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The Ecological Role of Interactions Between Plants in Agroecosystems

Amer Sunulahpašić[1], Sanja Čekić[2], Jelena Golijan[3], Saud Hamidović[4]

[1]*Ministry of Agriculture, Water Managament and Forestry, Central Bosnia Canton, Travnik, BiH*
[2]*Faculty of Agriculture, University of Banja Luka, Republic of Srpska, BiH*
[3]*Faculty of Agriculture, University of Belgrade, Serbia*
[4]*Faculty of Agriculture and Food Sciences Sarajevo, University of Sarajevo, BiH*

Abstract

Modern agricultural production considers intensive use of agro-technology and chemical agents, which in addition to multiple benefits, results in loss of diversity. One of the methods for improvement of ecological interactions within the agroecosystem is increasing the diversity of cultivated plants. Previous studies have shown the impact of diversification of crops on pest populations in agricultural agroecosystems and demonstrated how certain techniques such as intercropping, can significantly affect the control of herbivores. This paper presents the influence and the role of intercropping in suppression of pests, weeds and diseases. According to the data presented, it is evident that, by using intercropping, multiple beneficial effects for the plant populations can be achieved, followed by development of resistance mechanisms, as well as production of compounds with suppressive effects on overall plants pathogens, weeds and pests.

Key words: intercropping, plant resistance, diseases, pests, weeds

Introduction

Sustainable, economically payable and energy effective agricultural systems in the context of sustainable agriculture are constantly in the focus of farmers, scientists and legislation (Altieri, 1999; Altieri et al., 1983).

However, many agricultural actions of modern agricultural production (use of machinery, different plant species and varieties, manure, pesticides, etc.) lead to loss of biodiversity (Lithourgidis et al., 2011). Through these activities simplify the structure of the environment, natural diversity is reflected in a small number of cultivated plants and domesticated animals (Altieri, 1999).

Many authors point to various interactions between diversity and ecosystem functioning (Diaz and Cabidos, 2001; Loreau et al., 2001). These interactions are difficult to define in agroecosystems, because many experiments are not representative in terms of diversity and rotation of crop (Ceroni et al., 2007). Therefore, increasing the diversity is considered an action that affects the fertility of the land, the regulation of natural defence against pests and sustainable productivity (Scherr and McNeely, 2008). Cultivation of two or more plants in intercropping has enabled farmers to respond more adequately to the shift in market demands and environmental variations that may affect productivity (Gauchan and Smale, 2007), reduce the application of pesticides (Zhu et al., 2000) and achieve additional profit by cultivating high-quality traditional varieties (Smale et al., 2004). Increasing the diversity of cultivated plants within the agro-ecosystem enables the testing of certain interactions between plants and the ecological role of diversity (Hajjar et al., 2008). The intensity of interaction between plants in the agroecosystem can be increased as a function of time and space in different ways (Altieri, 1999), which lead to the stability of yield and reduction of diseases and pests (Malezieux et al., 2009).

Increasing plant diversity in agroecosystem by means of intercropping is a simple and efficient way of reducing diseases and pests (Smith and McSorley, 2000) and until today has been applied in many regions of the world (Ma et al., 2006). In addition, it is important to understand the mechanism in diversified agroecosystem responsible for the control of diseases and pests (Gurr et al., 2003).

The aim of this paper is to provide a review and show the role of interactions between plants, as well as the mechanisms that influence the reduction of the occurrence of diseases and pests in agroecosystems.

Increasing the diversity of cultivated plants and plant resistance to pests

An important aspect in the cultivation of two or more plant species in the agroecosystem is the increasing of resistance to pests and diseases. However, this aspect is very complex and can be both positive and negative. In any case, the resistance of plants was significantly higher in polyculture, but the efficiency of resistance is deviated (Trenbath, 1993).

The presence of two or more plant species in agroecosystem has stimulative effects on the presence of parasites and predators, which regulate the number of pest insects and thus minimize the use of expensive and toxic pesticides, as well as delay the disease by reducing the spread of the conflict and modifying environmental conditions, which are less suitable for the development of some pathogens. In comparison to monoculture, growing larger number of plants in the agroecosystem has a greater impact on the quality of agroecosystems and the plants themselves (Langer et al., 2007), which is important for creating effects of resistance to insects (Bukovinszky et al., 2004).

Even small modifications such as the selection of crops can significantly affect herbivorous insects and their natural enemies. If diversification of crops is properly defined in space and time, it can play an important role for the entire ecosystem in reducing pests (Markovic, 2013). Increasing the diversity of cultivated plants may affect the reduction of herbivorous insect prevalence, since they are harder to find host plants, or have difficulty finding them again after they leave (Andow, 1991). Also, eyesight and other stimulation from insects to neighboring plants can have positive effects on the host plant, making it less attractive for herbivorous insects (Markovic, 2013).

The appearance of broomrape *(Orobanche crenata)*, an important parasite of beans (*Vicia faba* L.) and peas (*Pisum sativum* L.), can be reduced by intercropping pea plants with oats (*Avena sativa* L.).

Cultivating rice (*Oryza sativa*) and peanuts (*Arachis hypogaea*) (at low and medium population size of peanut) results in lower intensity of bedbugs (*Nezara viridula* L.*)* and rice African moth (*Chilo zacconius* B.) infection compared to rice grown in monoculture (Epidi et al., 2008). This indicates that careful selection of combinations of plants can lead to a reduction of infection in the rice field. Also, growing vigne and cotton gives the best results in suppressing populations of chili thrips (*Scirtothrips dorsalis Hood)* and tobacco smothered molasses *(Bemisia tabaci* G.*)* on cotton (*Gossypium sp.*) (Chikte et al., 2008), as well as intercropping of cabbage (*Brassica oleracea var. capitata* L.) with clover (*Trifolium sp*.) in combating cabbage flies *Delia floralis* F. (Bjorkman et al., 2010).

Cotton (*Gossypium barbadense* L.) within intercropping with basil (*Ocimum basilicum* L.) was up to 50% less affected by infection of cotton rosy quiver worm (*Pectinophora gossypiella* Saunders) (Schader et al., 2005).

Volatile compounds, which are emitted by the leaves (green leaf volatiles-GLV), can play an important role in disrupting herbivores in finding a host plant (Aldrich et al., 2003).

Intercropping of barley (*Hordeum vulgare* L.) and palamides (*Cirsium arvense* L.), which may produce the volatile organic compounds and exudates, increased the barley resistance to the oat aphid *Rhopalosiphum padi* L. (Glinwood et al., 2004). These compounds can also be used to attract natural enemies of herbivorous insects (Hare, 2011) and serve as a signal for the induction of defence; consisting of C6 aldehydes, their derivatives and corresponding isomers (Arimura et al., 2009). They have a very important role in the defence of plants, because they are attractive to a large number of natural enemies (Hare, 2011). Kost and Heil (2006) showed that hexenyl acetate represents the primary GLV compound produced by plants. A large number of compounds belonging to the GLV group induce depolarization of the plasma membrane, with an increase of concentration of Ca^{2+}, which indicates that the GLV and some other compounds with low molecular weight have a significant effect in relation to compounds with high molecular weight, such as monoterpenes or sesquiterpenes (Zabelo et al., 2012).

These quick responses of plants, combined with changes in the transcription of genes are essential for the understanding of the defence mechanisms of plants against insects (Holopainen and Bland, 2013). Also, some plants reduce miners attack on cultivated plants in agroecosystem with the help of farnesene matter which is emitted by Chrysanthemum (Bennison et al., 2001). This way of "defence" of plants is particularly evident in intercropping involving economically significant agricultural plants. Thus, intercropping between multiannual grass molasses (*Melinis minutiflora P.Beauv.*) and corn (*Zea mays* L.) leads to a reduction of insect *Cotesia sesamiae* with the help of GLV which is formed during flowering multiannual molasses grass which include (E) -β-ocimene, α-terpinolene, and (E) -4,8-dimethyl-1,3,7-nonatrien (Khan et al., 2000).

Plants from the *Desmodium* genus produced GLV such as (E) -β-Ocimene and (E) -4,8-dimethyl-1,3,7-nonatrien, and a large amount of sesquiterpenes (Wang et al., 2010). Also, secondary metabolites of root of this plant have a negative impact on the development of parasitic covered seed *Striga hermonthica* (Khan et al., 2002). Some examples of successful control of insects by using of GLV, which is emitted by plants, are shown in Table 1.

Among substances that increase the resistance of plants to pests, methyl salicylate and methyl jasmonate stand out (Karban et al., 2006), which alone or in combination with other substances affect the increased attractiveness of natural enemies and lead to reduction of pests in field conditions, stimulating indirect plant defence mechanisms (Wang et al., 2011). For this reason, these interactions should be kept in mind when choosing varieties that will be grown in order to build a diverse and functional agroecosystem (Kellner et al., 2010).

Tab. 1. Insect control using GLV materials of plant (Cook et al., 2007)
Котрола инсеката примјеном испарљивих једињења листа биљке

Insect ***Инсект***	**Host plant** ***Биљка домаћин***	**Plant which repels insect** ***Биљка репелент***	**Plant which catches insects or produces GLV matter** ***Биљка која привлачи инсекте или производи испарљива једињења***	**Method for reducing the population** ***Методе за смањење популације инсеката***
Chilo partellus, Thrips tabaci	*Zea mays/ Sorghum bicolor*	*Melinis minutiflora/ Desmodium*	*Pennisetum purpureum/ Sorghum vulgare sudanese*	*Cotesia sesamiae*
Frankiniella occidentalis	*Chrysanthemum cinerarifolium*	*Rosmarinus officinalis*	(E)-β-farnezen	*Orius laevigatus, Stratiolapa, Gaeolaelaps aculeifer*
Rhagoletis cerasi	*Prunus avium*	N[5(b-glucopyranosyl) oxy-8-hydroxypalmitol] -taurine	Woody plants	Traping
Dendroctonus ponderosae	*Pinus contorta*	Verbenon	transverbenol, egzobrevikomin and mirecen	Without reduction

The diversity of plants and disease resistance

An interaction between plants in the agroecosystem contributes to the efficient fight against the disease. Increasing the diversity of cultivated plants provides functional diversity that affects the reduction of pathogen presence (Finckh et al., 2000).

Many examples confirm that interactions between plants significantly reduce infection caused by specific pathogens, mainly through the reduction of the spread of the spore, which occurs as a result of modifications to the conditions in the agroecosystem. For example, growing of wheat (*Triticum vulgare* L.) and black medick (*Medicago lupulina*) reduce the development of pathogenic fungus *Gaeumannomyces graminis*, which attacks wheat (Lennartsson, 1988).

Cultivating some legumes with corn reduces the intensity of bacterial rust *Xanthomonas campestris pv. phaseoli* (Fininsa, 1996), while a mixture of some legumes and barley in agroecosystem have influence on general reduction of the incidence of the disease by 20-40% (Hauggaard-Nielsen et al., 2008).

The development of pathogenic fungi *Didymella pinodes* is significantly reduced in the simultaneous cultivation of some cereals and leguminosae, which can be explained by modification of microclimate conditions and reduction of the period of wetting leaves during and after flowering (Schoeny et al., 2010).

However, in different systems of cultivation, there are different responses of plants in terms of resistance to diseases. There are four mechanisms by which phenomenon of plant disease can be reduced by applying intercropping, thereby reducing the degree of growth of pathogen: 1. plant in intercropping reduces pathogens attack on the host plant; 2. plants in intercropping directly interact with the attacked host plants; 3. plant in intercropping changes environmental conditions that stimulate the reduction of pathogen by its natural enemies; 4. presence of resistant plants, which are grown together with sensitive plants, can physically block the attack of inoculum of the pathogen on the host plant (Dordas, 2008).

Exudates of root systems play a key role in the rhizosphere (Bais et al., 2005). Rhizosphere zone is characterized by continuous production and secretion of toxic compounds that act on the pathogenic (Weir et al, 2004). Phenolic acids belong to this group of compounds (Ling et al., 2011). The growth of fungi *Cylindrocladium parasiticum* can be successfully inhibited by phenolic acids which are emitted by the roots of corn and soybeans (Gao et al., 2014). This acid suppresses the growth of *Fusarium oxysporum* in *vitro* condition (Hao et al., 2010). A similar suppressive effect on *Fusarium oxysporum* has chlorogenic and caffeic acid, which are placed in root exudates of watermelon *Citrullus lanatus* (Ling et al., 2013). Benzene derivatives and esters which can be found in root exudates of tomato (*Solanum lycopersicum* L.) and eggplant (*Solanum melongena*) can also have an effect in suppressing *Verticillium dahliae* (Liu and Zhou, 2009).

Diversification of crops and control of weeds

Because of negative consequences and periodically low efficiency of chemical treatment, control of weeds development by intercropping has become an important aspect in agricultural production. In terms of control of weed development, intercropping is a better solution compared to monoculture, especially if components of intercropping have a higher degree of absorption of nutrients from the weed flora (Olorunmaiye, 2010).

Plants cultivated in intercropping effectively adopt different nutrients in comparison to plants in monoculture, acting with them by inhibiting on growth of weeds.

Sorghum (*Sorghum vulgare* L.) together with some of the species of vigna (*Vigna sp*.) adopts a larger amount of light and larger amount of nutrients, and significantly reduces the weed population and dry biomass of weeds compared to sorghum grown in monoculture (Abraham and Singh, 1984). Cultivation of wheat (*Triticum vulgare* L.) and oilseed rape (*Brassica napus*) and wheat, oilseed rape and peas (*Pisum sativum* L.) have a tendency to a greater suppressive effect on weeds regarding any plants grown individually, indicating synergism between plants (Szumigalski and Van Acker, 2005). A more significant reduction degree of density and weed biomass was achieved in the cultivation of wheat and chickpea (*Cicer arietinum* L.) than in individual cultivation of these plants (Banik et al., 2006). Intercropping of peas (*Pisum sativum* L.) and flax (*Linum usitatissimum* L.) had a greater suppressive effect on growth of weed (63% in 2003 and 52% in 2004) compared to peas cultivated in monoculture (Saucke and Ackermann, 2006). Intercropping of corn and legumes significantly reduces the density of weeds in agroecosystem compared with corn in monoculture, which is related to the lack of light required for the growth of weeds (Bilalis et al., 2010).

Allelopathy is another approach to solving the problem of the appearance of weeds in agroecosystem. Some economically important plants produce chemical substances that have an inhibitory effect on the growth of weeds. Black mustard (*Brassica nigra* L.) produces allyl isothiocyanate, clover produces isoflavonoids and phenolic compounds, and oats (*Avena sativa* L.) create scopoletin (Weston, 1996). Some of these natural compounds are potentially used as bioherbicides (Nimbal et al., 1996). This group includes different compounds. Benzoxazolinone is a compound which is part of grass root exudate and they can have multiple physiological effects on weeds, such as the induction of oxidative stress (Schulz et al., 2013). Sarmentin and other fatty acids, as a pelargonical acid, may increase peroxidase activity and speed up the drying of leaves (Huang et al., 2010).

Citral is a well-known essential oil, which can inhibit microtubule polymerization (Dayan et al., 2012), while sorgoleon can inhibit photosystem 2 and the synthesis of 4-hydroxyphenylpyruvate dioxygenase, which is important for the synthesis of tyrosine (Trezzi et al., 2006).

Conclusion

In modern plant production, one of the most important problems is suppression of disease, pests and weeds. Efficiency of suppression depends on many factors. The presented data indicate that increase of crops diversification in agroecosystems can significantly affect the reduction of herbivores, weeds and diseases attack.

By intercropping, reduction of the number of pests and weeds prevalence can be achieved. Further research will be done regarding the better understanding of the intercropping functioning in the agroecosystems.

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Еколошка улога интеракција између биљака у агроекосистемима

Амер Сунулахпашић[1], Сања Чекић[2], Јелена Голијан[3] , Сауд Хамидовић[4]

[1]Министарство пољопривреде, водопривреде и шумарства СБК, Травник, ФБиХ, БиХ
[2]Пољопривредни факултет, Универзитет у Бањој Луци, Република Српска, БиХ
[3]Пољопривредни факултет, Универзитет у Београду, Београд-Земун, Србија
[4]Пољопривредно-прехрамбени факултет, Универзитет у Сарајеву, ФБиХ, БиХ

Сажетак

Савремена пољопривредна производња подразумијева интензивну употребу агротехнике и хемијских средстава, која поред вишеструких користи, доводи до губитка диверзитета. Једна од метода којом се промовишу еколошке интеракције у оквиру агроекосистема је повећање диверзитета гајених биљака. Досадашња истраживања су показала утицај диверзификације усјева на популацију штеточина у пољопривредним агроекосистемима и доказала како се одређеним техникама као што су међукултуре, може значајно утицати на контролу хербивора. У овом раду приказани су утицај и улога интеракција између биљака у повећању отпорности према болестима, штеточинама и коровима. Имајући у виду изнето, јасно се види да се применом интеркропинга могу постићи значајни позитивни ефекти за биљне популације, који се пре свега огледају у развоју механизама отпорности, као и продукцији једињења која имају супресивно ђеловање на патогене, корове и штеточине у глобалу.

Кључне ријечи: биљне интеракције, отпорност биљака, болести, штеточине, корови

Amer Sunulahpašić
E-mail address*: amers1612@gmail.com*

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