

Allelopathic soil activity in the rotation of some forage and technical crops

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Abstract

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Allelopathic soil activity of some forage and technical crops was studied on the initial development of *Lactuca sativa* L. It was found that: depending on the development index (*GI*), the allelopathic soil activity of the tested forage and technical crops grown in rotation pairs can be ranked in the following ascending order: Sugar beet/Vetch-oat mix (89.6%) → Sudan grass/Vetch-oat mix (86.0%) → Vetch-oat mix/Sugar beet (73.1%) → Alfalfa/Sudan grass (45.8%) → Stevia/Sorghum for grain (43.7%) → Sorghum for grain/Sugar beet (40.5%) → Sugar beet/ Sudan grass (31.3%) → Vetch-oat mix/Sudan grass (30.0%) → Sugar broom/Sorghum for grain (29.3%) → Wheat/Sudan grass (26.7%) → Sorghum for grain/Sorghum for grain (24.5%). The species from genus *Sorghum* (Sorghum for grain and Sudan grass) had a relatively high allelopathic effect and can be included as a component in future breeding programs and for biological weed control against weed species.

Keywords: allelopathic effect; forage crops; *Sorghum*; weed control

Introduction

In recent decades, research has focused on examining allelopathic relationships in agrophytocenoses (Lehoczky et al., 2011; Baličević et al., 2014; Novak, 2018; Serajchi et al., 2018).

It has been established that a number of annual and perennial wheat, legume and technical crops have allelopathic potential (Dadkhah & Rassam, 2016; Kunz, 2017; Baerson et al., 2008; Golubinova & Ilieva, 2014; Jesudas et al., 2014; Uddin et al., 2014). According to studies by Kato-Noguchi et al. (2007), Dayan et al. (2009), Mahmood et al. (2013), Jha et al. (2015), a part of the allelochemicals synthesized in the plant life cycle are formed by the root system and are accumulated in the rhizospheric soil area.

It has been established that the allelochemical separations from a number of plant species and the agro-ecological factors of the environment are one of the main factors determining the growth and development of crops, as well as their

rotation in crop rotation systems (Mamolos & Kalburtji, 2001; Shui et al., 2010). The established and implemented agricultural crop types and varieties have proven high yields, but there is no evidence of their allelopathic potential. The discovery of species with a high allelopathic effect will allow a reduction in pesticide inputs in their cultivation, which will allow the production of environmentally friendly products (Lehle & Putnam, 1983; Aleksieva & Serafimov, 2008; De Albuquerque et al., 2011; Fragasso et al., 2013; Iannucci et al., 2013).

According to Williamson and Richardson (1988), Zuo et al. (2010), Marinov-Serafimov et al. (2013) allelopathy can be considered as an opportunity for biological control against weeds. Models with high allelopathic potential have been found in a number of agricultural crops, and those in forage and technical crops in accessible literature are extremely limited (Aleksieva & Serafimov, 2008; De Bertoldi et al., 2012; McCarty et al., 2010; Marinov-Serafimov et al., 2015a, 2015b).

The aim of the study is to identify and compare allelopathic soil activity of some technical crops and forage, cultivated in crop rotation pairs with the use of standard laboratory methods, to include them as components in future selection programs as well as biological control against some weed species.

Materials and Methods

In the laboratory conditions of Institute of Forage Crops, Pleven, the soil activity of some forage and technical crops from the fields of Agricultural Institute, Shumen, was investigated for the initial development of *Lactuca sativa* L. (Table 1).

Table 1. Variants of experience

Variants		Crop rotation couple
№	code	
1	P_1	Sorghum for grain / Sugar beet
2	P_2	Sorghum for grain / Sorghum for grain
3	P_3	Wheat / Sudan grass
4	P_4	Vetch-oat mix / Sugarbeet
5	P_5	Fallow / Sudan grass
6	P_6	Sugar beet / Vetch-oat mix
7	P_7	Sugar beet / Sudan grass
8	P_8	Wheat / Sugar beet
9	P_9	Sudan grass / Vetch-oat mix
10	P_{10}	Vetch-oat mix / Sudan grass
11	P_{11}	Alfalfa / Sudan grass
12	P_{12}	Sugar broom / Sorghum for grain
13	P_{13}	Stevia / Sorghum for grain

The adapted method of Fujii et al. (2005) called “Rhizosphere Soil Method” (RSM) has been used to estimate the allelopathic potential.

12.0 g of soil was placed in Petri dishes (90 mm), and 15 ml (0.8%) agar was pipette on it. The sample is homogenized and a second layer of 5 ml (0.8%) agar is pipetted. Thus, the prepared samples are tempered for 72 hours at $18^{\circ}\text{C}\pm 2^{\circ}\text{C}$. In each Petri dish 25 seeds of *Lactuca sativa* L. are placed, Great Lakes variety. The prepared samples are incubated in a thermostat at $23^{\circ}\text{C}\pm 2^{\circ}\text{C}$ for five days. 0.8% agar was used for the control. Each variation was initiated in four replicates with 1 ml/l $\text{C}_{10}\text{H}_{14}\text{O}$ as a preservative.

The following indicators were determined for all experimental variants: sprouted seeds (%); length of one root (cm), hypocotyl and seedlings and fresh biomass per seedlings (g);

Seed sprouting ($GS_{\%}$) – ISTA (1985):

$$GS_{\%} = \frac{a}{b} \cdot 100 \quad (1)$$

in which: a is the number of sprouted seeds; b is the total number of sowed seeds; 100 is the coefficient;

Dynamic development index (DDI):

$$DDI = \left\{ \frac{t \log^2}{\log b - \log a} \right\} \quad (2)$$

in which: a and b are the % of sprouted seeds, the root length, hypocotyl and seedlings (cm) and/or fresh biomass of the seedlings (g), accordingly in the control variant and variants; t is the duration (days);

Inhibition index (I) by Sundra and Pote (1978):

$$I = (E_2 \cdot 100 / E_1) - 100 \quad (3)$$

in which: E_1 is the control variant indicator; E_2 is the indicator in variants.

The growth and accumulation rates for fresh biomass of the root and seedlings were determined by the adapted formula of Dauta et al. (1990):

$$\mu = \left\{ \frac{\ln N_t - \ln N_0}{t} \right\} \quad (4)$$

in which: N_t is the root length (cm), hypocotyl and seedlings or biomass for seedlings in the experimental variants; N_0 is the root length (cm), hypocotyl and seedlings or biomass for seedlings in the control variant; t is the duration (days);

Growth index (GI) by Gariglio et al. (2002):

$$GI = \left[\left(\frac{G}{G_0} \right) \cdot \left(\frac{L}{L_0} \right) \right] \cdot 100 \quad (5)$$

in which: G and G_0 are the sprouted seeds, accordingly for the variants and the control variant (%); L is the seedlings length in the variants, presented in percentages; L_0 is the seedlings length in the control variant, accepted as 100%;

Seedling vigor index (SVI) by Islam et al. (2009):

$$SVI = \left(\frac{S \cdot G}{100} \right) \quad (6)$$

in which: S is the length (cm) or the formed biomass (g) of the seedlings for variants; G – sprouted seeds (%);

Coefficient of allometry (CA) by Nasr and Mansour (2005):

$$CA = \left(\frac{L_s}{L_r} \right) \quad (7)$$

in which: L_s is the hypocotyls length (cm), L_r is the root length (cm);

Overall allelopathic potential (*OAP*) is determined by Jain et al. (2017):

$$OAP = IRG/100 \quad (8)$$

in which: *IRG* is the inhibition index in seedlings growth, 100 is the coefficient.

The mathematical and statistical processing of the experimental data was made after pre-transformation of the percentage of sprouted seeds by using the following formula:

$$Y = \arcsin \sqrt{\left(\frac{x\%}{100}\right)}$$

The obtained experimental results are mathematically and statistically processed with the STATGRAPHICS Plus software for Windows Version 2.1 and Statistica 10.

Results and Discussion

The results of the bio tests made with different soil samples have an indifferent to inhibitory effect on seed sprouting of the *Lactuca sativa* L. (Fig. 1).

The inhibition index (*I*) in seed sprouting, depending on the species of the donor, is in the range of 33.4 to 54.5% and can be conventionally divided into three groups: Group I (31 to 40%) in variants P_1 , P_4 , P_6 , P_7 , P_{11} and P_{13} , Group II (from 41 to 50%) in P_3 , P_{10} and P_{12} and Group III (over 50%) in P_2 and P_5 (Table 1 and 2).

An exception is found only in the crop rotation pairs – Wheat/Sugar beet (P_8) and Vetch-oat mix/Sudan grass (P_9), where indifferent interactions between the donor and the test plant (*L. sativa*) were recorded and the differences in control variants are statistically unproven (Fig. 1).

The data from biometric measurements on the root growth, hypostyle and seedlings in the early stages of *L. sativa* development allows to objectively assess and compare the allelopathic soil activity of the tested forage and technical crops (Table 1 and 2).

A specific species response to allelopathic soil activity was observed in the rotation of *L. sativa* in the studied crop rotation pairs.

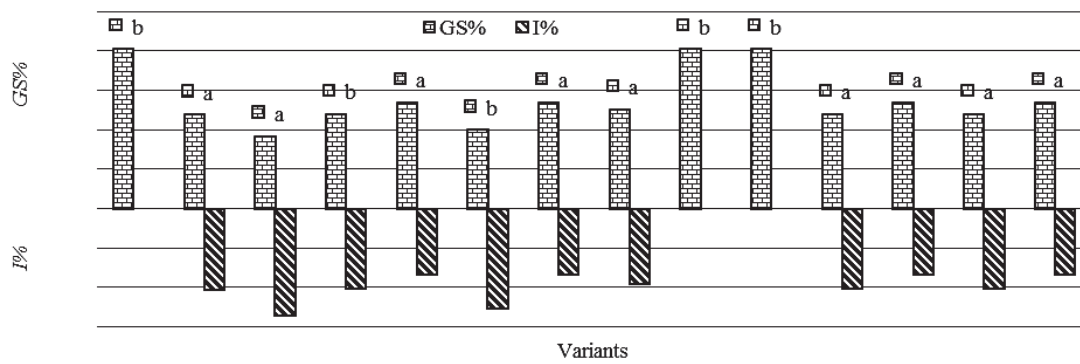
The root length is mainly reduced in *L. sativa* in the Fallow/Sudan grass (P_5) – variant I it is 57.6%, followed by P_1 , P_2 , P_3 , P_7 , P_{10} and P_{12} (*I* from 40.7 to 47.5%) as the differences were statistically proven to be reduced (at $P = 0.05$), and in the crop rotation pairs, P_4 , P_6 , P_8 , P_9 , P_{11} and P_{13} (*I* from 6.8 to 32.2%) were statistically unproven compared to the control variant.

Available soil samples from rotation pairs have a statistically proven depressing effect (*I* of 38.2 to 67.6%) on the growth of the *L. sativa* hypocotyls. Exceptions to the described dependence are found in the variants Fallow/Sudan grass P_5 and Sudan grass/Vetch-oat mix P_9 , as the differences are statistically unproven, compared to the control variant.

Similar results are obtained by monitoring the inhibition index (*I*) during the growth of the seedlings (root + hypocotyl) depending on the type of donor (Table 2).

The dynamic of fresh biomass accumulation in g for one seedlings in the initial growth stages of the test plant (*L. sativa*) depends on the same factors and follows the observed dependencies in terms of seedlings growth, cm. (Tables 1 and 2).

Therefore, the observed differences with respect to the studied parameters can be explained by species differences, as the comparisons between them are done under controlled



Legend: $GS_{\%}$ – germination seeds; *I* – inhibition index

Fig. 1. The allelopathic soil activity of forage and technical crops on seeds germination of *Lactuca sativa* L. under laboratory conditions

Table 2. Allelopathic soil activity of forage and technical crops on initial development of *Lactuca sativa* L. under laboratory conditions

Variants	Indicators														IVS	CA	
	Length, cm							Fresh biomass, g									
	radix	I	DDI	μ	hypokonyl	I	DDI	μ	seedlings	I	DDI	μ	radix	I			DDI
Control	5.9b			0.00	3.4b			0.00	9.3d			0.00	0.020cde			0.00	7.5
P_1	3.1a	47.5	-1.8	-0.13	1.4a	58.8	-1.27	-0.18	4.5bc	51.6	-1.6	-0.15	0.015abc	25.0	-3.9	-0.06	2.1
P_2	3.5a	40.7	-2.2	-0.10	1.5a	55.9	-1.37	-0.16	5.0bc	46.2	-1.8	-0.12	0.016abc	20.0	-5.0	-0.04	1.8
P_3	3.1a	47.5	-1.8	-0.13	1.1a	67.6	-1.00	-0.23	4.2abc	54.8	-1.4	-0.16	0.015ab	25.0	-3.9	-0.06	2.0
P_4	4.0ab	32.2	-3.0	-0.08	2.1a	38.2	-2.33	-0.10	6.1bc	34.4	-2.7	-0.08	0.019e	5.0	-21.9	-0.01	3.3
P_5	2.5a	57.6	-1.3	-0.17	2.4ab	29.4	-3.23	-0.07	4.9abc	47.3	-1.8	-0.13	0.014ab	30.0	-3.2	-0.07	4.0
P_6	4.0ab	32.2	-3.0	-0.08	1.7a	50.0	-1.62	-0.14	5.7bc	38.7	-2.3	-0.10	0.019e	5.0	-21.9	-0.01	3.1
P_7	3.1a	47.5	-1.8	-0.13	1.6a	52.9	-1.49	-0.15	4.7ab	49.5	-1.7	-0.14	0.015ab	25.0	-3.9	-0.06	2.4
P_8	5.5b	6.8	-16.0	-0.01	1.3a	61.8	-1.17	-0.19	6.8bc	26.9	-3.6	-0.06	0.013a	35.0	-2.6	-0.09	5.5
P_9	5.5b	6.8	-16.0	-0.01	2.5ab	26.5	-3.66	-0.06	8.0cd	14.0	-7.5	-0.03	0.019e	5.0	-2.6	-0.09	6.5
P_{10}	3.5a	40.7	-2.2	-0.10	1.2a	64.7	-1.08	-0.21	4.7abc	49.5	-1.7	-0.14	0.015ab	25.0	-3.9	-0.06	2.3
P_{11}	4.0ab	32.2	-3.0	-0.08	2.4a	29.4	-3.23	-0.07	6.4bcd	31.2	-3.0	-0.07	0.019e	5.0	-21.9	-0.01	3.4
P_{12}	3.5a	40.7	-2.2	-0.10	1.1a	67.6	-1.00	-0.23	4.6a	50.5	-1.6	-0.14	0.014ab	30.0	-3.2	-0.07	2.2
P_{13}	4.0ab	32.2	-2.89	-0.08	2.1a	38.2	-2.33	-0.10	6.1bcd	34.4	-2.7	-0.08	0.017abc	15.0	-6.9	-0.03	3.3

Legend: I – Index of inhibition; DDI – Dynamic Development Index; μ – Growth rate and accumulation of fresh biomass per seedling; SVI – seedlings vitality; CA – Alometry coefficient

conditions, which determines a relatively higher allelopathic potential in the variants $P_1, P_2, P_3, P_7, P_{10}, P_{11}$ and P_{12} , where one of the components in the crop rotation pair is a Sorghum species (Sorghum for grain, Sudan grass and Sugar broom) and the lowest in the case of Wheat/Sugar beet. Similar results are reported by Dayan et al. (2009), Jesudas et al. (2014), according to which Sorghum species have a high allelopathic potential that is determined by the root releases of sorgoleone-oil exudate, containing a mixture of benzoquinone lipids (Czarnota et al., 2003; Dayan et al., 2009; Uddin et al. 2014). There is also information on the presence of differences in the allelopathic potential in species of Sorghum (Weston et al., 2013).

The performed mathematical and statistical analyzes show that the studied variants have a retentive or inhibitory effect on the growth of seedlings in test plants (*L. sativa*) (I from 14.0 to 54.8%), decrease the growth rate (μ) (from 0.06 to -0.23) and the accumulation of fresh biomass (μ -0.01 ÷ -0.09), the development index (DDI from -1.4 to -7.5 and -2.6 to -21.9) and vitality (SVI from 1.8 to 7.5), and the allometry coefficients (CA) decreased from 0.3 to 1.7 times compared to the control variant (Fig. 2).

The complex assessment of the soil's allelopathic potential in crop rotation pairs of forage and technical crops by the Growth Index of test plants (*L. sativa*) can be conventionally ranked in the following ascending order: Sugar beet/Vetch-oat mix (89.6%) → Sudan grass/Vetch-oat mix (86.0%) → Vetch-oat mix/Sugar beet (73.1%) → Alfalfa/Sudan grass (45.8%) → Stevia/Grain sorghum (43.7%) → Grain sorghum / Sugar beet (40.5%) → Sugar beet/Sudan grass (31.3%) → Vetch-oat mix/Sudan grass (30.0%) → Sugar broom/Grain sorghum (29.3%) → Wheat/Sudan grass (26.7%) → Grain sorghum/Grain sorghum (24.5%). The total allelopathic potential ranges from 0.1 to 0.8. With the highest total allelopathic potential may be conventionally identified crop rotation units with the participation of species of the genus Sorghum *OAP* is 0.5 and relatively lower in P_9 Sudan grass/Vetch-oat mix, respectively, *OAP* 0.1. The observed differences can be explained by the likely releases of allelochemicals from the root system, which accumulate in the rhizosphere soil area, which also determines the differences in the donor inhibiting effect on the test plants.

Conclusions

Allelopathic soil activity was established of certain forage and technical crops (Grain sorghum, Sudan grass, Sugar broom, Wheat, Alfalfa, Vetch-oat mix, and Sugar beet) grown in rotating pairs using the test plant *Lactuca sativa* L.

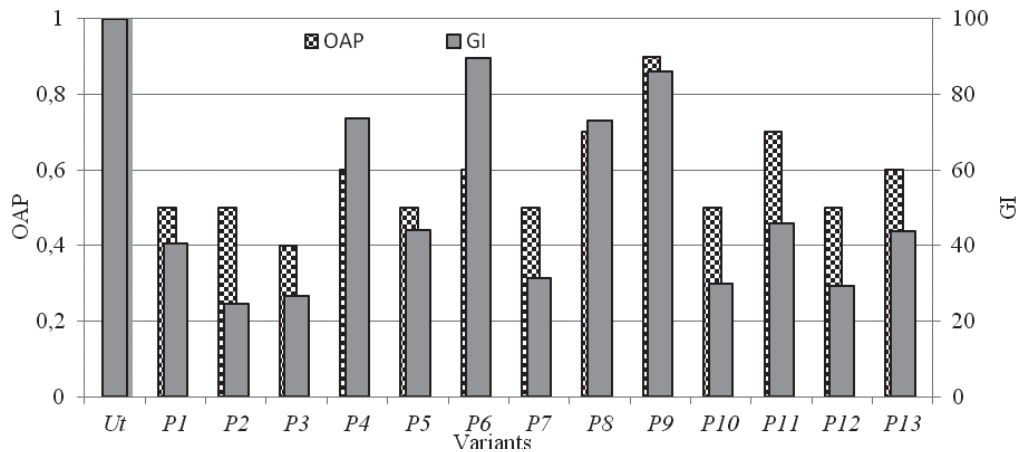


Fig. 2. Developmental index (GI) of test plant (*Lactuca sativa* L.) depending on the allelopathic soil activity and the overall allelopathic potential (OAP) of some forage and technical crops growing in rotation pairs

The greatest inhibitory effect on sprouting seeds and *Lactuca sativa* L. growth was found in the variants with the participation of Sugar beet and Sorghum species variants (Grain sorghum, Sudan grass and Sugar broth), and the differences being statistically proven to be reduced ($P = 0.05$) compared to the control variant.

Depending on the inhibitory effect on the initial development of *Lactuca sativa* L., the allelopathic effect of the tested forage and technical crops was determined, which can be ranked in the following ascending order: Sugar beet/Vetch-oat mix (89.6%) → Sudan grass/Vetch-oat mix (86.0%) → Vetch-oat mix/Sugar beet (73.1%) → Alfalfa/Sudan grass (45.8%) → Stevia/Grain sorghum (43.7%) → Grain sorghum/Sugar beet (40.5%) → Sugar beet/Sudan grass (31.3%) → Vetch-oat mix/Sudan grass (30.0%) → Sugar broom/Grain sorghum (29.3%) → Wheat/Sudan grass (26.7%) → Grain sorghum/Grain sorghum (24.5%).

Varieties from the Sorghum species (Grain sorghum, Sudan grass and Sugar broom) have a relatively high allelopathic potential and can be included in selection programs and used for the biological control of weed species.

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