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The importance of introducing cover crops in conventional agriculture

Значењето на покровните култури при нивно воведување во конвенционалното земјоделско производство

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Abstract

As a consequence of the continuous world population amplification in the last century, agricultural production became intense by excessive mineral fertilizers, pesticides, irrigation, and the practice of continuous cultivation of the same soil. It has a negative impact on the soil's physical, chemical, and biological properties, as a part of the natural environmental resources. Employing cover crops in conventional agriculture has numerous benefits: conservation of soil, surface and groundwater, benefits to the subsequent main plant cultivation in the crop rotational system, and protection of wildlife and biodiversity. Against many benefits, they could have some limitations due to farmers' lack of knowledge, labor and organizing skills for proper timeline and management for all agricultural operations, and lack of machinery for planting and terminating cover crops mechanically. In the Republic of North Macedonia, because of a decline in animal production and reduced availability of organic fertilizers, there is a need to introduce alternative organic manures. In general, there is a lack of thorough studies for the appropriate selection of plant species or their mixture determined by our agro-ecological conditions, as well as the purpose of their use. Additionally, there is a need to strengthen the knowledge and information-sharing mechanisms with Macedonian farmers.

Keywords: cover crops, sustainable agriculture, soil and water conservation, organic manure

Апстракт

Како резултат на постојаниот пораст на светската популација во последното столетие, земјоделското производство преку прекумерна употреба на минерални ѓубрива, пестициди, наводнување и постојана обработка на почвата, постанува интензивно. Овие случувања негативно влијаат врз физичките, хемиските и биолошките особини на почвата, која претставува природен ресурс на животната средина. Вклучувањето на покровните култури во конвенционалното земјоделство се огледува преку бројни придобивки кои тие ги имаат: заштита на почвата, надземните и подземните води, придобивки врз наредната култура во плодоредот и заштита на животинскиот свет и неговиот биодиверзитет. Покрај многуте придобивки тие имаат и некои недостатоци како резултат на нивна непрепознатливост кај производителите, потреба од зголемена работна сила и вештини за времено организирање и управување на сите земјоделски операции и недостаток на

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механизација за засновање и одложување на покровните култури, по механички пат. Во Република Северна Македонија, како резултат на намаленото сточарско производство, а со тоа и намалената достапност на органски ѓубрива, се јавува потреба за воведување на алтернативни органски ѓубрива. Генерално, постои недостаток на темелни истражувања во врска со изборот на соодветен вид покровна култура или нивна мешавина, согласно нашите агро-еколошки услови, како и причината за нивно одгледување. Дополнително, се јавува потреба од зајакнување на знаењето и механизмите за споделување на информации со македонските земјоделци.

Клучни зборови: покровни култури, оддржливо земјоделство, заштита на почвите и водите, органско ѓубриво

Introduction

Cover crops, also well known as catch crops, are crops mainly grown between cash crops in order to conserve soil structure, humidity, and productivity by offering a vegetation cover and reducing nutrient leaching (Sarrantonio & Gallandt 2003; Norberg & Aronsson 2019). Introducing cover cropping in an effort to enhance environmental protection is not a modern tool in agriculture production. According to Meisinger et al. (1991), cover cropping dates back to ancient agriculture as far back as 3000 years to the Chou Dynasty in China. Ancient civilizations used cover crops since they realized that they would increase crop yields cultivated for food. Furthermore, as a common agricultural practice, native Americans used to grow together three species, including corn, bean, and squash, mainly cause diversity as one of the advantages that mixed cover crop species have (Groff 2015).

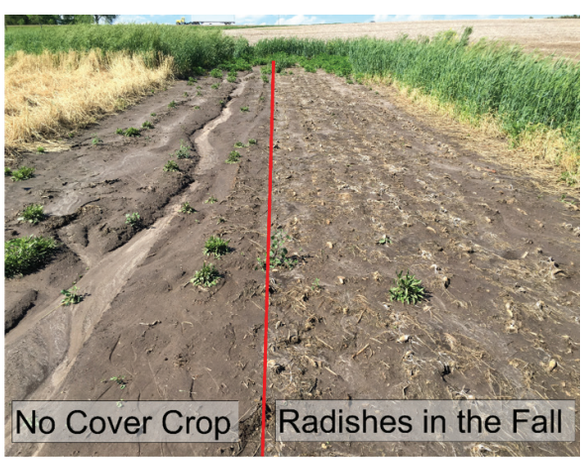

Figure 1. Effect of cover crop on soil erosion

The intensification of agricultural production using intense mechanization, fertilization, and application of pesticides and herbicides is a consequence of the world population amplification in the last century. It has a negative impact on the soil's physical, chemical, and biological properties, as a part of the natural environment. Conventional agriculture relies on high-productivity crop varieties grown as a single cash crop and a great application of pesticides and fertilizers (Krstic et al. 2018). After the harvest of these crops, the land stays bare until the following cash crop and is liable for wind and water erosion, loss of nutrients in deep layers, and surface runoff (Figure 1). Nutrients such as NO_3 and other agrichemicals from agricultural land end up in groundwaters and have detrimental effects on the groundwater quality (Meisinger et al. 1991; Salazar et al. 2013; Ugrenović et al. 2019; Norberg & Aronsson 2019). There are numerous cases where N fertilizers' excessive applications for the main crop under the condition of regular irrigation, a severe risk of diffuse pollution of surface water bodies and groundwater exist (Corradini et al. 2015; Simeonova et al. 2017). As van Kessel et al. (2009) stated, leaching of dissolved organic N from agro-ecosystems into surface water contributes to their eutrophication and acidification.

Nowadays, severe land degradation and water pollution are a genuine concern to society. To ensure the food needs for current and future generations, more and more attention is paid to sustainable production systems closely related to managing natural resources. In a battle to protect the environment, modern agriculture tends to protect, improve and efficiently use the soil, water, and biological resources, through integrated management skills (Yeganehpoor et al. 2015; Kocira et al. 2020). Among several conservation practices, the cultivation of cover crops has increased farmer's interest in the past decades (Parlak et al. 2015). Introducing cover crops in conventional agriculture has numerous benefits (Table 1), such as conservation of soil, surface and groundwater, benefits to the subsequent main plant cultivation in the crop rotational system and protection of wildlife and biodiversity (Salazar et al. 2013; Charles et al. 2017; Schenck et al. 2017; Sharma et al. 2018; Toom et al. 2019; Ugrenović et al. 2019). The subject of this review paper is to demonstrate the benefits of cover cropping from an environmental point of view and to briefly present the importance of introducing cover crops in Macedonian intensive conventional agriculture.

Effect of cover crops on soil and water conservation

The agricultural soils' degradation is mainly a consequence of the following practices: cultivating a monoculture, applying inordinate chemicals, and intensive agro-technical treatments (long-term tillage).

Table 2. Benefits of growing cover crops

Benefits on soil structure	Benefits on soil fertility	Benefits to the main crop in terms of protection	Environmental benefits
- better soil aeration;	- enrichment of the soil with nitrogen by legumes;	- suppression of weed vegetation;	- reduced erosion;
- reduced erosion caused by wind or water;	- improved phosphorus availability of major crops;	- separate cover crops suppress separate nematodes;	- reduced nitrogen leaching;
- reduced creation of soil crust;	- correction of the soil pH value;	- some cover crops are hosts of some beneficial insects;	- reduced water loses from the soil surface;
- reduced soil compaction;	- higher soil microbiology activity as a result of incorporated biomass		

Over the years, organic matter content has decreased and induced changes in soil physicochemical, biological, and quality properties. Residues of various cover crops, according to Turmel et al. (2015), help to return organic matter to the soil and maintain its health and quality. Autumn - sown cover crops are grown to cover the soil and protect it from erosion, prevent leaching of nutrients and produce biomass that may be incorporated into the soil (green manure), which will result in enhancement of organic matter content (Elhakeem et al. 2018). Sainju & Singh (2001) stated that cover crop mixtures containing legume and cereal crops might enhance above and below-ground biomass yield and C and N content. Ćupina et al. (2011), in a three-year field experiment, showed that cover crops have a significant impact on NO_3-N soil content. The highest nitrogen contribution has been assessed in the field pea (165.26 kg N ha^{-1}). In contrast, the bare plots and mineral fertilization treatments with 40 kg N ha^{-1} have demonstrated negative N balances (-59.48 kg N ha^{-1} and -25.40 kg N ha^{-1}, respectively).

Species utilized as cover crops most often are announced as legumes, grasses, and crucifers. Specifically, all of them have different capabilities on nutrient retention in their biomass, thus preventing nutrient leaching on one side and incorporating organic carbon and nitrogen when used as green manure on the other side. Lately, species from the mustard family (Brassicaceae) are getting attention in the cropping systems since their ability to grow fast and to achieve excellent land coverage (>80%) due to their potential to develop high biomass. Scientists emphasize their ability to act as biofumigants as they release biologically active compounds into the soil, which are toxic to soil nematodes, pathogens, and some weeds. Also, due to their capacity for high nutrient uptake, thanks to their deep root system, they retain N from the deeper soil layers and keep it for the next crop, thus protecting its leaking to drainage water (Ugrenović et al. 2019). In their study, Norberg & Aronsson (2019) showed that plots sown with oilseed radish (*Raphanus sativus* L.; fam. Brassicaceae) in the pure stand had significantly smaller mean N concentration in drainage water over 5 of 6 years compared with unplanted bare controls. They conclude that oilseed radish can reduce N leaching into groundwater without increasing the P leaching threat. On the other hand, cereal cover crops are used because of the vast amount of biomass they produce (Snapp et al. 2005) and their ability to reduce soil mineral N and to diminish the risk of N losses to drainage water (Sapkota et al. 2012). As a result of the high carbon and nitrogen ratio and slow decomposition of the residues (Ugrenović & Filipović 2017), cereals should be considered when the aim is to enrich the soil with organic matter (Snapp et al. 2005). Additionally, cereals play a role in weed suppression and prevention of soil erosion. Legumes, since their short growing season, are excellent cover crops. Because of their ability to fix atmospheric nitrogen, they could be used as green manure and plowed-in or as a crop residue. When they are incorporated into the soil, they enrich it with nutrients, either organic carbon or nitrogen, but significantly increase the input of N. This is especially beneficial for the subsequent cash crop (Lüscher et al. 2014; Olson et al. 2014; Wortman et al. 2012; Tosti et al. 2012; Ćupina et al. 2017). According to Kocira et al. (2020), legume cover crops have a multi-purpose character recognized in decreasing compaction and soil erosion, improving its structural and hydraulic properties, and elevating soil organic content and activity of microorganisms. Traditionally, cover crops were grown as single species (monoculture) or as simple legume-cereal mixtures (cultures) (Snapp et al. 2005). Nowadays, studies underline the advantage of implementing cover crops as species-diverse mixtures known as ''cocktails'' (MacLaren et al. 2019). Elhakeem et al. 2018; Thapa et al. 2018; Brainard et al. 2011; Schenck et al. 2017; Ugrenović et al. 2019, and many others emphasized that cover crop mixtures often result in better resource capture, greater productivity, and weed suppression compared with planted cover crops in monoculture. However, there is also evidence of better results achieved with cover crops grown in monoculture than in a mixture when weed suppression is a question (Smith et al. 2020; Vendruscolo et al. 2018).

It is well known that nutrients leaching from agricultural production systems commonly end up into receiving water and are a genuine concern for environmental protection. Besides the detrimental effect of inorganic forms of N leaching, DON (dissolved organic nitrogen) is not something that has to be underestimated. Van Kessel et al. (2009) point out that leaching of DON into stream and drinking water reservoirs causes eutrophication and can become a potential risk to human health. According to them and Liang et al. (2020), cropping systems in which animal manure or urine was applied showed significant DON losses. Apart from the study of Salazar et al. (2019), many other researchers explore the ability of cover crops to lower the amount of both DON and DIN (dissolved inorganic nitrogen) leaching (Salmerón et al. 2011; Gabriel et al. 2012).

Effect of cover crops on wildlife and biodiversity protection

Using cover crops in fallow periods of crop production is an important management tool mainly for reducing nutrient loss and controlling soil erosion. Furthermore, their incorporating in the soil is a widely growing strategy of sustainable agriculture systems because they increase the amount of nitrogen and carbon compounds introduced in the soil, which become the main source of energy for soil microorganisms (Fageria et al. 2005; Brookes et al. 2008; Sharma et al. 2018). According to Bardgett & van der Putten (2014) & Finney et al. (2017), mixtures of multiple species of cultivated cover crops positively impact soil fertility due to diversification of the available food sources for microorganisms and the consequent cash crop, though. Numerous field experiments were conducted in order to examine the effect of simplified crop rotation and diversified crop rotation on soil microbial activity (Finney et al. 2017; Peralta et al. 2018). Results showed that multi-species cover crop mixtures marked a significant increase in the functional groups of microorganisms responsible for the soil's suppressive properties. Above mentioned proves an intensive development of microorganisms and plant protection properties. On the contrary, some species of plants often used as cover crops share the same soil pathogens with the main crop. A live host plant over the winter can maintain or elevate pathogen populations (Smiley et al. 1992) and increase the incidence of main crop seedling root disease (Schenck et al. 2017; Lu et al. 2000). However, to avoid or mitigate this risk, several management improvements like an appropriate selection of species (brassicas, grasses, or legumes), the timing of planting and termination of the cover crop, and methods of termination (chemical or mechanical) should be taken into account.

Long-term cover crop usage significantly contributes to increased biodiversity in the soil environment, especially the earthworm population (*Lumbricidae*), which reduces nutrient and sediment losses in surface runoff (Schmidt et al. 2001; Korucu et al. 2018). Roarty et al. (2017) marked higher earthworm populations when Poaceae and Fabaceae species like oat and pea, respectively, were used as cover crops in comparison with *Brassica* species like mustard which announced large above-ground biomass, but less earthworm population. On the other hand, *Brassica* species, with their flowers, attract many beneficial insects like pollinators, predators, and parasitoids (Figure 2). Therefore, with their establishment between two main cash crops, a positive impact on the biodiversity of valuable insects and bio-control of harmful ones could be achieved (Ugrenović et al. 2019). Besides *Brassica* species, also other legume species used as cover crops (for instance, clovers) are helpful to attract pollinators for improving the rate of pollination in crop fields, orchards, and vineyards (Reddy 2017). Most of these pollinators (57%) belong to the order *Hymenoptera*, within the most numerous are: honeybees (13.8%), wild bees and bumblebees (42.3%), then flies of the order *Anthomyia* (19.8%) and the families Anthomyiidae and Syrphidae (Ugrenović et al. 2019).

Figure 2. *Apis mellifera* as a pollinator of *Brassica napus* L.

Disadvantages of cover crops

Introducing cover crops in crop rotational systems could have some limitations due to farmers' lack of knowledge, proper timeline and management for all agricultural operations, labor and lack of machinery for planting, and terminating cover crops mechanically. Farmers employing cover crops should not expect immediate beneficial results since, in the beginning, they will have increased expenditures for new equipment (Sharma et al. 2018) on one side. On the other, the desired significant increases in main crop yields will occur after the long-term use of cover crops in crop rotations due to the time need it to improve both soil fertility and stores of organic matter (Blanco-Canqui et al. 2015; Toom et al. 2019). Another negative aspect is the confirmation of Lu et al. (2000); Димов (2013) and Bakker et al. (2016) that cover crops are hosts

for insects and pathogens which use the cover crop to complete their life cycle in the offseason and act as a major pest for the main crop, evoking yield loss.

Additionally, cover crops used as grass cover between the rows of fruits and vines plantations could be a reason for rodents' appearance and contribute to increased expenditures for labor and deratization.

Moreover, according to many authors, the negative influence of cover crops on subsequent crops is in connection with the reduction of soil water storage, especially in water-limited regions or when production is under rain-fed conditions and the precipitations are rare (Nielsen et al. 2015; Ćupina et al. 2017; Krstić et al. 2018).

Reasons for implementing cover crops in conventional agriculture in North of Macedonia

The primary sources of soil pollution in the Republic of North Macedonia are mineral fertilization, municipal waste, and urban and industrial activities. Pollution is a real concern to society because it affects biological diversity loss and malfunctioning ecosystems, including excessive input of nutrients (primarily nitrogen and phosphorous). Our country has 1.268.000 ha of agricultural land, of which 510.000 ha are arable land areas. Due to intensive agriculture emphasized by agro-technical measures, soil organic matter, nutrients, and bioactivity are decreasing. On the other hand, erosion processes contribute to the high rate of soil degradation in North Macedonia and result in high topsoil losses, humus, and nutrients from agricultural land. In general, an area of 30000-80000 ha is irrigated and is more prone to land and water degradation since more intensive nutrient leaching (Brajanoska et al. 2018; Stafilov & Šajn, 2019).

Like other Balkan countries (Vojnov et al. 2020), livestock production is not developed enough in our country. Even it has a general trend of decline in the number of livestock units (Table 3). According to the State Statistical Office data, the total number of cattle for 2018 and 2019 were 256 181 and 217 790, respectively, or it decreased by 15% in 2019 compared with 2018. Therefore, as a lack of enough liquid and solid manure from the animal husbandry and, on the other hand, the degradation of the natural environmental resources (soil and water) as a result of increased application of mineral fertilizers, there is a need of introducing alternative organic manures. Cover crops are an accurate match for both economic and environmental aspects. Unfortunately, a common practice in our plant production is leaving the land field bare and fallow after the main crop harvest until the next sowing season.

Table 2. Total number of livestock in North Macedonia by years

Year	Cattle
2010	259 887
2011	265 299
2012	251 240
2013	238 333
2014	241 607
2015	253 442
2016	254 768
2017	255 036
2018	256 181
2019	217 790

Sources: State Statistical Office (2019)

On the one hand, there is a lack of information for producers about the benefits of employing cover crops in commercial production, so there is a need to strengthen the knowledge and information-sharing mechanisms. On the other hand, there is a need to assess the effects of different cover crops grown as green manure under our agro-ecological conditions. Presumably, implementing them in crop rotation systems under rain-fed conditions will not be satisfying since they will contribute to water depletion in main crop growth. Additionally, due to decreased average precipitations and increased average temperatures compared with the long-term average (Domazetova 2011; UHMR 2020), the employment of cover crops will be accepted under irrigation conditions. Nevertheless, testing, selection, and breeding efforts, over the long term, should identify potential cover crop species that can match the lack of precipitations and have positive effects on the main crop in our environmental conditions.

Conclusion

We could summarize that cover crops are an essential measure that has been taken in sustainable agriculture. They increase environmental protection by reducing soil erosion (water and wind erosion), providing better physical, chemical, and biological soil properties, reducing nitrate N leaching, and reducing groundwater pollution. Furthermore, with their establishment between two main cash crops, a positive impact on the biodiversity of useful insects and bio-control of harmful ones could be achieved.

Against many benefits, they could have some limitations due to labor and lack of machinery for their planting and terminating. Moreover, some cover crops are hosts for insects and pathogens, which use the cover crop to complete their life cycle in the offseason and act as a major pest for the main crop, evoking yield loss.

In our country, because of the decline of animal production and reduced availability of organic fertilizers, there is a need to introduce alternative organic manures. Cover crop species have different agro-technical requirements as well as morphological,

physiological, and phenological characteristics. Therefore more attention should be paid to proper selection of cover crop species in conditions where rainfalls are limited. In general, there is a lack of thorough studies for an appropriate selection of plant species or their mixture determined by our agro-ecological conditions, as well as the purpose of their use. Additionally, there is a need to strengthen the knowledge and information-sharing mechanisms with Macedonian farmers.

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