]. It was established that fertilization with higher rates of phosphorus fertilizers delays the beginning of the critical period of competition between weeds and lettuce [14]. It is typical for most of the research which cover the injury thresholds and the critical periods of competition between weeds and crops that they are too multidirectional, include various crops, cultivation methods and types of weeds, and some are bound to different phenophases of the crop development.

The goal of this investigation was to establish the biological injury thresholds of the main weeds to seedlingless growing of tomatoes, which will provide an opportunity to manage the technology by applying agrotechnically more expedient and ecologically safer weed control systems.

II. MATERIALS AND METHODS

To achieve this goal a field trial was conducted in the conditions of artificial weed infestation, and variants were made of particular types of weed at particular density.

The tomatoes were grewed on a high level bed after a design of 120 + 40/25 cm. The trial was set after the block method in 4 replications with the following variants:

1. Check – weeding with various types of weeds;
2. Check – weeded during vegetation;
3. Mixed weeding with 4 plants from the various types of weeds;

Variants from 4 to 7 were weeding with green bristle-grass (Setaria *veridis* P.B.) with density of 1, 2, 4 and 8 plants per m^2, respectively;

Variants from 8 to 11 were weeding with cockspur grass (*Echinochloa crus-galli* L.) with density of 1, 2, 4 and 8 plants per m^2, respectively;

Variants from 12 to 15 were weeding with Redroot pigweed (*Amaranthus retroflexus* L.) with density of 1, 2, 4 and 8 plants per m^2;

Variants from 16 to 19 were weeding with fat hen (*Chenopodium album* L.) with density of 1, 2, 4 and 8 plants per m^2;

Variants from 20 to 23 were weeding with black nightshade (*Solanum nigrum* L.) with density of 1, 2, 4 and 8 plants per m^2;
Variants from 24 to 27 were weeding with jimsonweed (*Datura stramonium* L.) with density of 1, 2, 4 and 8 plants per m^2.

The trial investigated the following indexes: weeding, growth, development and productivity of tomatoes, content of soil humidity and soil nutrients. The weeds were recorded by the quantity-weighing method by types at the end of vegetation. The tomatoes growth and development were recorded with development index, whereas the yield – with productivity index. The yield data was statistically processed by analysis of variance. The content of soil humidity was determined by stages in the 0-30 cm layer by the thermostatic method. The soil nutrients content was established by stage in the 0-30 cm layer. The mineral nitrogen was determined with the Parnas-Wagner distillation apparatus and the mobile forms of phosphorus were determined colorimetricaly by Egner-Riem, and potassium – by flame photometry.

III. RESULTS AND DISCUSSION

The results which express the interdependency in surface biomass to the main weeds (Table 1) show that their air dry weight reduced but not regularly with the increase of weed number per area unit. With green bristle-grass the weight was reduced from 62.3 g for 1 number per 1 m^2 to 49.3 g, i.e. with 19.9 % for 4 n. per m^2 and reached 38.8 g (with 37.7 %) for 8 n. per m^2. The interspecies competition was stronger at 8 weeds per m^2 where the air dry weight sharply decreased. With redroot pigweed the interspecies competition is almost the same. It was greatest for fat hen, where the weight from 593.3 g for 1 n. per 1 m^2 dropped down to 309.6, i.e. with 47.7 % for 4n per 1 m^2 and reached 193.1 g, i.e. decreased with 67.5% for 8 n. per 1 m^2. The values for black nightshade were close to these. The weakest interspecies competition was seen for jimsonweed, where with the increase of weed number from 1 to 8 n. per 1m^2, their weight decreased from 1056 g to 839 g, i.e. with 20.5 %. In the interspecies competition the most persistent weeds were cockspur grass and Redroot pigweed, and the most sensitive were fat hen and black nightshade.

Table 2 and Table 3 show the competitive relations between the weeds and tomatoes about the soil macroelements. In the third leaf stage of the tomatoes, the content of mineral nitrogen varied from 13.5 to 27.1 mg per kg soil for all the variants. Phosphorus varied from 4.4 to 7.8 mg per 100 g soil and potassium – from 2 to 12 mg per 100 g soil. At this stage the weeds were very small or had just emerged and therefore did not impact the content of soil macroelements, regardless of their density. The values of absorbed nutrients were very different for the different weeds in the stage of tomato ripening (Table 3). The content of nitrogen, phosphorus and potassium in the noweeded check was lowest – 16.2 mg per kg soil, 4.6 and 9 mg/100 g soil, respectively. By increasing the weed density in all variants was also increased the amount of used soil macroelements. At an equal number of weeds per area unit, most nitrogen was used by fat hen and black nightshade - with 69.4 % and 57.3 % more compared to check weeded, phosphorus – by jimsonweed, and potassium almost to the same amount by black nightshade, fat hen, cockspur grass and redroot pigweed.

Table I: Dependence of surface biomass of tomatoes of the weeding

Variant №	Type of weed	Number	Average weight of surface biomass, g	Variant №	Type of weed	Number	Average weight of surface biomass, g
1	*Setaria viridis* P.B.	23	38.1	12	*Amar. retroflexus* L.	1	525.8
	Echinochloa crus-galli L	3	39.5	13	*Amar. retroflexus* L.	2	400.2
	*Amaranthus retroflexus*L	13	171.3	14	*Amar. retroflexus* L.	4	367.2
	Datura stramonium L.	2	272.7	15	*Amar. retroflexus* L.	8	312.1
	Chenopodium album L	4	162.7				
	Solanum nigrum L.	16	147.8				
2	Check – weeded during vegetation			16	*Chenopod. album* L.	1	593.3
3	*Setaria viridis* P.B.	4	44.9	17	*Chenopod. album* L.	2	435.1
	Echinochloa crus-galli L	4	124.1	18	*Chenopod. album* L.	4	309.6
	*Amaranthus retroflexus*L	4	354.4	19	*Chenopod. album* L.	8	193.1
	Datura stramonium L.	4	629.9				
	Chenopodium album L	4	156.9				
	Solanum nigrum L.	4	170.3				

4	*Setaria viridis* P.B.	1	62.3	20	*Solanum nigrum* L.	1	435.3
5	*Setaria viridis* P.B.	2	52.7	21	*Solanum nigrum* L.	2	302.3
6	*Setaria viridis* P.B.	4	49.3	22	*Solanum nigrum* L.	4	318.7
7	*Setaria viridis* P.B.	8	38.8	23	*Solanum nigrum* L.	8	211.0
8	*Echinochloa crus-galli* L.	1	140.0	24	*Datura stramonium* L.	1	1056.2
9	*Echinochloa crus-galli* L.	2	146.7	25	*Datura stramonium* L.	2	1097.7
10	*Echinochloa crus-galli* L.	4	107.0	26	*Datura stramonium* L.	4	923.4
11	*Echinochloa crus-galli* L.	8	77.3	27	*Datura stramonium* L.	8	839.7

Table II: Agrochemical characteristic of the soil - third leaf stage of tomatoes

Var. No	mg /1000 g soil			mg /100 g soil		pH ($_{H2O}$)	Salts content ms/cm^{-1}
	NH_4- N	NO_3- N	N_{min}	P_2O_5	K_2O		
1.	5.4	16.2	21.6	5.0	6	7.3	40
2.	13.5	8.1	21.6	5.0	4	7.2	30
3.	8.1	5.4	13.5	4.8	11	7.2	80
4.	8.1	16.2	24.3	5.4	8	7.2	20
5.	10.8	13.5	24.3	6.1	9	7.1	50
6.	13.5	5.4	18.9	6.4	7	7.1	66
7.	8.1	19.0	27.1	7.3	10	7.1	30
8.	19.0	8.1	27.1	6.1	10	7.2	90
9.	16.2	8.1	24.3	7.5	7	7.2	80
10.	10.8	16.2	27.0	7.5	13	7.1	100
11.	13.5	18.0	31.5	5.1	12	7.1	80
12.	8.1	8.1	16.2	5.8	6	7.1	60
13.	10.8	10.8	21.6	6.4	8	7.0	90
14.	10.8	13.5	24.3	7.3	5	7.0	70
15.	8.1	16.2	24.3	5.9	10	6.9	90
16.	10.8	8.1	18.9	5.1	10	7.1	70
17.	13.5	10.8	24.3	6.2	3	7.0	90
18.	13.5	8.1	21.6	6.5	8	7.1	90
19.	10.8	8.1	18.9	5.8	8	7.2	60
20.	8.1	5.4	13.5	4.8	10	7.1	80
21.	5.4	10.8	16.2	5.2	9	7.1	100
22.	8.1	10.8	18.9	6.7	13	7.1	60
23.	13.5	8.1	21.6	7.8	10	7.1	90
24.	21.6	16.2	37.8	4.4	8	7.1	90
25.	10.8	8.1	18.9	5.1	10	7.0	100
26.	5.4	13.5	18.9	6.8	10	7.1	90
27.	10.8	13.5	24.3	7.0	2	7.1	100

Table III: Agrochemical characteristic of the soil - ripening stage of tomatoes

Var. No	mg/1000 g soil			mg/100 g soil		pH ($_{H2O}$)	Salts content ms/cm^{-1}
	NH_4-N	NO_3-N	N_{min}	P_2O_5	K_2O		
1.	5.4	10.8	16.2	4.6	9	6,9	100
2.	19.0	19.0	38.0	6.7	19	6,9	110
3.	8.1	8.1	16.2	4.8	9	7,1	110
4.	16.2	19.0	35.2	6.1	19	7,0	100
5.	13.5	13.5	27.0	6.1	17	7,1	120

6.	16.2	10.8	27.0	5.8	17	7,1	120
7.	13.5	13.5	27.0	5.5	14	7,0	100
8.	19.0	10.8	29.8	5.8	13	7,0	90
9.	16.2	13.5	29.7	5.8	14	7,1	100
10.	16.2	13.5	29.7	5.8	14	7,1	100
11.	16.2	8.1	24.3	5.5	13	7,0	120
12.	13.5	19.0	32.5	6.1	19	7,1	110
13.	10.8	16.2	27.0	5.8	15	6,9	100
14.	8.1	13.5	21.6	5.5	14	7,0	100
15.	8.1	19.0	27.1	5.5	13	7,1	120
16.	16.2	19.0	35.2	5.8	19	7,1	100
17.	13.5	16.2	29.7	5.8	17	7,1	110
18.	19.0	8.1	27.1	5.5	14	7,1	100
19.	8.1	13.5	11.6	5.5	13	7,0	100
20.	19.0	19.0	38.0	6.1	15	7,2	100
21.	13.5	16.2	29.7	6.4	15	7,1	100
22.	10.8	10.8	21.6	5.5	14	7,0	110
23.	8.1	8.1	16.2	5.5	13	7,1	90
24.	16.2	16.2	32.4	5.8	15	7,1	110
25.	19.0	10.8	29.8	5.5	14	7,0	100
26.	13.5	13.5	27.0	5.5	14	7,1	120
27.	13.5	13.5	27.0	5.1	14	7,1	90

The unproductive water consumption by the soil is one of the main factors in the weed competition. The results (Table 4) show that in the third leaf stage the humidity content in 0-30 cm layer at mixed weeding was 31.3 % less than the check (crops without weeds). At density of green bristle-grass 2 n. per m^2, the humidity content was almost the same with the clean crops. By increasing the weed density the unproductive water consumption was also increased. The highest humidity consumption in the third leaf stage was observed for black nightshade and jimsonweed, and the least consumed amount – for green bristle-grass. In the budding and ripening stages of tomatoes, the humidity content in the soil for the variant of mixed weeding was even less than the clean crops (with 43.7 %). In this period even smaller weed density led to higher humidity consumption. At the end of vegetation again the mixed weeding and the weeding with black nightshade appeared as the greatest competitors for the tomatoes regarding the water. At 8 n. per m^2 for black nightshade the soil humidity content was 48.5 % less than the clean crops.

Table IV: Impact of weeding on the soil humidity in the 0-30 cm soil layer, % of FMC

Variant No	Humidity content, % of FMC*		
	Third leaf stage	Budding	Ripening
1.	41.1	43.5	34.3
2.	84.5	77.8	83.4
3.	58.0	43.8	33.6
4.	83.1	61.3	63.1
5.	83.2	60.5	62.5
6.	68.0	61.2	57.4
7.	66.8	58.6	52.9
8.	79.1	68.1	73.7
9.	76.8	64.7	60.8
10.	67.4	63.5	54.1
11.	66.3	58.6	50.4
12.	72.9	66.5	66.2
13.	72.6	63.0	60.1
14.	63.9	61.0	54.3
15.	63.9	54.9	48.5

16.	70.7	62.7	62.6
17.	71.0	61.1	52.1
18.	62.2	59.2	47.6
19.	62.8	57.5	46,2
20.	71.0	62.6	61.1
21.	68.0	62.7	54.2
22.	59.2	57.6	48.2
23.	58.7	55.9	42.9
24.	69.9	60.5	64.4
25.	68.0	57.5	56.0
26.	61.6	56.1	51.9
27.	61.0	53.4	47.7

* FMC – full moisture capacity

The competitive relations between tomatoes and weeds were manifested in the vegetative development of the crop. The data in Table 5 shows that the different weeds suppress the tomato development to a different degree. The green bristle-grass at density of 2 n. per m^2 did not affect the plant height. There was an insignificant negative effect from fat hen of the same density (the tomatoes were 2.7 % behind in their development compared to the clean crops). This may be due to the fact that the green bristle-grass plants were generally small, whereas fat hen emerged a little later and the tomatoes had certain advantage in their own development. By increasing the weed density, the difference in tomato plants height from these variants and from the clean crop plants also increased. The strongest negative impact on tomato growth was observed with black nightshade and jimsonweed. The same tendencies were observed for leaf number and flower number. With higher weed density, the plants had a delayed development and formed their reproductive organs relatively later. The lowest development index compared to the check was recorded at density of 8 n. per m^2 of jimsonweed (-33.4). The weakest negative effect on tomato growth at density of 8 n. per m^2 was by green bristle-grass. The development index was -13.1 compared to the clean crops. At equal number per area unit the monocot weeds suppressed the crop more weakly than the dicotyledonous ones.

The dependency of yield on the different types of weeds and the degrees of weeding is shown in Table 6. The highest yield (47375 kg/ha) was obtained from the variant weeding with green bristle-grass at density of 2 n. per m^2, which exceeded the weeded check with 4 %, but the difference was not significant.
By increasing the density of the different weeds (1, 2, 4 and 8 plants per m^2) the tomato yield decreased which was clearly expressed at the higher density of 8 n. per m^2. The yield of cockspur grass, for example, decreased from 93 % to 70-50 %, for redroot pigweed it decreased from 92 % to 76-53 %.

As we compared the variants at equal level of weeding (8 n. per m^2), it is seen with the different weeds that jimsonweed had the strongest negative impact. The yield was 65 % lower than the clean crops, and the differences were well proven. The result for black nightshade was similar. The yield was 62 % lower. Weeding with green bristle-grass had the weakest negative impact. The yield decreased with 40 % with well proven difference.

Table V: Morphological indexes and development of the tomato plants

Variant No	Type of weed	Nimber of m^2	Tomato height, cm	%	Number of leaves	%	Number of flowers	%	Development index
1.	Check - noweeded	61	21	56.7	4	57.1	2	50	- 45.4
2.	Check – weeded during vegetation	-	37	100.0	7	100.0	4	100	-
3.	Mixed weeding	24	24	64.8	4	57.1	2	50	- 42.7
4.	*Setaria veridis* P.B.	1	34	91.8	6	85.7	3	75	-15.8
5.	*Setaria veridis* P.B.	2	38	102.7	6	85.7	4	100	-3.8
6.	*Setaria veridis* P.B.	4	36	97.3	6	85.7	4	100	-5.6
7.	*Setaria veridis* P.B.	8	33	89.2	5	71.4	4	100	-13.1
8.	*Echinochloa crus-galli* L.	1	32	86.5	4	57.1	3	75	-27.1
9.	*Echinochloa crus-galli* L.	2	35	94.6	5	71.4	4	100	-11.3
10.	*Echinochloa crus-galli* L.	4	32	86.5	5	71.4	4	100	-14.0
11.	*Echinochloa crus-galli* L.	8	30	81.1	5	71.4	4	100	-15.8
12.	*Amaranthus retroflexus* L.	1	28	75.6	6	85.7	3	75	-21.2

13.	*Amaranthus retroflexus* L.	2	33	89.2	6	85.7	4	100	-8.3
14.	*Amaranthus retroflexus* L.	4	30	81.1	5	71.4	4	100	-15.8
15.	*Amaranthus retroflexus* L.	8	26	70.3	5	71.4	3	75	-27.7
16.	*Chenopodium album* L.	1	34	91.8	6	85.7	3	75	-15.8
17.	*Chenopodium album* L.	2	36	97.3	6	85.7	4	100	-5.6
18.	*Chenopodium album* L.	4	33	89.2	6	85.7	4	100	-8.3
19.	*Chenopodium album* L.	8	30	81.1	5	71.4	4	100	-15.8
20.	*Solanum nigrum* L.	1	34	91.8	6	85.7	3	75	-15.8
21.	*Solanum nigrum* L.	2	31	83.8	5	71.4	4	100	-14.9
22.	*Solanum nigrum* L.	4	28	75.6	5	71.4	3	75	-26.0
23.	*Solanum nigrum* L.	8	24	64.8	5	71.4	3	75	-29.6
24.	*Datura stramonium* L.	1	31	83.8	4	57.1	2	50	-36.3
25.	*Datura stramonium* L.	2	30	81.1	5	71.4	4	100	-15.8
26.	*Datura stramonium* L.	4	27	72.9	6	85.7	4	100	-13.8
27.	*Datura stramonium* L.	8	25	67.6	4	57.1	3	75	-33.4

Table VI: Influence of weed infestation on the productivity of tomatoes

Variant №	2011		2012		average kg/ha	relative yield %	
	X	± d	x	± d		$k_{1=100}$	$k_{2=100}$
1	14370	- 32890	11500	-32160	12935	-	28
2	47260	-	43660	-	45460	351	-
3	15120	- 32140	12330	-31330	13725	106	30
4	49340	+ 2080	43380	-280	46360	358	102
5	51090	+ 3830	43660	0	47375	366	104
6	34650	-12610	36660	-7000	35655	276	78
7	34140	-13120	20000	-23660	27070	209	60
8	41510	- 5750	42935	-725	42222	326	93
9	38830	- 8430	43000	-660	40915	316	90
10	31210	-16050	32660	-11000	31935	247	70
11	26640	- 20620	19330	-24330	22985	178	50
12	43040	- 4220	40630	-3030	41835	323	92
13	41840	- 5420	41660	-2000	41750	323	92
14	36010	- 11250	32660	-11000	34335	265	76
15	29920	-17340	18660	-25000	24290	188	53
16	41710	- 5550	41480	-2180	41595	322	91
17	41800	- 5460	41660	-2000	41730	323	92
18	37030	- 10230	34160	-9500	35595	275	78
19	26480	- 20780	18330	-25330	22405	173	49
20	34060	-13200	34835	-8825	34448	266	76
21	26760	-20500	32330	-11330	29545	228	65
22	23160	-24100	26000	-17660	24580	190	54
23	17580	-29680	16830	-26830	17205	133	38
24	25550	-21710	40149	-3511	32850	254	72
25	23070	-24190	40330	-3330	31700	245	70

26	23130	-24130	25660	-18000	24395	188	54
27	17190	-30070	14660	-29000	15925	123	35
GD 5%	8560		9240				
GD 1%	12930		11850				
GD 0.1%	15100		14340				

IV. CONCLUSIONS

The strongest weed interspecies competition was observed with fat hen and black nightshade, and the weakest was with jimsonweed. In the interspecies competition the most resilient weeds were cockspur grass and redroot pigweed, and the most sensitive were fat hen and black nightshade.

At an equal number of weeds per area unit, the greatest amount of nitrogen was consumed by fat hen and black nightshade, phosphorus - jimsonweed and potassium at almost the same extent - black nightshade, fat hen, cockspur grass and redroot pigweed.

The strongest competitor to tomatoes for water was black nightshade, and the weakest was green bristle-grass.

The negative weed effect on tomato growth and development varied depending on the degree of weed infestation and weed species composition. The strongest negative effect on tomato growth was by black nightshade and jimsonweed, and the weakest was by green bristle-grass.

The highest injury levels at intensive tomato production were manifested by jimsonweed and black nightshade and the biological thresholds of weeds was 1 plant per m^2. The cockspur grass, redroot pigweed and fat hen had lower injury levels. Their biological thresholds of weeds were 2 plants per m^2. The green bristle-grass manifested the lowest injury level. Its biological threshold was 4 plants per m^2.

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