https://doi.org/10.26651/allelo.j/2019-46-2-1213 0971-4693/94 Euro 20.00
Allelopathy Journal 46 (2): 251-264 (March, 2019) *International Allelopathy Foundation* 2019
Table: 6, Figs : 3, Photo : 1

Effects of decomposing biomass of *Festuca arundinacea, Festuca ovina* and *Festuca rubra* lawn cultivars on growth of other lawn grasses

H. Lipińska, A. Kępkowicz*, M. Sykut and I. Jackowska
University of Life Sciences, Lublin 20-950, Poland
E. Mail: akepkowicz@wp.pl, hlipinskapl@gmail.com

(Received in revised form: January 12, 2019)

ABSTRACT

We studied the effects of aboveground biomass (vegetative shoots) of 6-cultivars of *Festuca arundinacea, Festuca ovina* and *Festuca rubra* on growth of other lawn grasses. The shoots were cut and left in the field and determined their effects on the initial growth, root length and seedling height of other lawn grass cultivars-acceptors. The allelopathic properties of donors were assessed in pot culture. The flavonoids and phenolics acids contents were determined in plant samples of each test variety. The *F. ovina* variety 'Pintor' and *F. rubra* 'Olivia' exhibited the highest allelopathic potential. Allelopathic potential of test cultivars depended on the flavonoids and phenolic acids contents in their leaves. Their highest contents were found in leaves of *F. rubra* cultivar 'Olivia'; the highest contents of phenolic acids were found in leaves of cultivars *F. ovina* 'Pintor', *F. rubra* 'Areta' and 'Olivia' and lowest in the leaves of *F. ovina* 'Espro'. Leaving the cut biomass on the lawn surface should be discouraged, because of its adverse effects on the acceptor plants growth. There was no fertiliser effect of cut biomass left in the lawn.

Key words: Allelopathy, cut lawn grass, flavonoids, *Festuca arundinacea*, *Festuca ovina* and *Festuca rubra*, lawn cultivars, phenolics acids, potential, seedlings growth.

INTRODUCTION

Lawn mowing is key maintenance measure for the durability of lawns. The lawn is mowed few dozen times in growing season depending on the grass type (12,23). After mowing, the cut biomass can be used as compost or mulch. According to common belief, leaving the cut biomass in lawn, adds some nutrients after its decomposition i.e. it increases the soil fertility and also solves the problem of disposal of biomass. However, as per allelopathy literature, the aboveground parts of grasses (e.g. leaves, stems) are rich in many water-soluble allelopathic compounds. These compounds are leached by water or during the biomass decomposition and affects the plants (21,22,27). We assumed that the aboveground biomass (left after the cutting) can have both positive and negative allelopathic impacts on the growth and development of other sward components and consequently, its floristic composition and ornamental value.

The lawns, often consists of multiple species (16). It is important to identify the reasons for the change in their floristic composition and deterioration of aesthetic value. With high aesthetic value, the lawn cultivars of *Festuca rubra* and *Festuca ovina* are important components of seed mixtures to establish various types of lawns in Poland, Western Europe and elsewhere. The lawn cultivars of *F. arundinacea*, particularly are used for the turfing of areas (Photo 1).

*Correspondence author, [1]Department of Grassland and Landscape

Photo 1. The test donors *Festuca arundinacea, Festuca rubra* and *Fectuca ovina*

This study aimed to assess the effects of mowed aboveground vegetative shoots of selected lawn cultivars of *Festuca arundinacea*, *Festuca ovina* and *Festuca rubra*, placed on the sandy substratum, on the initial growth of other lawn cultivars, commonly used in seed mixtures of lawns.

MATERIAL AND METHODS

The studies were done in pots (dia 16.5 cms and depth 30 cms, filled with 3 kg quartz sand) in Department of Grassland and Landscape, University of Life Sciences, Lublin, in growing seasons of 2010-2014. The experimental treatments were: 6 lawn cultivars of 3 species of *Festuca* grasses as Donors and following cultivars, commonly sown in lawns, were the Acceptors as under:

Donor lawn spp.	**Receptor lawn spp.**
Festuca arundinacea (*Fa*) 'Asterix'; *Festuca ovina* (*Fo*) 'Espro' and 'Pintor' as well as *Festuca rubra* (*Fr)* 'Areta', 'Nimba' and 'Olivia'	*Agrostis capillaris* 'Niwa', *Festuca arundinacea* 'Asterix', *Festuca ovina* 'Espro', *Festuca rubra* 'Areta', *Lolium perenne* 'Stadion' and *Poa pratensis* 'Bila'

These Donor cultivars are more persistent and resilient to unfavourable conditions (27).

Donor biomass

In biotest we determined the effects of fresh cut, above-ground, vegetative donor shoots placed on substrate (150 $g \cdot pot^{-1}$i.e. equal to biomass left in the lawn surface after mowing) on seedling emergences, root lengths and heights of acceptors. In control no biomass was added on the substrate surface.

The donor biomass was obtained from the monoculture plots from the field experiment at Research Station, Sosnowica (Longitude 23.0914, Latitude 51.521, mean height above sea level - 154 m, annual rainfall - 160 mm, max temp - 20,7^{o}C, min temp - 5,9^{o}C). When the plants were 8 cms tall, they were cut at 4 cms height. The plant material was washed with running water to remove soil remnants and other impurities, dried in hot air even at 80 ^{o}C (for 3 days in laboratory) and cut into 2 mm pieces. During the study period (at the end of each vegetation season), soil samples were taken from the turfs of field experiment sites: A : Those where biomass was left on the surface, and B : Those where biomass was removed immediately after mowing.

Bioassays

The experiment was done in completely randomized design, with three repetitions, using the Root Exudates Recirculating System modified by authors (26). The biotest was repeated four times each year. The investigation was done in climate controlled laboratory, [12-h (7.00 am to 7.00 pm) artificial light with a SON-T Agro type high pressure output lamp (average light intensity of approx. 3000 lux), Air temperature : 22 and 25°C].

Twenty seeds of species (acceptors) were sown per pot. These plants were watered daily with 100 ml solution of distilled water + Hoagland's medium-2. The test parameters (seedling emergences, root lengths and heights) of acceptors of *A. capillaris* were determined after 10 days, *L. perenne* and *F. arundinacea* after 14, *F. ovin*a and *F. rubra* after 21, and *P. pratensis* after 28 days (13).

Chemicals analysis

Flavonoids and phenolic acids content were determined in samples of each test cultivar (Donor). The total flavonoids content was analysed by High Performance Liquid Chromatography (HPLC), while the phenolic acids by Ultra Performance Liquid Chromatography (UPLC); the analyses were done at Biochemistry Institute of IUNG PIB, Puławy.

HPLC analysis. To determine the flavonoids, methanol extracts (0.5 g material and 20 ml of 80 % methanol to HPLC) were prepared, then the extract was evaporated, the residue was dissolved in water and loaded to the preparative RP18 column (2 x 35 cms). Conditions of separation: Stationary phase RP 18 (4 x 250mm, 10 µm), Mobile phase - linear gradient state, Eluent A - 1% H_3PO_4, Eluent B - 40% acetonitrile in 1% H_3PO_4, Linear gradient 0-100% B in 70 min, temperature 50^{o}C, Flow 1 ml/min, DAD detector - detection at 228.8 nm. Based on calibration curves for routine standard, flavonoid content was calculated and expressed in mg $\cdot g^{-1}$ of dry matter.

UPLC-MS analysis. The grass samples were frozen, lyophilised and grounded. 100 mg plant material was eluted with 80% MeOH in a Dionex ASE 200 extractor (100˚C, 1500 psi, 3 static cycles). Methanol was evaporated from the extract and residue was dissolved in water. It was loaded to an RP-18 microcolumn, stabilised in advance with methanol and distilled water. To remove carbohydrates, the microcolumn was washed with 1 ml H_2O, and the fraction with phenolic acids was removed from the microcolumn with 4 ml of 40 % MeOH. The phenolic fraction obtained was evaporated and quantitatively dissolved in 1 ml of 40 % MeOH for the UPLC-MS analysis. Phenolic acids (protocatechuic acid, 4-hydroxy-benzoic acid, vanillic acid, caffeic acid, syringic acid, p-Coumaric acid, ferulic acid, and sinapinic acid), were determined with Waters ACQUITY UPLC chromatography system coupled with a Waters TQD mass spectrometer in SRM mode (single reaction monitoring), negative ionisation. Phenolic acids were separated on an ACQUITY UPLC HSS C18 column (1.0 x 100 mm, 1.8 µm) at 30˚C. The 0.1% HCOOH-MeCN gradient was used.

The soil's pH (PN-ISO 10390:1997) and content of bioavailable phosphorus (PN-R-04023:1996), potassium (PN-R-04022:1996 + Az1:2002) and magnesium (PN-R-04020:1994 + Az1:2004) were determined (9). Soil reaction was determined (pH_{KCl}) in 1 mol KCl dm^{-3}; phosphorus and potassium using the Egner-Riehm (DL): phosphorus by colorimetric method, potassium by flame photometry and magnesium after extraction of

0.0125 mol $CaCl_2$ dm^{-3} from soil, using the Atomic Absorption Spectrometry (AAS) method. These analyses were done in Chemistry laboratory, Agricultural Station, Lublin.

Statistical analysis: The results were processed statistically using the SAS v.91 program, with the use of variance analysis and Tukey's test for $\alpha \leq 0,05$. Mean values in the columns between which no statistically significant differences occurred are marked with the same letter.

RESULTS AND DISCUSSION

Biotest

The above-ground, cut vegetative shoots of turf grass cultivars (donors) placed on sandy substrate had significant impact on the initial growth and development of tested acceptors. The disruptions of the properties of cytoplasmic membranes in enzymatic systems or cellular metabolism occurring at this stage can disrupt many life processes such as the fluid and mineral balance, photosynthesis, breathing and growth of plants (34,44). In consequence, species whose initial growth has been weakened by allelopathic substances can be displaced from communities, including grass communities, by species less sensitive to these substances (21,22), thus influencing the durability and aesthetic value of lawn (23,27). The allelopathic substances released from the decomposing, above-ground, vegetative shoots inhibited the emergence of tested plants (Table 1). Young plants are very sensitive to allelopathic substances, whose contents decreases with increase in plants age (14,26).

Table 1. Inhibitory influences of cut vegetative shoots of lawn grass cultivars (Donors) placed on the substrate and in control (substrate without leaves) on the seedlings emergence of Acceptor plants

Acceptor (species/cultivar)	Control	Substrate with donors leaves					
		F. arundinacea cv	*F. ovina* cv		*F. rubra* cv		
		“Asterix”	“Espro”	“Pintor”	“Areta”	“Nimba”	“Olivia”
A. capillaris “Niwa”	74b	49a	48a	49a	44a	43a	33a
F. arundinacea “Asterix”	83a	67a	72a	63a	72a	63a	72a
F. ovina “Espro”	94d	83cd	80cd	50ab	69c	67bc	44a
F. rubra “Areta	95b	73a	68a	69a	66a	82ab	74a
L. perenne “Stadion”	85c	49a	69bc	61ab	68bc	67ab	61ab
P. pratensis “Bila”	81d	42a	67cd	50ab	53abc	72d	63bc

The same letters indicate the lack of significant differences between mean values in the particular columns
cv: cultivar

Seedlings emergence: The *F. ovina* ‘Pintor’ and *F. rubra* ‘Olivia’ cultivars decreased the emergence of acceptors plants, except that of *F. arundinacea*. The *F. ovina* ‘Pintor’ strongly inhibited the seedlings emergence of *F. ovina* ‘Espro’ (46 % inhibition) than control. While the donor *F. rubra* ‘Olivia’ caused inhibition in *A. capllaris* (55 %) and *F. ovina* (53 %) (Fig. 1). The *F. arundinacea* ‘Asterix’ and *F. rubra* ‘Areta’ cultivars significantly inhibited the seedlings emergence of *A. capillaris, F. rubra and P. pratensis*, among others. The *F. arundinacea* 'Asterix' inhibited the emergence of *P. pratensis* by 48% and *L. perenne* by 42 % than control. *Festuca rubra* 'Areta' on the other hand, caused 40 % inhibition in seedlings emergence of *A. capillaris.* The *F. ovina* 'Espro' and *F. rubra* 'Nimba' cultivars were less inhibitory to the emergence of the acceptors. Among acceptors, *A. capillaris* was most sensitive to all donors, its emergence was significantly lower than control. *F. arundinacea* seedlings emergence was least sensitive to all treatments.

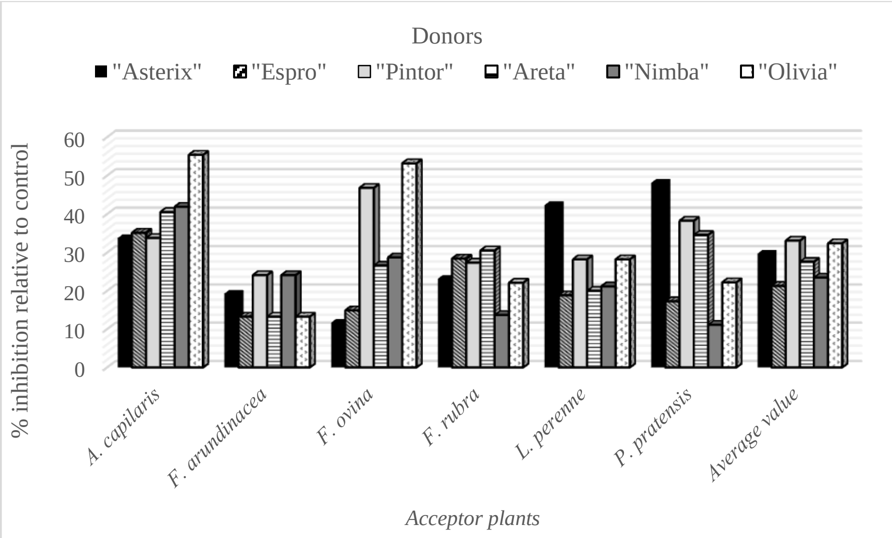

Figure 1. Inhibitory (%) effects of Donor on the seedling emergence of Acceptor plants over the control

Root length: When assessing the impact of lawn grass cultivars (donors) on the root length of acceptor seedlings, the *F. arundinacea* 'Asterix', *F. ovina* 'Pintor' and 'Olivia' *F. rubra* cultivars had the highest inhibitory allelopathic potential (Table 2). The *F. arundinacea* 'Asterix' reduced the roots length of *F. ovina* (48 %), *P. pratensis* (33 %) than control (Fig. 2). The *F. arundinacea* cultivar only inhibited the root growth of *L. perenne.* The *F. ovina* 'Pintor' donor inhibited the seedling root growth of *A. capillaris* (23 %) to *F. ovina* (52 %) than control. The *F. rubra* 'Olivia' decreased the *F. ovina* roots length (52%) than in control (Fig. 2). Among the donors studied, the *F. ovina* 'Espro' and *F.* rubra 'Nimba' were least inhibitory to roots length (Fig. 2). The allelopathic effect of decaying grass biomass is conditioned by the sensitivity of acceptors (25). The *A. capillaris* as acceptor was the most sensitive. In all treatments, its roots were shorter than control treatments. The *F. ovina* was very sensitive. The only exception was that its root length was similar to control, when the donor was the same variety (*F. ovina* 'Espro'). On the other hand, *F. arundinacea* was not very sensitive to substances released from the decomposing leaves of donors (except for *L. perenne*), because of its largest seed size among the species studied. Large seeds are far less sensitive to the impact of allelopathic substances than small seeds (32).

Table 2. Inhibitory effects of cut vegetative shoots of lawn grass cultivars (Donors) placed on the substrate and in control (substrate without leaves) on the roots length of Acceptor plants

Acceptor (species/cultivar)	Control	Substrate with donors leaves					
		F. arundinacea cv	*F. ovina* cv		*F. rubra* cv		
		"Asterix"	"Espro"	"Pintor"	"Areta"	"Nimba"	"Olivia"
A. capillaris "Niwa"	1.3b	1.0a	0.9a	1.0a	1.1a	0.8a	0.9a
F. arundinacea "Asterix"	1.8ab	1.8ab	2.1b	1.2a	2.0b	1.7ab	1.7ab
F. ovina "Espro"	2.3b	1.2a	2.0b	1.1a	1.3a	1.27a	1.1a
F. rubra "Areta	3.0c	2.6abc	2.2ab	2.1ab	1.8a	2.3abc	2.2ab
L. perenne "Stadion"	2.3b	1.7a	3.1c	3.1c	3.3cd	3.8d	2.4b
P. pratensis "Bila"	1.4b	0.9a	1.3b	1.0a	1.1a	1.5b	1.0a

The same letters indicate the lack of significant differences between mean values in the particular columns
cv: cultivar

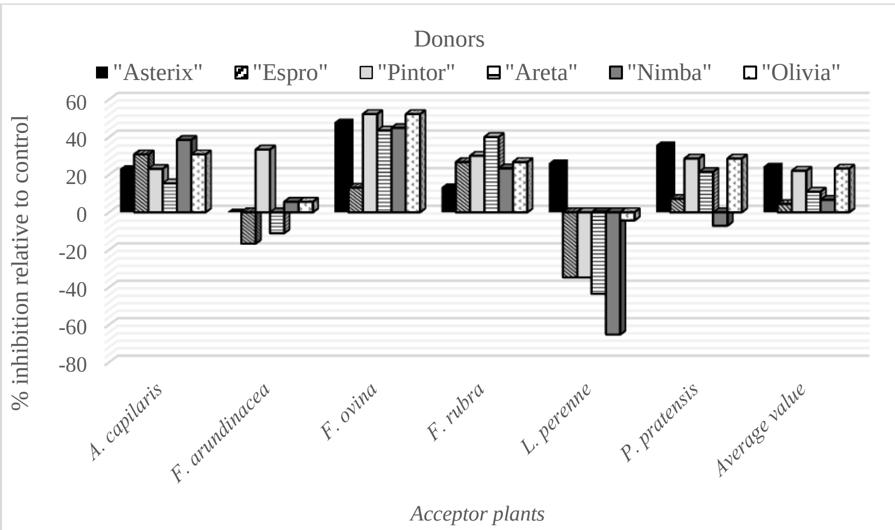

Figure 2. Inhibitory/stimulatory (%) effects of Donor on the root growth of Acceptor plants over the control

Seedling height: Among the parameters assessed, the acceptor seedlings height varied least under the influence of cut and decomposing aboveground vegetative shoots of donors. This is confirmed by the fact that the variable reactions of acceptors depends on their development phase, concentration and source of allelopathic substances (11). In decomposing biomass, its biological activity depends on the degree and duration of its decomposition, it is higher in beginning than in final period (31). This is confirmed by the results, which indicate that greater inhibitory effects occurred during the roots growth rather than the aboveground shoots growth of the acceptors. A greater sensitivity of roots (than aboveground shoots) to allelopathic substances is known (17). In biotests, the *F. ovina* 'Pintor' proved strong inhibitor (Table 3). The seedling height of *L. perenne* was not reduced by the leaves of this cultivar placed on the sandy substrate. *F. rubra* 'Olivia' also significantly inhibited the seedling height (Fig. 3). Under the influence of this donor, the seedlings of *A. capillaris, F. ovina* and *P. pratensis* were 20-27% lower than in control treatments. The investigation also proved stimulatory effects of donors. The *F. ovina* 'Espro', has great influence on the seedlings of all acceptors than in control (76% higher in *P. pratensis*). The *F. arundinacea* 'Asterix' increased the height of acceptor seedlings (except *A. capillaris*) than control. It showed that stimulatory effects may not be due to increase in soil fertility but due to decomposing biomass and the shorter persistence of phytotoxic substances. Thus allelopathic effects may be due to short persistence of simple phenolic acids, rather than compounds which degrade with difficulty (18). Among the acceptors tested, the *A. capillaris* seedlings were most sensitive to the substances released from the decomposing shoots, while the seedlings of *L. perenne* were least sensitive.

Table 3. Inhibitory influences of cut vegetative shoots of lawn grass cultivars (Donors) placed on the substrate and in control (substrate without leaves) on the seedlings height of Acceptor plants

Acceptor (species/cultivar)	Control	Substrate with donors leaves					
		F. arundinacea cv	*F. ovina* cv		*F. rubra* cv		
		"Asterix"	"Espro"	"Pintor"	"Areta"	"Nimba"	"Olivia"
A. capillaris "Niwa"	2.2d	1.5ab	2.3d	1.7c	1.5bc	1.3a	1.6bc
F. arundinacea "Asterix"	7.8ab	9.5c	8.7bc	7.6ab	7.5ab	6.1a	8.9bc
F. ovina "Espro"	5.8bc	6.4c	6.0bc	4.2a	6.4c	5.6bc	4.4a
F. rubra "Areta	7.8a	9.5b	8.7ab	7.6a	7.5a	8.9ab	7.8a
L. perenne "Stadion"	6.0a	6.8ab	7.2ab	6.8ab	8.0b	6.9ab	6.8ab
P. pratensis "Bila"	3.0b	3.2b	5.3e	2.1a	2.4a	4.9d	2.4a

The same letters indicate the lack of significant differences between mean values in the particular columns
cv: cultivar

We found variable allelopathic potential of the studied donors plants. The *F. rubra* 'Nimba' was least inhibitory to the emergence, root length and seedling height of the acceptors, while the *F. rubra* 'Olivia' and *F. ovina* 'Pintor' were most inhibitory. The significant allelopathic potential of these species is already known (3). *Festuca ovina* and *F. rubra* - turf grasses (commonly used in USA and Europe) are significantly inhibitory to *D. sanguinalis*, *T. repens* and *T. officinale*, etc. Studies by Majchrzak (29) and Lipińska *et al*. (27) also indicated adverse impacts of the proximity of *F. rubra* on other plant species (*Triticum aestivum* L. and *Secale cereale* L., *Agrostis capillaris* and *Poa pratensis*, respectively). The *F. arundinacea* 'Asterix' was also very allelopathic to selected acceptors (*A.capillaris, L.perenne* and *P. pratensis,* especially). Its allelopathic activity to other plant species has also been shown (4,45). Lipińska (20), reported that water extracts from *F. arundinacea* leaves inhibited the initial growth of grasses and legumes, while, Bertoldi *et al.* (4), found that alcohol extracts from *F. arundinacea* biomass considerably inhibited the seed germination and root growth of *L. sativa.* The hypothesised allelopathic activity of this species has also been confirmed (10,35).

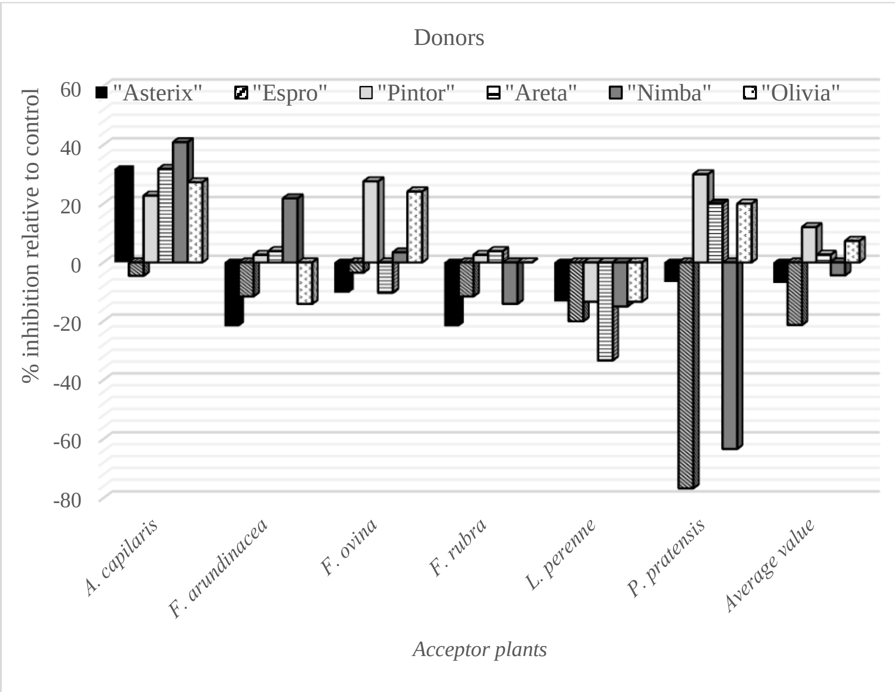

Figure 3. Inhibitory/stimulatory (%) effects of Donor on the seedling growth of Acceptor plants over the control

Chemicals

The phenolic acids and flavonoid contents were determined in leaves of turf grass cultivars. These compounds are major group of secondary metabolites with great diversity and broad spectrum of impacts (8,42). Although they are present in all plant tissues, their greatest amounts occur in leaves, roots and plant residues (7). The phenolic acids and flavonoids contents in donor leaves were variable. The fundamental differences in species' and cultivars' ability to synthesise the allelochemicals and thus their impact, as found in this study are consistent with other studies (19).

The highest flavonoid content was found in *F. rubra* 'Olivia' > *F. rubra* 'Nimba' > *F. ovina* 'Pintor' and *F. arundinacea* 'Asterix'. The lowest flavonoids content occurred in leaves of *F. rubra* 'Areta' and *F. ovina* 'Espro'. The highest (total) phenolic acids content was found in leaves of *F. ovina* 'Pintor'; it was moderate in leaves of *F. rubra* 'Areta' and 'Olivia'. The lowest phenolic acid content was in leaves of *F. ovina* 'Espro' (Table 4).

Table 4. Total flavonoids content (expressed as rutin content in mg $\cdot g^{-1}$ of dry matter) and phenolic acid content ($\mu g\ g^{-1}$ of dry matter) in the aboveground shoots of the lawn grass cultivars (donors)

Flavonoids, Phenolic acids	Substrate with donors leaves					
	F. arundinacea cv	*F. ovina* cv		*F. rubra* cv		
	"Asterix"	"Espro"	"Pintor"	"Areta"	"Nimba"	"Olivia"
Flavonoids	0.921	0.698	0.935	0.384	1.045	2.275
Phenolic acids						
Protocatechuic acid	0.5	0.31	0.66	0.82	0.52	0.77
4-Hydroxy-benzoic acid	-	-	0.67	0.67	-	-
Vanillic acid	1.14	0.43	2.53	2.5	2.36	1.49
Caffeic acid	1.46	1.57	1.23	3.14	2.09	4.31
Syryngic acid	1.25	0.65	2.69	2.27	2.42	2.13
p-Coumaric acid	19.49	9.82	39.64	21.93	21.59	23.14
Ferulic acid	11.24	9.75	13.16	14.16	9.94	12.57
Sinapinic acid	0.47	0.47	0.95	0.75	0.78	0.67
Total	35.55	23	61.53	46.24	39.7	45.08

cv: cultivar

Among the phenolic acids identified in leaves of cultivars studied, the p-Coumaric acid was highest in leaves of *F. ovina* 'Pintor' (Table 4) and is very allelopathic (1). This was followed by ferulic acid, whose highest content was found in leaves of *F. rubra* 'Areta' followed by *F. ovina* 'Pintor'. Washed out of the dead shoots, ferulic acid is highly phytotoxic with caffeic acid (1,44). The allelopathic potential of coumaric and ferulic acid was also confirmed by Wu *et al.* (39), who found inhibition of root growth of *Poa annua* seedlings under the influence of these acids extracted from *Bouteloua dactyloide*. The inhibitory effects of p-Coumaric acid on the growth of *Echinochloa cruss-galli* was shown by Xu *et al.* (40). The highest content of 4-Hydroxybenzoic acid, vanillic acid, syringic acid, and sinapinic acid was found in leaves of *F. ovina* 'Pintor'. The highest content of caffeic acid was found in leaves of *F. rubra* 'Olivia', and the highest content of protocatechuic acid was found in leaves of *F. rubra* 'Areta'. Even small amounts of these compounds can reduce the bioavailability of mineral elements (Ca, Mg, P, K *et.al.*) (24,25), as well as the activity of many biological processes, thereby slowing down the growth and development of plants (*L. sativa, Melaleuca ericifolia i Poa labillardierei* and *F. arundinacea, S. sudanense*) (36,37). They are present both in plant tissues and in soil, where the plants are cultivated (5). Secondary metabolites, particularly phenolic acids, are also present in many cultivated and wild-growing grass species (15,20,33,38,43). The existence of areas free of plants, as well as the reduced diversity of species in the neighbourhood of *F. rubra*, may be due to presence of allelopathic compounds (6). Owing to phenolic acids, *F. arundinacea* (cultivars infected with *Neotyphodium coenophialum*) modifies the rhizosphere, thus affecting the growth and development of other components in sward (30,45). The presence of phenolic acids in cultivated plants can reduce the germination of many weeds (4,41). The phenolic acids exert negative impact on plants (1,2).

There were large differences in content of studied compounds between the cultivars of particular species. The cultivars of *F. rubra* showed significant variation in flavonoids content. It was lowest in the leaves of 'Areta" cultivar compared to 'Oliva' cultivar. There were considerable differences in the phenolic acid contents in leaves between the cultivars of *F. ovina* ‘Pintor’, it was 3-times high than in ‘Espro’.

In evaluating the relationship between the total flavonoid and phenolic acid contents in leaves of tested donors and their allelopathic potential, [% inhibition (relative to control) of a given parameter (regardless of acceptor)] the greatest correlation was found in *F. ovina* cultivars ‘Pintor’ (Table 5). The leaves of this variety contained the highest content of phenolic acids and high content of flavonoids. Its mixing with sand caused the greatest inhibition (among tested donors) in germination and seedling heights and roots elongation of acceptor. High correlations between the flavonoid and phenolic acid contents in leaves and their allelopathic potential were also found in *F. rubra* cultivar ‘Olivia’.

Table 5. Flavonoid and phenolic acid contents in above-ground vegetative shoots of lawn varieties of grass (donors) and their allelopathic potential (% inhibition relative to control)

Donors	Total content of		Donor seedlings allelopathic inhibition (%)		
	Flavonoids ($mg \cdot g^{-1}$ s.m.)	phenolic acids ($\mu g \cdot g^{-1}$ s.m)]	Germination	Root lengths	Heights
A. capillaris “Niwa”	0.921	35.55	29.7	24.3	-7
F. arundinacea “Asterix”	0.698	23.00	21.3	4.4	-21
F. ovina “Espro”	0.935	61.55	33.1	22.1	12
F. rubra “Areta	0.384	46.25	27.6	10.9	2.6
L. perenne “Stadion”	1.045	39.70	23.4	6.6	-4
P. pratensis “Bila”	2.275	45.07	32.4	23.2	7.3

The negative impacts of decaying, above-ground, turf grass shoots, identified in laboratory conditions may be related to allelopathic effects. However, it is not clear that effects recorded under controlled conditions will also occur in the fields. Nevertheless, they allow better understanding of plant interactions (positive or negative) which determines the inter-compatibility of different species or even cultivars. Use of this knowledge in selection of cultivars for mixtures and in successive stages of establishment and use of lawn will be beneficial for the durability of components and the aesthetic qualities of lawns (23,28).

Physico-chemical properties of soil

There was no impact of cut, above-ground biomass left on the lawn surface on soil pH, in contents of bioavailable phosphorus, potassium or magnesium. The soil pH under lawns of studied turf grass cultivars was acidic or slightly acidic and did not significantly differ between the studied cultivars, nor between the tested lawns: A - with the cut biomass left on the surface, and B - from which the biomass was removed immediately after mowing (Table 6). Large differences in P, K and Mg levels were found between the studied cultivars, while the differences between Ai B treatments occurred only in some treatments. The phosphorus content in soil ranged from 7.5 to 14.3 mg (low to medium). Only on lawns with biomass left on them (A) of cultivars *F. arundinacea* 'Asterix', *F.*

ovina 'Pintor' and *F. rubra* 'Areta', the phosphorus content was medium than on lawns of same cultivars but from which the biomass was removed (B). The potassium contents of tested samples were high and medium. Leaving cut plant biomass on the lawn did not increase the soil potassium content. Meanwhile, the soil magnesium content in the soil was high in all lawns, except in lawns of *F. ovina* 'Espro' and *F. rubra* 'Olivia', from which cut biomass was removed.

Table. 6. Soil pH and contents of bioavailable phosphorus, potassium and magnesium (mg $100g^{-1}$) under lawns of turf grass cultivars (Field experiment)

Donor (species/cultivar)	Treatment	pH	Content of Bioavailable elements content (mg per 100 g soil)		
			Phosphorus (P_2O_5)	Potassium (K_2O)	Magnesium (Mg)
F. arundinacea “Asterix”	Control	5.32	9.3 (L)	12.7 (H)	4.8 (H)
	Sward cut left on the lawn	5.35	10.6 (M)	12.7 (H)	5.5 (H)
F. ovina “Espro”	Control	4.84	10.3 (M)	13.0 (H)	3.6 (H)
	Sward cut left on the lawn	5.47	10.2 (M)	8.7 (M)	4.3 (H)
F. ovina “Pintor”	Control	5.47	9.6 (L)	16.0 (H)	5.0 (H)
	Sward cut left on the lawn	5.69	14.7 (M)	13.3 (H)	4.4 (H)
F. rubra “Areta”	Control	5.14	8.0 (L)	7.8 (H)	4.1 (H)
	Sward cut left on the lawn	5.89	14.3 (L)	8.0 (M)	4.8 (H)
F. rubra “Nimba”	Control	5.44	9.8 (L)	11.5 (M)	4.8 (H)
	Sward cut left on the lawn	5.06	7.5 (L)	9.9 (M)	4.6 (H)
F. rubra “Olivia”	Control	4.93	12.5 (M)	13.6 (H)	3.8 (M)
	Sward cut left on the lawn	5.20	12.4 (M)	11.6 (M)	4.6 (H)

Control : Sward cut immediately removed from lawn, Nutrients status - L: Low, M: Medium, H: High

CONCLUSIONS

1. The allelopathic potential of tested donors varied and followed the order: *F. rubra* ‘Olivia’ > *F. ovina* ‘Pintor’ > *F. rubra* ‘Nimba’. The allelopathic substances released from the decomposing cut leaves were very inhibitory to seedling emergence than aboveground shoot growth.
2. Among the acceptors, *A. capillaris* was most sensitive > *P. pratensis* > *F. arundinacea* ‘Asterix’ cultivar.
3. The highest flavonoid content was in *F. rubra* ‘Olivia’ cultivar leaves, while, the highest phenolic acid content was in leaves of *F. ovina* ‘Pintor’, *F. rubra* ‘Areta’ and ‘Olivia’ cultivars. The lowest content of these compounds was found in leaves of *F. ovina* ‘Espro’. The highest content of phenolic acids was plant material of all test cultivars was of *p*-Coumaric acid, particularly in leaves of *F. ovina* ‘Pintor’ and ferulic acid in leaves of *F. rubra* ‘Areta’.

4. Owing to the unfavourable allelopathic impact of grass cuttings on the initial growth of acceptors and the absence of any fertilising effect of above-ground biomass, it is advisable not to leave lawn cuttings on the lawn surface.

REFERENCES

1. Almaghrabi, O.A. (2012). Control of wild oat (*Avena fatua*) using some phenolic compounds I. Germination and some growth parameters. *Saudi Journal of Biological Sciences* **19**: 17-24.
2. An, M., Zeng, R.S., Johnson, I.R. and Lovett, J.V. (2003). Modelling aeration effects on plant residue allelopathy. *Allelopathy Journal* **11**: 195-201.
3. Bertin, C., Weston, L.A., Huang, T., Jander, G., Owens, T., Meinwald, J. and Schroeder, F.C. (2007). Grass roots chemistry: *Meta*-tyrosine, an herbicidal non-protein amino acid. *Proceedings*, *National Academy* of *Sciences* **43**: 16964-16969.USA
4. Bertoldi, C., Leo, M., Ercoli, L. and Braca, A. (2012). Chemical profile of *Festuca arundinacea* extract showing allelochemical activity. *Chemoecology* **22**: 13-21.
5. Bi, Y.M., Jiao, X.L, Li,J.F., Tian,G.L., Lu, X., Zhang, X.M. and Gao,W.W. (2018). A comparison of extraction methods of phenolic acids in wheat and American ginseng soil. *Allelopathy Journal* **45**:77-88.
6. Bostan, C. and Moisuc, A. (2009). The study of vegetable extract action of *Lolium perenne* L. on some perennial graminaes chemical composition. *Research Journal of Agricultural Science* **41**: 9-14.
7. Bostan, C., Moisuc, A., Cojocariu, L., Horablaga, M., Horablaga, A and Marian F. (2012).Allelophatic substances and their ability to influence the grasses quality. *Research Journal of Agricultural Science* **44**: 179-186.
8. Bostan, C., Moisuc, A., Radu, F., Cojocariu, L., Horablaga, M. and Sărățeanu, V. (2010). Effect of *Poa pratensis* extracts on growing and development of perennial grasses seedlings. *Research Journal of Agricultural Science* **42**: 372-377.
9. Brodowska, M., Jackowska, I., Brodowski, R., Kurzyna-Szklarek, M., Bojanowska, M. and Lipińska, H. (2018). Soil testing methods. Problems of soil environment changes. *Monografia Naukowa*. Tow. Wyd. Nauk. Libropolis, 70-78.
10. Buer, C.S., Imin, N. and Djordjevic, M.A. (2010). Flavonoids: New roles for old molecules. *Journal of Integrative Plant Biology* **52**: 98-111.
11. Bulut, Y. and Demir, M. (2007). The allelopathic effects of Scots Pine (*Pinus sylvestris* L.) leaf extracts on turf grass seed germination and seedling growth. *Asian Journal of Chemistry* **19**: 3169-3177.
12. Czarnecki, Z and Harkot, W. (2002). Influence of cutting frequency on area sodding of lawn varieties of *Lolium perenne*. *Łąkarstwo w Polsce* **5**: 43- 48.
13. Dorywalski, J., Wojciechowicz, M. and Baritz, J. (1964). *Seed Assessment Methods*. pp 112, PWRiL, Warszawa.
14. Emeterio, L.S., Arroyo, A. and Canals, R.M. (2003). Allelopathic potential of *Lolium rigidum* Gaud. on the early growth of three associated pasture species. *Grass and Forage Science* **59:** 107-112.
15. Fragasso, M., Platani, C., Miullo, V., Papa, R. and Iannucci, A. (2012). Assessment of allelopathic potential of root exudate of wild oat (*Avena fatua* L.) in rhizosphere soil. *Agrochimica* **56:** 120-128.
16. Harkot, W. and Lipińska, H. (2007). Lawns in village adjacent gardens. *Czasopismo Techniczne* **10**: 204-206 (Polish).
17. Ilam, A. and Begum, S. (2011). Evaluation of allelochemical effects of *Hordeum vulgare* extracts. *Bangladesh Research Journal* **5**: 295-305.
18. Kashif, M.S., Cheema, Z.A., Farooq, M. and Anwar-ul-Hassan (2015). Allelopathic interactions of wheat (*Triticum aestivum*) and little seed canarygrass (*Phalaris minor*). *International Journal of Agriculture and Biology* **17:** 363-368.
19. Kovar, P., Vozar, L. and Jančovič, J. (2013). The influence of water extracts of selected turfgrass species on germination and initial growth of *Poa annua* L. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* **74**: 677- 681.
20. Lipińska, H. (2005). Allelopathic effects of grasses and biodiversity of plant communities. *Grassland Science in Europe* **10**: 380-383.
21. Lipińska, H. and Harkot, W. (2005). Allelopathic effects of water leachates of *Poa pratensis* leaves on other grassland spp. *Allelopathy Journal* **16**: 251-260.
22. Lipińska, H. and Harkot, W. (2007). Allelopathic activity of grassland species. *Allelopathy Journal* **19**: 3-36.

23. Lipińska, H., Harkot, W., Czarnecki, Z., Kornas, R., Stamirowska-Krzaczek, E. and Lipiński, W. (2018). The effect of decomposing biomass of the grasses *Festuca arundinacea, Festuca ovina and Festuca rubra* on the species composition and quality of lawns. *Acta agrobotanica* **71:**17-48 DOI 10.5586/aa.1748
24. Lipińska, H. and Lipiński, W. (2009). Initial growth of *Phleum pratense* under the influence of leaf water extracts from selected grass species and the same extracts improved with $MgSO_4 \cdot 7H_2O$. *Journal of Elementology* **14**: 101-110.
25. Lipińska, H., Lipiński, W. and Sykut, M. (2015). Allelopathic potential of water and enriched extracts from the leaves of selected lawn grass species *Fresenius Environmental Bulletin* **24:** 4581-4588.
26. Lipińska, H. and Oleszek, W. (2002). Application of RERS (Root Exudate Recirculating System) for the studies of allelopathic potential of *Poa pratensis*. *Allelopathy Journal* **10**: 39-44.
27. Lipińska, H., Sykut, M. and Harkot, W. (2013). The effects of water extracts from leaves of *Festuca rubra, F. ovina* and *F. arundinacea* on the initial growth and development of other grass species. *Acta Agrobotanica* **66**: 61-70.
28. Lipińska, H., Sykut, M., Kępkowicz, A., Wańkowicz, W., Bieske-Matejak, A., Zachariasz, A., Kornas, R. and Lipiński, W. (2016). The allelopathic impact of the cut aboveground biomass of *Lolium perenne* on the species composition and aesthetic value of lawns. *Annales UMCS*, S. E, **71(3**): 61-72.
29. Majchrzak, L. (2007). Cereals germination in the neighbourhood of grain *Avena Fatua* L. and *Festuca rubra* L.- allelopathic aspect. *Annales UMCS*, S. E. **62**: 185-192.
30. Malinowski, D.P., Belesky, D.P. and Fedders, J.M. (1999). Endophyte infection may affect the competitive ability of a tall fescue grown with red clover. *Journal of Agronomy and Crop Science* **193**: 91-101.
31. Narwal, S.S. (1994). Interactions between plant communities. (In:) *Allelopathy in Crop Production*, pp. 19-161. Scientific Publishers Jodhpur, India.
32. Politycka, B. and Lipińska, H. (2005). Pot cultures: Simple tool and complex problem. *Allelopathy Journal* **16**: 47-62.
33. Saánchez-Moreiras, A.M., Weiss, O.A. and Reigosa-Roger, M.J. (2004). Allelopathic evidence in the *Poaceae*. *Botanical Review* **69**: 300-319.
34. Simon Lebecque, S., Crowet, J-M., Lins, L., Delory, B.M., Jardin, P. Fauconnier, M-L. and Deleu, M. (2018). Interaction between the barley allelochemical compounds gramine and hordenine and artificial lipid bilayers mimicking the plant plasma membranę. *Scientific Reports* **8**:9784. DOI:10.1038/s41598-018-28040-6.
35. Taylor, L.P. and Grotewold, E. (2005). Flavonoids as developmental regulators. *Current Opinion in Plant Biology* **8**: 317-323.
36. Uddin, M.N., Robinson, R.W., Andrew Buultjens, A., Al Harun Md.A.Y. and Shahana Haque Shampa, S.H. (2017). Role of allelopathy of *Phragmites australis* in its invasion processes. *Journal of Experimental Marine Biology and Ecology* **486:** 237-244.
37. Wang, R., Liu, S.W., Xin, X.W., Chen, S., Peng, G.X., Su, Y.J and Song, Z.K. (2017). Phenolic acids contents and allelopathic potential of 10-cultivars of alfalfa and their bioactivity. *Allelopathy Journal* **40:**63-70.
38. Weih, M., Didon, U.M.E., Rönnberg-Wästljung, A.C. and Björkman, C. (2008). Integrated agricultural research and crop breeding: Allelopathic weed control in cereals and long-term productivity in perennial biomass crops. *Agricultural Systems* **97**: 99-107.
39. Wu, L., Guo, X. and Harivandi, M.A. (1998). Allelopathic effects of phenolic acids detected in buffalograss (*Buchloe dactyloides*) clippings on growth of annual bluegrass (*Poa annua*) and buffalograss seedlings. *Environmental and Experimental Botany* **39**: 159-167.
40. Xu, G.F., Zhang, F.D., Li, T., Wu, D. and Zhang, Y. (2010). Induced effects of exogenous phenolic acids on allelopathy of a wild rice accession (*Oryza longistaminata*, S37). *Rice Science* **17**: 134-140.
41. Yansen, F. (2007). The test of allelopathic potential of three species of the genus *Alstonia*. *Journal Akta Agrosia* **101**: 14-22.
42. Zeng, R.S., Mallik, A.U. and Luo, S.M. (2008). *Allelopathy in Sustainable Agriculture and Forestry*. Springer, New York, USA, pp. 411.
43. Zheng, Y. and Li, M. (2018). Autotoxicity of phenolic acids in root exudates of *Andrographis paniculata* (Burm. f.) Ness. *Allelopathy Journal* **45**: 153-162.
44. Zhou, Y.H., Yu, J.Q., Huang, L.F. and Nogues, S. (2004). The relationship between CO_2 assimilation, photosynthetic electron transport and water-water cycle in chill-exposed cucumber leaves under low light and subsequent recovery. *Plant, Cell and Environment* **27**: 1503-1514.
45. Zhu, W. and Shen, Y. (2004). Allelopathic effects of *Trifolium repens* and *Festuca arundinacea* on seedling growth of *Brassica chinenesis*. *Acta Prataculturae Sinica* **13:** 106-111. (Chinese)