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Allelopathy – an element of the overall strategy for weed control

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Abstract: Changes in weed associations under the influence of a number of factors require the exploration of new options for weed control. This article summarizes the main technologies in experimental methods used to study allelopathic relationships in the weed – crop system. Problems associated with methodical productions are discussed. The paper provides an overview of the results of our and foreign studies related to the practical application of weed control by using: allelopathic protector, suffocation, or rotary allelopathic companion plants, toxic extracts of allelopathic plants, mulching or burial of crop residues etc. In allelopathic relationships, the total destruction of all weed species in agrophytocenoses cannot be expected. Allelopathy should be seen as an element of the overall strategy for weed control. Profound theoretical studies on the methods for the practical application of allelopathy in modern agriculture are required.
Key words: allelopathy, weeds, alternative weed control.

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Introduction

Weeds are a constant and widespread companion of agricultural production, inflicting substantial damages to it that often exceed the total losses caused by diseases and pests (UNCED 1992).

A major problem with weeds is their great diversity of species, high biological and ecological plasticity, which facilitates their rapid adaptation and dissemination (Bruce and Ghersa 1992, Stoimenova and Alexieva 2003, Stoimenova *et al.* 2003, Zimdahl 2004, Booth *et al.* 2010).

Worldwide experience shows that the introduction of industrial technologies in agriculture is impossible without highly efficient and rational weed control (Fennimore and Doohan 2008). Changes in weed associations under the influence of a number of factors require the exploration of new possibilities for weed control (Legere *et al.* 1993, Streibig *et al.* 1993). Integrated control is recognized as the preferred strategy in the United Nations Conference on Environment and Development program (UNCED 1992). Its advantages include complexity, more effective destruction of weeds and a lower risk of environmental pollution. Weed control for resistant populations according to Powels and Brandt (1996) requires the use of chemical and non-chemical methods and approaches. Scientific researches on weeds in recent years have focused mainly on the development of highly effective systems for integrated control.

In this respect, the search for alternative means of weed control is of utmost importance. There is a growing interest in allelopathy in agriculture at present, as this phenomenon could provide perspective alternative methods of weed control and help reduce the application of synthetic herbicides (Putnam and Defrank 1983, Delabays 2005, Peneva 2005).

Results and Discussion

Although allelopathy is under study by ecologists, chemists, soil scientists, agronomists, herbologists, biologists, plant physiologists and molecular biologists, the complicated interrelations in the "weed - crop plant" system are not fully understood (Macias *et al.* 2003b). The interaction between weeds and crops is simultaneous and / or sequential with a direct or indirect effect of one plant species on another, through the synthesis of various chemical compounds - allelochemicals that are released into the environment having inhibiting and/or stimulating effect on seed germination and the initial development of a number of weeds and crops (Rice 1974, Hunt 1982, Brown and Morra 1995, Chung *et al.* 1997, Moer and Huang 1997, Reigosa *et al.* 1999, Agraval *et al.* 2002, Chaniago 2003, Fujii 2003, Hong *et al.* 2003, Hoque *et al.* 2003, Iqbal *et al.* 2003, Kadioglu *et al.* 2005, Marchin-Silva and Aqüila 2006, Verma and Rao 2006, Georgieva *et al.* 2007, Ahmad 2012, Ravlic *et al.* 2013).

The obtained results are contradictory, confirming to a different extent the inhibitory or stimulating effect of various weeds upon seed germination of agricultural crops (Ebana *et al.* 2001, Kadioglu *et al.* 2005, Serafimov *et al.* 2005, Aleksieva and Serafimov 2008, Golubinova and Georgieva 2009, Kalinova *et al.* 2012, Nikolić *et al.* 2012, Baličević *et al.* 2013, Yarnia *et al.* 2013).

The difficulties in clarifying allelopathic relationships are due to various experimental methods through which the distinction between allelopathy and competition in plant communities cannot be made (Steven *et al.* 1984, Stoimenova 1990, Nacova 2004, Stoimenova *et al.* 2004a, Stoimenova *et al.* 2004b, Serafimov *et al.* 2008). According to Grace and Tilman 1990, Rice 1995, Inderjit and Del Moral 1997, and Willis 2007, the nature of competitive and allelopathic relationships in agrophytocenoses is determined by many factors.

The most commonly used method to demonstrate allelopathic interference in plant communities or in the "weed - crop plant" system is to establish the stimulating or inhibitory effect of extracted plant materials on test plants or to study the effect of plant residues and their application in quartz sand and/or in the soil, under laboratory conditions (Topalov 1986, Kaworu *et al.* 2001, Adetayo *et al.* 2005, Paneva 2006).

In a number of studies (Moyer and Huang 1997, Bruce *et al.* 1999, Gill *et al.* 2000, Turk and Tawaha 2002, Hoque *et al.* 2003, Adetayo *et al.* 2005, Vasilakoglou *et al.* 2006, Ashrafi *et al.* 2007, Koloren 2007, Brooks 2008, Kayode and Ayeni, 2009), in order to determine allelopathic interference between weeds and crop plants, plant material extracted from fresh or dry weed biomass was used, while the concentrations of the extracts were significantly higher than those occurring in agrophytocenoses in the case of dropping and decomposition of weed biomass in the soil. The extraction is carried out with different carriers - distilled water or organic solvents (Stoimenova 1990, Kaworu *et al.* 2001, Burda and Oleszek 2004, Elemar and Filho 2005, Maigahani *et al.* 2007).

The extraction of plant materials, however, does not take into account the fact that most of the solvents used can increase the diffusion of allelochemicals, and the release of such chemicals that may not be released under field conditions (Putnam *et al.* 1983).

When performing experiments under greenhouse conditions, the addition of plant residues into the soil can result in changes in the structure of the culture medium and/or its ability to retain water in comparison with the control variant (Qasem and Hill 1998). The changes in the structure of the medium may impact root system formation in the test plants. In this case, the problem can be overcome by adding nutrient solutions after insertion of the plant material. This, on the one hand, can compensate for the exported quantities of nutrients and mask the studied allelopathic effect on the other, as the allelopathic impact of weeds is more pronounced at lower fertility (Rice 1995). The inevitable variation in the results when performing allelopathic studies in laboratory conditions is due to microorganisms that grow relatively well in the extracts and their activity may degrade or alter individual allelochemicals (Putman and De Frank 1983, Nair *et al.* 1990, Weidenhamer 1996) and have an effect on the pH of the medium (Marinov-Serafimov and Dimitrova 2007). The problem in this case can be overcome by the addition of thymol in the preparation of extracts (Marinov-Serafimov *et al.* 2007a). The variation in the results of the laboratory tests is due to the suboptimal amounts of water and/or water extract required for seed germination in allelopathic studies in laboratory conditions (Wolk *et al.* 1989, Suriyong *et al.* 2002, Marinov-Serafimov *et al.* 2007b, Golubinova and Vasilevska 2008).

The allelopathic effect in the “weed - crop” system is studied via "stair step apparatus". This method, developed by Bell and Koeppe (1972) and modified by Lovett and Jokinen (1984), allows the addition of the filtrates from the root system of the weed - crop to the circulating solution.

When using a "stair step apparatus" it is to be taken into account that the amount of the filtered nutrients from weeds may be less compared to those of the crops. Therefore, the filtrates may differ in nutrient content, mineral concentrations and allelochemicals.

According to Qasem and Hill (1998), Rice (1995), if the nutrients added to the "stair stepped apparatus" cannot compensate for the inhibitory effect on the development of the test plants, including weeds, this is an evidence of allelopathic interaction; whereas if the addition of nutrients to the "stair stepped apparatus" stimulates the development of weed species rather than crop plants, in this case the interaction between the test plants can be defined as a competition.

Over the last decades, scientific research on determining the chemical structure of allelochemicals has been expanding. Various allelochemicals have been identified - phenolic acids, coumarins, terpentinoids, flavonoids, alkaloids, glycosides, glycosinolats, terpenes, phenols, derivatives of tropine with esterified hydroxyl group - O - acetyl tropine etc. (Rice 1995, Richard 1999), through which the allelopathic interference in the “crop – weed” and “weed-crop” systems and the incompatibility between crops are more accurately determined.

According to Blum (1996), allelopathic interference between plant species is a result of the combined action of allelochemicals on the physiological processes of the acceptor plants. It has been established that allelopathic interrelations in plant communities are variable and strongly limited by abiotic (temperature, precipitation, solar radiation, nutrients etc.) and biotic (diseases, pests etc.) environmental factors (Chou 1990, Alsaadawi 1992). Einhelling found in his experimental work Einhelling (1996) that the synthesis of allelochemicals in the plant organisms increases under the influence of stress factors, and thereby increases their allelopathic potential.

According to the summarized results of Rice (1995) and Ahmed (2004), some allelochemicals have been studied in detail and those that are more promissing are already being manufactured in laboratories or in semi-factory conditions and used in agricultural production with promising results. Therefore, allelochemicals as natural products provide opportunities for weed control, and their practical application will not cause contamination to the agricultural produce and the environment, since this mechanism of biological interaction between two or more plant species could be used as an alternative method of regulating weed density, as well as helping to reduce the introduction of synthetic herbicides (Murphy 2001, Macías *et al.* 2003a, Macías *et al.* 2003b, Reigosa *et al.* 2006, Brooks 2008, Kruidhov 2008).

According to the studies of Olofsdotter *et al.* (1995), Hwu *et al.* (1999), allelopathy plays a key role in regulating weed density in artificial plant communities (agrophytocenoses) under field conditions and the possible correlation between the allelopathic potential and the physiological and morphological characteristics, which are important from an agronomic point of view.

At the present stage of agricultural practices, allelopathy can be used for weed control by the application of cover crops (Lotz *et al.* 1991, Callaway and Forcella 1993, Lemerle *et al.* 1996, Dimitrova 1998, Lindquistet *et al.* 1998, Dimitrova 2005 and 2008), allelopathic rotational or companion crops (Putnam and Duke 1978, Barnes and Putnam 1986), toxic extracts of allelopathic plants (Habib and Ranman 1988); mulching or burial of plant residues (Putnam 1988); natural herbicides (Putnam 1988); selection of allelopathic crop varieties with weed suppressing potential (Einhelling and Leather 1988, Aleksieva and Serafimov 2008).

The studies of Peters (1986), Dimitrova (1993), Liebman and Gallandt (1997), and Dimitrova (2003) established that the use of Avena sativa as a cover crop is an effective biological tool for weed control in the seed production of *Dactylis glomerata* L. and *Lolium perenne* L. This is probably due to its ability to accumulate and release the allelochemical "scopoletin" which inhibits the growth of weeds.

A good alternative, from an economic and environmental perspective, is the cultivation of alfalfa in mixed crops with perennial grasses including *Dactylis glomerata* L., *Bromus inermis* L., *Agropyron desertorum* Fisch. Schult. In this instance, the crop has a higher weed suppressing capacity as compared to its independent growing, receiving three times less herbicide treatment. Weeds are at a manageable level, suppressed at the lowest level of the grass compositions, not reaching the phases of seed formation.

The mixed crops of the three types of cultures have good mutual tolerability and a higher productivity (22% to 35%). These studies show that the cultivation of alfalfa with some perennial grains in mixed crops and the use of oats as a cover crop, serving as biological means of weed control, is an alternative to building a system of good plant protection practices (Dimitrova 1998; 2005). The perennial grass mixtures of *Medicago sativa* L. with some perennial cereals (*Dactylis glomerata* L., *Bromus inermis* L., *Agropyron desertorum* Fisch. Schult.) reduce the density and the formation of surface biomass of the perennial weeds (*Sorghum halepensis* L. Pers. and *Cirsium arvense* L.) as a result of which their invasion is limited (Dimitrova and Marinov-Serafimov 2007a; 2007b).

In the system of an environmentally friendly agriculture, the usage of certain cereal cover crops (*Hordeum sativum, Avena sativa, Secale cereale*) in the year of establishment of alfalfa crops could be a successful alternative to the conventional technology.

The cover crops have the ability to suppress weeds, allowing for a more efficient use of land during the first year of alfalfa growing, when its rate of growing and development is slow. Under the conditions of the study, in ascending order of aggressiveness, the cover crops are as follows: *Hordeum sativum*, *Avena sativa*, *Secale cereale* (Baker and Smith, 1987, Dimitrova 2008). Biological incompatibility between *Medicago sativa* L. and *Festuca arundinacea* Scherb is observed. Similar results were also obtained in the experimental work of Marinov-Serafimov 2010, Marinov-Serafimov *et al*. 2010, according to whom the usage of oats as allelopathic mulching culture in the soybean crop reduces the degree of weed infestation and the amount of accumulated dry biomass of late spring weeds, but has a pronounced negative effect on the soybean plants.

In modern agriculture the problem of weed control and the use of chemical substances for plant protection remains. The integrated system of weed control largely complies with the principle of ecology and environmental protection (Olygarenko and Tkacheva 1999, Stoimenova *et al.* 2008). The use of allelopathy jointly with other plant potentials (e.g. early vitality, leaf size, plant height and tillering) is an important step towards the further development of systems for sustainable crop production, relying less on herbicide use Lemerle e*t al.* (1996). In allelopathic relationships, the total destruction all of weed species in agrophytocenoses cannot be expected. Allelopathy should be seen as an element of an overall strategy for weed control. Extensive theoretical studies on the methods for practical application of allelopathy in modern agriculture are required.

Conclusion

Allelopathy plays a key role in regulating weed density in artificial plant communities (agrophytocenoses). Studies on allelopathy in crop – weed systems were studied, and allelopathy has become a reality in the agricultural practice, using cover crops, green manures, intercrop ping, etc. However, allelopathy is a dynamic process that involves interaction between weeds and crops in agrophytocenoses, under the influence of a number of factors - climate conditions, soil type, temperature, precipitation, solar radiation, nutrients, previous crops, companion crops, diseases, pests and many other factors as determinants of the occurrence of allelopathic interaction.

Future allelopathic research should preferably focus on the following: a) to determine the role of allelopathy in agrophytocenoses; b) to identify allelopathic compounds in weed and culture plants; c) to develop new methods for isolating allelopathic chemicals in weed and culture plants; d) to determine the impact of allelopathic chemicals onto the initial development of a number of weeds and crops plants; e) to develop experimental methods and new techniques to differentiate between allelopathy and competition in plant communities; f) to determine allelopathic interference in the “crop – weed” and “weed-crop” systems as well as incompatibility between crops; g) to develop methods for the practical application of allelopathy in modern agriculture.

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ALELOPATIJA – ELEMENT SVEUKUPNE STRATEGIJE ZA SUZBIJANJE KOROVA

- pregledni rad -

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Rezime

Za promenu korovske zajednice pod uticajem niza činilaca neophodno je istražiti nove mogućnosti suzbijanja korova. U ovom radu prikazane su glavne tehnologije u okviru eksperimentalnih metoda za ispitivanje alelopatskih odnosa u sistemu korov – gajena biljka. Razmatrani su problemi u vezi sa utvrđivanjem metoda. Sumirani su rezultati naših i stranih istraživanja o praktičnoj primeni suzbijanja korova pomoću alelopatskih zaštitnih biljaka, plodoreda, toksičnih ekstrakata alelopatskih biljaka, malčiranja ili zaoravanja žetvenih ostataka itd. U alelopatskim odnosima, nije moguće potpuno uništenje svih korovskih vrsta u agrofitocenozama. Alelopatiju treba posmatrati kao element sveukupne strategije suzbijanja korova. Neophodno je sprovesti detaljna teoretska istraživanja metoda praktične primene alelopatije u savremenoj poljoprivredi.

Ključne reči: alelopatija, korovi, alternativno suzbijanje korova.