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PHYSIOLOGICAL AND BIOCHEMICAL PARAMETERS OF SOIL-PLANT SYSTEM UNDER ALLELOPATHIC STRESS: DIAGNOSTIC ANALYSIS AND CONTROL

The diagnostic analysis of functional state of the soil-plant system under allelopathic stress has been carried out for its optimization. For this purpose, it has been used a number of physiological and biochemical parameters. The influence of winter rape biomass (Brassica campestris L. f. biennis D.C.) as green manure on allelopathic, biochemical and physiological properties of the soil-plant system on an example of perennial plantings of lilac cultivars (Syringa vulgaris L.) of the M.M. Gryshko National Botanical Garden of the NAS of Ukraine collection was studied. Green biomass of winter rape during flowering stage was added into grey forest soil at 3.5 kg/m² on mentioned areas of the arboretum. It was established that the application of winter rape biomass as green manure significantly improved the functional state of the soil-plant system under long-term cultivation of lilac plants. Structural components of the soil-plant system stabilized under the influence of green manure biomass decay products, which positively affected both allelopathic and biochemical soil properties and the physiological state of the lilac plants. There have been qualitative dynamic changes in soil-plant system for the green manure action, which manifested stimulation of growth processes, intensification of humification (by the phenolic acids pool), improving the redox regime, restructuring of component composition of photosynthetic pigments, and eventually increase in adaptive ability of lilac plants. As this trend persisted not only for the direct action of this factor, but also in its after-effect (next growing season after application of green manure biomass) can recommend the use of winter rape as green manure for optimization of soil-plant system under allelopathic stress.

Key words: soil-plant system, green manure, winter rape, lilac, allelopathic stress, allelopathic activity, redox potential, phenolic acids, photosynthetic pigments.

Long-term cultivation of lilacs collection of M.M. Gryshko National Botanical Garden led to allelopathic stress due to accumulation of allelochemicals released from decaying lilac residues in the soil [8, 14].

Since each biological system is a complex, which is manifested in the heterogeneity of its component composition and variability of characteristic features in time and space, there is a need for diagnostics of its functional state of several of the most informative parameters. Such parameters reveal the relation between stability and variability of the phenomenon. One of the goals of the diagnostic analysis of complex systems is the optimization of their functioning [4].

Application of green manure biomass is a well-known manner of the soil-plant system improvement under allelopathic stress [6]. Green manures proved as effective alternative means for conservation and restoration of soil fertility [1, 5].

The plants of *Brassicaceae* have been successfully used as a green manure, including winter rape, thanks to valuable chemical composition of green biomass and their phytosanitary properties [9, 12, 16].

Objective — the diagnostic analysis of the soil-plant system under allelopathic stress through physiological and biochemical parameters for further control and to achieve its optimal functioning.

Material and Methods

Green manure as biomass of winter rape (*Brassica campestris* L. f. *biennis* D.C.) during the flowering stage was added into grey forest soil at 3.5 kg/m² under perennial plantings of lilac cultivars (*Syringa vulgaris* L.) 'Taras Bulba', 'Mme Lemoine', 'Michel Buchner' on areas of the arboretum of M.M. Gryshko National Botanical Garden of the NAS of Ukraine. The soil without green manure biomass was used as control.

The experiment has been carried out for 2 vegetation periods. Plant and soil samples were collected in 1, 3, 6 (the first vegetation period) and 12, 18 (the second vegetation period) months after decay of green manure biomass.

The functional state of the soil-plant system was analyzed on the following physiological and biochemical parameters: allelopathic activity and redox potential of soil, phenolic acids content in soil, composition and ratios of the main photosynthetic pigments in leaves.

Allelopathic activity of soil was studied by Neubauer-Schneider method [2]. 'Poliska 90' cultivar of winter wheat (*Triticum aestivum* L.) was used as the test plant. Redox potential and phenolic acids content in soil were determined according to [3]. The main photosynthetic pigments content in leaves of lilac plants was determined spectrophotometrically [7].

Experimental data were statistically analyzed using the software package Microsoft Excel.

Results

Study of soil allelopathic activity under lilacs cultivars by Neubauer-Schneider method showed positive effects winter rape as green manure (Table 1). Green manure biomass promoted the stimulation of growth processes, the accumulation of dry matter of shoots and roots of test plants.

Should be mentioned that in the first month after the decay of green manure biomass these indices were at or below the control. Obviously, this is due to the accumulation in soil of a large amount of mobile organic substances that are able to detect growth-inhibitory activity.

The increase in the decay duration of green manure contributed to improving the allelopathic state of the soil under lilac cultivars, which persisted for 18 months.

In general, green manure raised shoots growth of test plants by 5—22 % of control, root growth by 7—35 % of control, dry matter accumulation of shoots by 6—27 % of control and the roots by 16—75 % of control depending on the area of cultivation of lilac cultivars.

Thus, the decay products of green manure biomass more influence growth and dry matter accumulation of test plants roots.

Biochemical state of the soil in growing areas of lilac cultivars was assessed by redox potential values (Table 2). The rate of accumulation and composition of organic matter is closely associated with redox processes.

Table 1. **Effect of green manure on allelopathic activity of soil under *Syringa vulgaris* cultivars (test plant — winter wheat), % to control — soil without green manure biomass**

Indices	Months after decay of green manure biomass				
	1	3	6	12	18
Soil under 'Taras Bulba' cultivar					
Shoot length	98.1 ± 2.0	108.1 ± 2.2	122.2 ± 2.4	117.0 ± 2.3	109.0 ± 2.2
Root length	95.2 ± 1.8	120.2 ± 2.4	135.0 ± 2.7	128.1 ± 2.6	120.2 ± 2.4
Shoot dry matter	92.2 ± 1.7	116.9 ± 2.3	126.9 ± 2.5	120.2 ± 2.4	115.1 ± 2.3
Root dry matter	97.5 ± 1.9	134.5 ± 2.7	174.5 ± 3.5	150.1 ± 3.0	135.3 ± 2.7
Soil under 'Mme Lemoine' cultivar					
Shoot length	101.2 ± 2.0	103.8 ± 2.1	113.8 ± 2.3	107.1 ± 2.1	105.0 ± 2.1
Root length	102.0 ± 2.2	107.0 ± 2.2	115.3 ± 2.4	109.2 ± 2.2	112.2 ± 2.2
Shoot dry matter	95.1 ± 1.9	114.1 ± 2.3	125.1 ± 2.5	116.2 ± 2.3	110.1 ± 2.3
Root dry matter	97.2 ± 1.8	120.5 ± 2.4	128.8 ± 2.6	120.1 ± 2.4	115.5 ± 2.4
Soil under 'Michel Buchner' cultivar					
Shoot length	90.1 ± 1.8	105.0 ± 2.0	113.7 ± 2.3	105.0 ± 2.1	102.1 ± 2.0
Root length	101.5 ± 2.0	117.2 ± 2.3	127.1 ± 2.5	122.1 ± 2.4	125.0 ± 2.5
Shoot dry matter	88.1 ± 1.8	107.0 ± 2.1	115.1 ± 2.3	109.5 ± 2.3	106.2 ± 2.1
Root dry matter	93.0 ± 1.7	124.3 ± 2.5	146.8 ± 2.9	130.8 ± 2.6	120.1 ± 2.4

Low or at the control values of the redox potential after 1 month of decay of green manure biomass point out accumulation of mobile products of winter rape decay, which is consistent with the allelopathic activity results (See Table 1).

During the following months of decay of green manure biomass increase in redox potential values of 1.1—1.4 times to control was observed. At the same time direction of redox processes changed towards the weak reduction, that is more favorable to the course of humification, growth, development and the formation of nutrition regime of plants.

Phenolic acids are important precursors of humic substances in soil [15]. At the same time we know that at certain stages of their transformation when phenolic acid is not involved in the processes of humification and are in a free state in soil solution, they can actively participate in allelopathic phenomena and affect the growth of plants [13, 15].

Therefore, the study of qualitative and quantitative content of phenolic acids was the next step in our research.

It was shown that after 6 months decay of green manure biomass phenolic acids amount increased in 1.1—1.2 times to control, mainly due to hydroxycinnamic acids (ferulic and coumaric) (Table 3).

After 18 months of decay of green manure biomass phenolic acids content decreased in 1.3—1.5 times to control, indicating their active involvement in the processes of humification.

Accumulation of phenolic acids in control indicates a violation humification processes in the soil of lilacs growing areas under long-term culture conditions and the possibility of their participation in allelopathic phenomena of plants growth processes inhibition.

We know about the ability allelochemicals affect various physiological processes in plants, including photosynthesis [11]. This prompted us to evaluate the state of the soil — plant system using such informative parameters as content and ratios of photosynthetic pigments.

Significant improvement of allelopathic and biochemical properties of soil under *S. vulgaris* cultivars during decay of green manure biomass affected the state of pigment systems of lilac plants (Table 4).

Application of green manure promoted accumulation of chlorophyll *a* and *b*, and carotenoids. Moreover, the chlorophyll *a/b* ratio decreased by increasing the proportion of chlorophyll *b*. At the same time the values of chlorophyll *a* + *b*/ carotenoids ratio decreased under decay of green manure biomass, indicating the increase in share of carotenoids in relation to chlorophyll.

Accumulation mostly chlorophyll *b* can be considered as a protective reaction aimed at supporting structure of light-harvesting complex of photosystem II under adverse environmental conditions [10].

It is known that carotenoids prevent photodestruction of chlorophyll, contribute to strengthen-

Table 2. **Effect of green manure on redox potential of soil under *Syringa vulgaris* cultivars, mV**

Treatment	Months after decay of green manure biomass				
	1	3	6	12	18
Soil under 'Taras Bulba' cultivar (control)	255.0 ± 5.1	244.0 ± 4.9	275.0 ± 5.5	260.0 ± 5.4	240.0 ± 4.8
Soil under 'Taras Bulba' cultivar + green manure	225.0 ± 4.5	270.0 ± 5.4	310.0 ± 6.2	325.0 ± 6.5	340.0 ± 6.8
Soil under 'Mme Lemoine' cultivar (control)	272.0 ± 5.4	282.0 ± 5.6	260.0 ± 5.1	250.0 ± 5.0	255.0 ± 5.1
Soil under 'Mme Lemoine' cultivar + green manure	260.0 ± 5.2	294.0 ± 5.9	315.0 ± 6.3	340.0 ± 6.8	365.0 ± 7.3
Soil under 'Michel Buchner' cultivar (control)	251.0 ± 5.0	277.0 ± 5.5	281.0 ± 5.6	270.0 ± 5.4	262.0 ± 5.2
Soil under 'Michel Buchner' cultivar + green manure	255.0 ± 5.1	296.0 ± 5.8	310.0 ± 6.2	335.0 ± 6.7	320.0 ± 6.4

ing the antioxidant properties of plants and provide stable functioning of chloroplasts under stress conditions [10]. Therefore the increase in carotenoids and chlorophyll *b* content is an adaptive response to allelopathic stress in this particular case.

To summarize, green manure raised adaptive ability of lilac plants under allelopathic stress.

Conclusions

It was established that the application of winter rape biomass as green manure significantly improved the functional state of the soil-plant system under long-term cultivation of lilac plants.

Structural components of the soil-plant system stabilized under the influence of green manure biomass decay products, which positively affected both allelopathic and biochemical soil properties and the physiological state of the lilac plants.

There have been qualitative dynamic changes in soil-plant system for the green manure action, which manifested stimulation of growth processes, intensification of humification (by the fenolic acids pool), improving the redox regime, restructuring component composition of photosynthetic pigments, and eventually increase in adaptive ability of lilac plants.

Table 3. **Effect of green manure on phenolic acids content in soil under *Syringa vulgaris* cultivars, mg/kg**

Phenolic acid	Treatment					
	Soil under 'Taras Bulba' cultivar (control)	Soil under 'Taras Bulba' cultivar + green manure	Soil under 'Mme Lemoine' cultivar (control)	Soil under 'Mme Lemoine' cultivar + green manure	Soil under 'Michel Buchner' cultivar (control)	Soil under 'Michel Buchner' cultivar + green manure
6 months after decay of green manure biomass						
Ferulic	5.7 ± 0.11	7.2 ± 0.14	6.0 ± 0.13	6.6 ± 0.13	5.3 ± 0.11	4.4 ± 0.09
p-Coumaric (trans-)	7.9 ± 0.16	11.2 ± 0.22	8.2 ± 0.16	13.4 ± 0.27	9.8 ± 0.20	11.2 ± 0.22
p-Coumaric (cis-)	2.1 ± 0.04	2.4 ± 0.05	1.9 ± 0.04	2.3 ± 0.05	1.0 ± 0.02	2.5 ± 0.05
Syringic	3.1 ± 0.06	3.1 ± 0.06	3.4 ±0.07	4.0 ± 0.08	4.3 ± 0.09	4.6 ± 0.09
Vanillic	4.7 ± 0.09	4.7 ± 0.09	5.0 ± 0.10	5.9 ± 0.12	5.7 ±0.11	7.0 ± 0.14
p-Hydroxybenzoic	2.1 ±0.04	3.6 ± 0.07	3.0 ± 0.05	4.5 ± 0.09	2.5 ± 0.05	2.2 ± 0.04
m-Coumaric	3.0 ± 0.06	3.0 ± 0.05	3.4 ± 0.07	3.8 ± 0.08	4.4 ± 0.09	3.8 ± 0.08
o-Coumaric	5.8 ± 0.12	6.0 ± 0.12	6.2 ± 0.12	6.0 ± 0.12	5.8 ± 0.12	8.2 ± 0.16
Total	34.4 ± 0.69	41.2 ± 0.82	37.1 ± 0.74	46.5 ± 0.93	38.8 ± 0.78	43.9 ± 0.88
18 months after decay of green manure biomass						
Ferulic	5.5 ± 0.11	5.6 ± 0.12	8.4 ± 0.17	6.0 ± 0.12	6.0 ± 0.13	5.7 ± 0.11
p-Coumaric (trans-)	15.6 ± 0.31	10.8 ± 0.22	16.8 ± 0.34	9.5 ± 0.19	11.6 ± 0.23	9.2 ± 0.18
p-Coumaric (cis-)	6.8 ± 0.14	5.6 ± 0.11	7.0 ± 0.14	6.4 ± 0.13	6.2 ± 0.12	5.8 ± 0.12
Syringic	4.0 ± 0.08	2.8 ± 0.06	3.7 ± 0.07	3.1 ± 0.06	3.4 ± 0.07	4.5 ± 0.09
Vanillic	7.9 ± 0.16	6.3 ± 0.13	6.8 ± 0.14	4.5 ± 0.09	6.3 ± 0.13	3.2 ± 0.06
p-Hydroxybenzoic	4.1 ± 0.08	1.7 ± 0.03	4.4 ± 0.09	2.6 ± 0.05	2.9 ± 0.06	2.1 ± 0.04
m-Coumaric	6.2 ± 0.12	2.1 ± 0.04	5.0 ± 0.10	7.0 ± 0.15	9.0 ± 0.18	6.4 ± 0.13
o-Coumaric	4.0 ± 0.08	2.0 ± 0.05	3.9 ± 0.08	2.6 ± 0.05	7.0 ± 0.16	1.5 ± 0.03
Total	54.1 ± 1.08	36.9 ± 0.74	56.0 ± 1,12	41.7 ± 0.83	52.4 ± 1.05	38.4 ± 0.77

Table 4. **Effect of green manure on photosynthetic pigments content in the leaves of *Syringa vulgaris* cultivars, mg/100 g fresh matter**

Treatment	Chlorophyll		Carotenoids	Chlorophyll *a* + *b* / Carotenoids
	a + *b*	*a*/*b*		
3 months after decay of green manure biomass				
‘Taras Bulba’ cultivar (control)	253.0 ± 5.1	2.10 ± 0.04	51.6 ± 1.0	4.90 ± 0.10
‘Taras Bulba’ cultivar + green manure	285.0 ± 5.7	1.60 ± 0.03	66.3 ± 1.3	4.30 ± 0.09
‘Mme Lemoine’ cultivar (control)	235.0 ± 4.7	1.90 ± 0.04	33.1 ± 0.7	7.10 ± 0.14
‘Mme Lemoine’ cultivar + green manure	262.2 ± 5.2	1.50 ± 0.03	43.7 ± 0.9	6.00 ± 0.12
‘Michel Buchner’ cultivar (control)	270.5 ± 5.4	2.30 ± 0.05	42.3 ± 0.8	6.40 ± 0.13
‘Michel Buchner’ cultivar + green manure	295.0 ± 5.9	1.70 ± 0.03	60.2 ± 1.2	4.90 ± 0.10
6 months after decay of green manure biomass				
‘Taras Bulba’ cultivar (control)	240.0 ± 4.8	2.40 ± 0.05	46.1 ± 0.9	5.20 ± 1.00
‘Taras Bulba’ cultivar + green manure	310.0 ± 6.2	1.80 ± 0.04	68.9 ± 1.4	4.50 ± 0.09
‘Mme Lemoine’ cultivar (control)	250.2 ± 5.0	1.80 ± 0.03	40.3 ± 0.8	6.20 ± 0.12
‘Mme Lemoine’ cultivar + green manure	290.3 ± 5.8	1.40 ± 0.03	54.8 ± 1.1	5.30 ± 0.11
‘Michel Buchner’ cultivar (control)	255.2 ± 5.1	2.00 ± 0.04	42.5 ± 0.8	6.00 ± 0.12
‘Michel Buchner’ cultivar + green manure	315.4 ± 6.3	1.60 ± 0.03	75.1 ± 1.5	4.20 ± 0.08
18 months after decay of green manure biomass				
‘Taras Bulba’ cultivar (control)	280.0 ± 5.6	2.00 ± 0.04	48.3 ± 1.0	5.80 ± 0.12
‘Taras Bulba’ cultivar + green manure	334.4 ± 6.7	1.70 ± 0.03	71.1 ± 1.4	4.70 ± 0.09
‘Mme Lemoine’ cultivar (control)	240.1 ± 4.8	2.20 ± 0.04	40.0 ± 0.8	6.00 ± 0.12
‘Mme Lemoine’ cultivar + green manure	300.5 ± 6.0	1.90 ± 0.05	58.9 ± 1.2	5.10 ± 0.10
‘Michel Buchner’ cultivar (control)	261.0 ± 5.2	1.80 ± 0.04	45.0 ± 0.9	5.80 ± 0.12
‘Michel Buchner’ cultivar + green manure	332.1 ± 6.6	1.50 ± 0.03	75.5 ± 1.5	4.40 ± 0.09

As this trend persisted not only for the direct action of this factor, but also in its after-effect (next growing season after application of green manure biomass) can recommend the use of winter rape as green manure for optimization of soil-plant system under allelopathic stress.

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ФІЗІОЛОГІЧНІ ТА БІОХІМІЧНІ ПАРАМЕТРИ СИСТЕМИ ҐРУНТ—РОСЛИНА ЗА УМОВ АЛЕЛОПАТИЧНОГО СТРЕСУ: ДІАГНОСТИЧНИЙ АНАЛІЗ ТА КЕРУВАННЯ

Проведено діагностичний аналіз функціонального стану системи ґрунт—рослина за умов алелопатичного стресу для її оптимізації. З цією метою використано низку фізіологічних і біохімічних параметрів. Вивчено вплив біомаси озимої суріпиці (*Brassica campestris* L. f. *biennis* D.C.) як сидерату на алелопатичні, біохімічні та фізіологічні властивості системи ґрунт—рослина на прикладі багаторічних насаджень сортів бузку (*Syringa vulgaris* L.) колекції Національного ботанічного саду ім. М.М. Гришка НАН України. Зелену біомасу озимої суріпиці у фазі цвітіння вносили у кількості 3,5 кг/м^2 в сірий лісовий ґрунт під насадженнями сортів бузку. Встановлено суттєве поліпшення функціонального стану системи ґрунт—рослина при використанні сидерату за умов тривалого культивування рослин бузку. Під впливом продуктів деструкції біомаси сидерату стабілізувалися структурні компоненти системи ґрунт—рослина, що позитивно позначилося як на алелопатичних та біохімічних властивостях ґрунту, так і на фізіологічному стані рослин бузку. Зафіксовано динамічні якісні зміни системи ґрунт—рослина за дії сидерату, що виявлялися в стимулюванні ростових процесів, активізації гуміфікації (за рахунок пулу фенолкарбонових кислот), поліпшенні окисно-відновного режиму, перебудові компонентного складу фотосинтетичних пігментів і підвищенні адаптаційної здатності рослин бузку. Оскільки така тенденція зберігалася не лише під час безпосередньої дії зазначеного чинника, а й при його післядії (наступна вегетація після внесення зеленої біомаси), можна рекомендувати застосування озимої суріпиці як сидерату для оптимізації системи ґрунт—рослина за умов алелопатичного стресу.

Ключові слова: система ґрунт—рослина, сидерат, озима суріпиця, бузок, алелопатичний стрес, алелопатична активність, окисно-відновний потенціал, фенолкарбонові кислоти, фотосинтетичні пігменти.

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ФИЗИОЛОГИЧЕСКИЕ И БИОХИМИЧЕСКИЕ ПАРАМЕТРЫ СИСТЕМЫ ПОЧВА—РАСТЕНИЕ В УСЛОВИЯХ АЛЛЕЛОПАТИЧЕСКОГО СТРЕССА: ДИАГНОСТИЧЕСКИЙ АНАЛИЗ И УПРАВЛЕНИЕ

Проведен диагностический анализ функционального состояния системы почва—растение в условиях аллелопатического стресса для ее оптимизации. С этой целью использовали ряд физиологических и биохимических параметров. Изучено влияние биомассы озимой сурепицы (*Brassica campestris* L. f. *biennis* D.C.) в качестве сидерата на аллелопатические, биохимические и физиологические свойства системы почва—растение на примере многолетних насаждений сортов сирени (*Syringa vulgaris* L.) коллекции Национального ботанического сада им. Н.Н. Гришко НАН Украины. Зеленую биомассу озимой сурепицы в фазе цветения вносили в количестве 3,5 кг/м^2 в серую лесную почву под насаждениями сортов сирени. Установлено существенное улучшение функционального состояния системы почва—растение при использовании сидерата в условиях длительного культивирования растений сирени. Под влиянием продуктов деструкции биомассы сидерата стабилизировались структурные компоненты системы почва—растение, что позитивно отразилось как на аллелопатических и биохимических свойствах почвы, так и на физиологическом состоянии растений сирени. Зафиксированы динамические качественные изменения системы почва—растение под воздействием сидерата, которые проявлялись стимулированием ростовых процессов, активизацией гумификации (за счет пула фенолкарбоновых кислот), улучшением окислительно-восстановительного режима, перестройкой компонентного состава фотосинтетических пигментов и повышением адаптационной способности растений сирени. Поскольку такая тенденция сохранялась не только во время непосредственного действия данного фактора, но и при его последействии (следующая вегетация после внесения зеленой биомассы), можно рекомендовать применение озимой сурепицы в виде сидерата для оптимизации системы почва—растение в условиях аллелопатического стресса.

Ключевые слова: система почва—растение, сидерат, озимая сурепица, сирень, аллелопатический стресс, аллелопатическая активность, окислительно-восстановительный потенциал, фенолкарбоновые кислоты, фотосинтетические пигменты.