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REVIEW PAPERS

CATCH CROPS AND THE SOIL ENVIRONMENT – A REVIEW OF THE LITERATURE*

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Abstract

This review analyzes the effect of catch crops on the chemical, physical and biological properties of the soil environment. Catch crops deliver environmental benefits, and they are widely recommended by programs which promote environmentally friendly agricultural practices. Plant species (such as white mustard and phacelia) characterized by rapid growth in early stages of development as well as low soil and nutrient requirements are best suited for the role of catch crops. The aim of this study was to determine the influence of catch crops on the content of organic carbon (C) and nutrients in soil, the factors that determine the rate of organic matter decomposition in soil. Catch crops can limit the migration of nutrients (in particular nitrogen – N and phosphorus – P) into deeper soil layers, and they influence soil pH, the physical parameters of soil such as compaction, porosity, water content and temperature, and the biological and enzymatic activity of soil. Catch crops play very important roles in agricultural ecosystems, and their influence is determined mainly by habitat conditions (weather and soil parameters), plant species, biomass volume and agronomic factors. Catch crops increase the organic carbon content of soil, they limit nutrient leaching (in particular nitrogen and phosphorus) into deeper soil horizons, decrease soil compaction, improve soil aeration and soil water relations, increase soil porosity, improve soil structure, enhance microbial and enzymatic activity in soil. Catch crops increase agricultural production in all climates, soils and farming systems.

Keywords: chemical properties, physical properties, biological properties, gas exchange.

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INTRODUCTION

Crop plants are a source of food and feed, but catch crops are also cultivated to restore soil fertility. Catch crops deliver environmental benefits, and they are widely recommended by programs which promote environmentally friendly agricultural practices. Catch crops improve soil structure, promote the formation and stability of soil aggregates, limit water loss and migration of nutrients into deeper soil layers, they shade and cool the soil surface, protect soil against wind and water erosion, promote the growth of soil-dwelling microorganisms and enhance soil biological activity (Arlauskienė, Maikšteniene 2010, Ji, Unger 2001, Wanic et al. 2013, Piotrowska-Długosz, Wilczewski 2014*a*,*b*).

Plant species characterized by a short growing season, rapid growth in early stages of development, low soil and nutrient requirements are best suited for the role of catch crops. White mustard is the most popular catch crop species with a high dry matter yield, which effectively controls the spread of the golden nematode (*Globodera rostochiensis*) in soil. Phacelia is also a popular and rapidly growing catch crop species which has low soil and nutrient requirements and a short growing season. Phacelia is a species that is unrelated to crop plants, which rules out the transmission of pests and diseases and exerts phytosanitary effects on soil (Kraska, Mielniczuk 2012).

The aim of this review is to analyze the influence of catch crops on the soil environment.

CHEMICAL PROPERTIES OF SOIL

Catch crops are cultivated to improve the organic matter content of soil, prevent nutrient leaching (mainly nitrogen – N and phosphorus – P) and enhance the activity of soil-dwelling microorganisms (Askegaard, Eriksen 2008, N'Dayegamiye, Tran 2013, Piotrowska-Długosz, Wilczewski 2014*a*,*b*, Liu et al. 2015). Catch crop biomass is incorporated into the soil to increase its organic carbon (C) content. The quantity of organic matter is determined by a plant species, seeding date, length of the growing season, agronomic factors, weather and soil conditions. In a study by N'Dayegamiye and Tran (2013), the total catch crop biomass varied widely from 274 kg ha^{-1} in *Trifolium pratense* to 5840 kg ha^{-1} in *Echinochloa crus-galli*. The biomass values reported by Talgre et al. (2011) were also high, in the range of 2883 kg ha^{-1} in *Lotus corniculatus* to 4779 kg ha^{-1} in *Melilotus albus* (Table 1). The rate at which organic matter is decomposed is largely determined by its quantity and the C:N ratio (Talgre et al. 2012). Catch crops with a narrow C:N ratio induce rapid changes in the physical and biological properties of soil (Abdallahi, N'Dayegamiye 2000), and they accelerate soil mineralization. The above

Table 1

Content of organic carbon and the C:N ratio in catch crop biomass (kg ha^{-1})

Catch crops	C	C:N	Soil	Percipitation, air temperature	Country/Authors
Hordeum vulgare	1340.1	19.91	Typical Calcixerept, clay loam	350 mm, 14°C	Spain SANZ-COBENA et al. (2014)
Brassica napus	830.1	14.81			
Vicia villosa	622.0	11.20			
Trifolium pratense	4125*	25	Stagnic Luvisol, sandy loam	584 mm, 6.1°C	Estonia TALGRE et al. (2012)
Lotus corniculatus	2883*	31			
Medicago sativa	3536*	26			
Melilotus albus	4779*	27			
Lupinus angustifolius	876	15	Endocalcari-Endohypogleic Cambrisol, clay loam on silty clay	630 mm ** 85.5 mm (with catch crops) 6.5-7.0°C	Lithuania JANUŠAUSKAITĖ et al. (2013)
Lupinus angustifolius + *Avena sativa*	617	14			
Sinapis alba	1477	13			
Trifolium pretense	274 -353	24-27	Humic gleysol, silt loam	1184 mm, 6.2°C**	Canada N'DAYEGAMIYE and TRAN (2013)
Echinochloa cruss galli	2264-5840	35-37			
Fagopyrum esculentum	1355-1874	26-30			
Brassica campestris	1173-2387	20-25			
Brassica hirta	1417-1970	23-28			
White mustard	363-481*	13.0	Haplic luvisol on calcareous bedrock	604 mm, 11.5°C	France CONSTANTIN et al. (2010)
Raphanus sativus or winter cereal	585-622*	16.8-17.2	Reddina with a loam texture on chalk	605 mm, 10.8°C	
Lolium multiflorum	998*	28.2	Dystric cambisol on granite bedrock	1213 mm, 12.1°C	

* including the root system

** data for central Lithuania and Quėbec City (Canada): https://pl.climate-data.org

increases the yield and the N content of successive crops. Most catch crops, in particular plants of the family *Fabaceae*, are characterized by low hemicellulose and lignin content and high N content, and they are generally quickly decomposed in soil. The C:N ratio of catch crops ranged from 11.2 in *Vicia villosa* to 37 in *Echinochloa crus-galli* (Table 1).

The rate of organic matter decomposition is determined not only by a plant species, its biomass volume and C:N ratio, but also by soil conditions (temperature, moisture content, acidity, aeration, etc.). The humification rate of organic matter from catch crops is estimated at 28%, and it is much higher than in cereal straw (11-14%) – Thomsen, Christensen (2004). However, the accumulation of organic matter in soil is a long-term process, and it is not always evaluated in research studies. N'Dayegamiye and Tran (2001) demonstrated that catch crops (clover, millet, buckwheat, rapeseed and mustard) significantly increased the total C and N content of soil (mostly millet and rapeseed), but did not influence the C and N content of labile and heavy fractions of organic matter. In a study by Pałys et al. (2009), serradella, red clover, white clover and hop trefoil also contributed to a significant increase in the C content of soil. However, the above catch crops did not lead to changes in the chemical properties of soil in a 3-year experiment (Eichler-Löbermann et al. 2008), a 4-year experiment (Wanic et al. 2013) and an 8-year experiment (Debosz et al. 1999). This indicates that catch crops have low biomass volume and are rapidly mineralized (Wanic et al. 2013). In a model study by Blombäck et al. (2003), catch crops cultivated for 6 years increased the organic matter content of soil by less than 2%. Catch crops also increase humic acid and humin concentrations and decrease the content of fulvic acids in soil (Krężel, Miklaszewski 1988).

Catch crops inhibit nutrient leaching (mainly N and P) into deeper soil horizons (Askegaard, Eriksen 2008). During the growing season, catch crops take up soil nutrients and incorporate them into plant tissues; therefore, they can effectively remove excess nutrients from the soil profile (Liu et al. 2015). Nutrients are accumulated in plant tissues and are gradually released from decomposing organic matter. Talgre et al. (2012) and Wojciechowski and Wermińska (2016) found the highest nutrient uptake levels in peas, faba beans and their intercrops. The amount of N fixed by catch crops varies across species, and it is determined by their biological N fixation ability, biomass volume, seeding date, availability of N in soil and habitat conditions (Van DAm 2006). Under the most favourable weather conditions, catch crops accumulated 50-100 kg N (up to 200 kg N in some studies), 7-10 kg P and 40-60 kg K per hectare. In nutrient-poor soils, catch crops are not highly effective fertilizers due to low biomass yields (Liu et al. 2015). Organic matter is gradually decomposed by soil-dwelling organisms, which leads to the release of plant-available nutrients (Wilczewski et al. 2013). Catch crops which accumulate more nutrients are also more abundant sources of nutrition for the successive crop.

Catch crops inhibit N leaching more effectively than agricultural treatments such as reduced tillage or fertilization, and they produce longer-lasting results. In soils planted with catch crops, phosphate concentrations are maintained below 50 mg l^{-1} for an extended period of time (Constantin et al. 2010). Askegaard et al. (2005) demonstrated that catch crops decreased N leaching by 20% (grasses and oilseed crops) to 70% (protein crops). However, phosphate concentration at a depth of 60 cm increases when the growth of catch crops is limited. The beneficial influence of catch crops decreases in long-term cultivation. Nutrient leaching is lower in compact soils and dry climates, and higher in light soils and compact loamy soils with higher moisture content (Constantin et al. 2010). Macdonald et al. (2005) demonstrated that catch crops deliver the greatest benefits when grown on sandy soils, where N is most rapidly lost. Owing to biological N fixation, catch crops of the family *Fabaceae* supply soil with more inorganic N than non-leguminous plants (Rinnofner et al. 2008). In a study by Talgre et al. (2011), the concentrations of NO_3- and NH_{4+} in soil were not reduced in treatments with catch crops, relative to the control treatment without a catch crop.

When catch crops are discontinued, organic matter is rapidly mineralized by microorganisms, which increases nitrogen leaching loss and contributes to denitrification. Blombäck et al. (2003) demonstrated that in the first year after the discontinuation of catch crop use, 30% of N was lost due to mineralization. Similar results were reported by Thomsen and Christensen (1999) in a study analyzing the mineral content of soil 5 years after the discontinuation of catch crops. This problem can be resolved through crop rotation schemes involving plants that effectively take up excess nitrates from soil. Winter wheat is characterized by a long growing season, and it is capable of absorbing around 35% of N deposited in the soil by the preceding catch crop. The above indicates that in fields planted with catch crops, N fertilization can be limited without the risk of lower yields (Hansen et al. 2000, Berntsen et al. 2006).

Catch crops, in particular plant species which accumulate significant amounts of P, increase the phosphorus content of soil and minimize P leaching. In a study by Eichler-Löbermann et al. (2008), oilseed radish, phacelia and ryegrass produced 3-times more aerial biomass and accumulated nearly twice as much P as did buckwheat and serradella. Catch crops which produce less biomass accumulate less P and are less effective in preventing the loss of this nutrient. In general, perennial plants produce more biomass and accumulate more P than annual plants because the former have a wider root to shoot ratio (Liu et al. 2015). Phosphorus is gradually released from decomposing organic matter of catch crops. During the growing season, catch crops produce root secretions which solubilize P and make it more available to plants. An important role is played by mycorrhizal fungi that enter into a symbiotic relationship with the plant's roots. The release of P from organic matter is a complex process which is determined by many factors, including the P content of soil, catch crop species, the N:P ratio in organic matter, the rate of mineralization and the P cycle. The content of available P is also influenced by the plant species. Phacelia and ryegrass are characterized by similar P uptake, but they exert different effects on the concentration of plant-available P in soil and P uptake by the main crop (Eichler-Löbermann et al. 2008). These authors demonstrated that phacelia and serradella increased the P content of soil and P uptake by the main crop. Not all catch crops favour the accumulation of phosphorus in the soil, for instance ryegrass immobilized P, thus decreasing the P content of soil and P uptake by the main crop. According to Schomberg and Steiner (1999), the above could result from the presence of P-deficient organic matter in soil. The described scenario is observed when catch crops have a wide C:P ratio (Singh, Jones 1976) and/or when their P content is below the mineralization threshold of 200-300 mg 100 g^{-1} DM. Phosphorus could also be immobilized by the extensive root system of ryegrass which is abundant in lignin, a compound which is resistant to biochemical degradation (Rasse et al. 2006).

Phosphorus is also released by the roots and shoots of plants exposed to freeze-thaw cycles during winter. According to Liu et al. (2013), plants that undergo freezing and thawing lose more P than plants not exposed to extreme fluctuations in temperature. The greatest amounts of P are lost from the aerial parts of plants. The amount of P released by shoots and roots is highly correlated with their total P content. Some research shows that catch crops can increase the pH of soil (Orzech 2013), whereas other studies do not confirm these findings (Pałys et al. 2009, Majchrzak 2015).

PHYSICAL PROPERTIES OF SOIL

Catch crops influence the physical properties of soil. During the growing season, plants protect the soil against wind and water erosion, and crust formation (Sumner, Stewart 1992). The organic matter introduced into the soil increases the C and N content of soil, soil compaction and soil moisture content (Fraser et al. 1988). In the studies conducted by Hubbard et al. (2013), Majchrzak (2015), and Tendziagolska et al. (2010) catch crops decreased soil compaction (Table 2). The incorporation of *Sinapsis alba* biomass decreased soil compaction in the arable layer (to a depth of 10 cm) by 22.2% (Majchrzak (2015). In turn, soil compaction in the 0-20 cm layer decreased by 5.8% (Tendziagolska et al. 2010). Catch crops such as *Lolium multiflorum*, *Trifolium pratense* and *Sinapsis alba* had no influence on soil compaction (Wojciechowski 2009, Orzech 2013). However, de Cima et al. (2015) demonstrated significant variations in the physical parameters of soil between a conventional system and an organic system with cover crops. In the cited study, soil water content ranged from 15.2 to 19.8%, dry bulk density – from 1.39 to 1.60 Mg m^{-3}, total porosity – from 38.7 to 46.5%, and air-filled porosity – from 13.1 to 19.1%. Plant-available water and non-available water was estimated at 15.8-22.8 and 4.6-14.0%, respectively. Soil permeability ranged from 19.9 to 103.8 cm d^{-1}.

Catch crops left in the field as mulch increased the moisture content of soil by inhibiting surface runoff, improving infiltration and decreasing evaporation (Ji, Unger 2001, Wanic et al. 2013). Hubbard et al. (2013) demonstrated that catch crops increased hydraulic conductivity and volumetric soil

Table 2

Impact of catch crops on soil compaction

Catch crops	Soil layer (cm)	Increase/ decrease (%)	Soil (texture), annual percipitation and air temperature	Country/Authors
Crotalaria juncea	0-2.5	-1.2	loamy sand 1192 mm 18.6°C	USA HUBBARD et al. (2013)
Lolium perenne, mixtures of *Lolium perenne* and *Chichorium* and *Trifolium* species	0-5	-3.3	78% sand,13% silt, 9% clay 704 mm 7.3°C	Denmark CHIRINDA et al. (2010)
Sinapis alba	0-10	-22.2	loamy sand 600 mm 8.3°C	Poland MAJCHRZAK (2015)
Trifolium repens	0-20	-5.8	loamy sand 548 mm 9.7°C	Poland TENDZIAGOLSKA et al. (2010)
Raphanus sativus	0-20	-5.2	silt loam 10% sand, 77% silt,13% clay 681 mm 7.7°C	Poland GŁĄB and KULIG (2008)
Lolium multiflorum *Trifolium pratense* *Sinapis alba*	0-30	0	sand or loamy sand 546-600 mm, 5.5-7.8°C	Estonia: DE CIMA (2015) Poland: ORZECH (2013) WOJCIECHOWSKI (2009)

moisture content. However, in a study by GŁĄB and KULIG (2008), fodder radish mulch did not influence the content of available or productive water in soil.

Plants of varied height and root density take up water and nutrients from deeper soil horizons. They form pores in the soil profile, which promotes root growth in successive crops, improves aeration and water penetration. Organic matter increases soil porosity and promotes macropore formation (GŁĄB, KULIG 2008). Decomposed plants are a source of nutrients for earthworms, and they improve habitat conditions for soil-dwelling microorganisms. Earthworms increase the number of medium-sized and large pores, which increases soil porosity. They also improve the structure of soil and the stability of soil aggregates (SUMNER, STEWART 1992). Organic matter decreased bulk density to 1.25 g cm^3 at a depth of 0-10 cm and increased macropore size by as much as 125.5%, but only in the treatment with reduced tillage (GŁĄB, KULIG 2008). Catch crops play an important role in compact soils in simplified tillage systems by increasing total porosity and decreasing the bulk density (GŁĄB, KULIG 2008) of soil, which can be attributed to higher C content and higher soil biological activity (GHUMAN, SUR 2001).

In the reviewed studies, catch crops exerted highly varied effects on soil temperature. Wanic et al. (2013) did not observe any influence of ploughed-in biomass of red clover and Italian ryegrass on soil temperature, whereas Majchrzak (2015) reported that white mustard induced a significant increase of approximately 0.7-0.9°C in soil temperature. According to Dahiya et al. (2007), decomposing plants create an insulation layer between soil and the external environment and minimize daily fluctuations in temperature. The effect of catch crops on soil temperature decreases with depth.

Catch crops increase evapotranspiration during the growing season. Van Dam and Leffelaar (1998) demonstrated that evapotranspiration was 4-5 times higher in fields with winter rye and fodder radish as catch crops, where potential evapotranspiration levels were occasionally exceeded. However, when catch crops were left in the field as mulch, evapotranspiration decreased below the levels noted in fallow plots (Kaye, Quemada 2017).

BIOLOGICAL PROPERTIES OF SOIL

Catch crops induce changes in the size and structure of microbial communities (Table 3) and the activity of soil enzymes. Plants promote the development of selected groups of soil-dwelling microorganisms, while inhibiting the growth and enzymatic activity of other microbial groups (Elfstrand et al. 2007). These differences result from changes in the physical properties of soil and the supply of readily available C and N, which constitute substrates for soil microbes.

Soil-dwelling microorganisms act as transitional nutrient reservoirs and are responsible for the decomposition and transformation of organic matter (Ananyeva et al. 1999). Microbial biomass and activity are the main biological indicators of soil quality, and they respond rapidly to agronomic factors, in particular fertilization, pesticides and tillage. Catch crops stimulate soil enzymatic activity by promoting the the growth of microorganisms, inducing enzyme production and the activity of enzymes released by plants. The ability of various microbial groups to produce enzymes is influenced by plant species. Catch crops stimulate the development of selected microbial groups, and inhibit the growth of other microorganisms (Elfstrand et al. 2007). They are a source of nutrients for microorganisms both during and after the growing season (Thorup-Kristensen et al. 2003).

Piotrowska-Długosz and Wilczewski (2014a) reported greater abundance of microbial biomass (by 30-50%) in soil enriched with decomposing *Pisum sativum* as the catch crop (Table 3). Microbial biomass in soil also increased by more than 20% in treatments where *Lolium perenne,* mixtures of *Lolium perenne*, *Chicorium* and *Trifolium pratense* and *Trifolium repens* were grown as catch crops (Chirinda et al. 2010), and by 2.4-2.6 fold when the applied catch crops were *Trifolium pratense, Brassica napus* and their mixtures

Table 3

Impact of catch crops on the abundance of soil-dwelling microorganisms

Catch crops	Microorganisms	Soil (texture), annual percipitation and air temperature	Country/Authors
Pisum sativum	25.6-29.2 19.7* N mg kg^{-1}	79% sand, 15% silt, 65% clay 432 mm 7.8°C	Poland Piotrowska-Długosz and Wilczewski (2014*a*)
Lolium perenne, mixtures of *Lolium perenne* and *Cichorium* and *Trifolium* species	39-47 32-36* N mg kg^{-1}	78% sand, 13% silt, 9% clay 704 mm 7.3°C	Denmark Chirinda et al. (2010)
Trifolium pratense *Brassica napus* their mixture	265.7 290.0 293.1 111.3* C g kg^{-1}	73% sand, 15% silt, 12% clay 564 mm + watering 19.1°C **	Spain Tejada et al. (2008)
Green manure (grass)	Bacteria: 34.3 20.3* nmol g^{-1} Fungi: 1.8 0.95* nmol g^{-1}	23% sand, 41% silt, 36% clay 670 mm 5.8°C**	Sweden Elfstrand et al. (2007)

* without catch crops

** data for Sevilla (Spain) and for Uppsala (Sweden): https://pl.climate-data.org

(Tejada et al. 2008). Bacterial biomass increased by 70% and fungal biomass increased by 90% when grasses were grown as catch crops (Elfstrand et al. 2007). Soil-dwelling microorganisms secrete enzymes that decompose organic matter, therefore soil enzymatic activity increases when green fodder is incorporated into the soil (Tejada et al. 2008). Fresh plant biomass is a source of readily available nutrients for microorganisms, and its quality influences the rate of organic matter decomposition and nutrient release (Arlauskienė, Maikšteniene 2010).

Majchrzak (2015) demonstrated that white mustard ploughed in the spring did not influence the total counts of bacteria and copiotrophs, but increased the counts of *Azotobacer*, fungi and oligotrophs, and enhanced dehydrogenase activity in soil. The incorporation of catch crop biomass of white mustard and a mixture of oats with legumes into the soil also stimulated the growth of cellulose-decomposing bacteria (respectively by 31% and 57%) (Wojciechowski 2009).

According to Piotrowska and Wilczewski (2012), *Pisum sativum* biomass significantly increased the microbial biomass and enzymatic activity of soil. This above could be attributed to biological N fixation, which influences enzymatic activity (Roldán et al. 2003), as well as the relatively high volume of field pea biomass. Legume plants are particularly abundant in N and other plant-available nutrients. Legume biomass is characterized by a narrow C:N ratio, and it stimulates microbial activity in soil, which promotes organic matter decomposition (Fageria et al. 2005, Piotrowska, Wilczewski 2012). The above could be attributed to the biological fixation of nitrogen, which influences enzymatic activity (Roldán et al. 2003). Piotrowska and Wilczewski (2012, 2014*a*,*b*) reported that field peas and oilseed radish catch crops increased the activity of enzymes such as alkaline phosphatase (by nearly 20%), acid phosphatase (by nearly 20%), ß-glucosidase (by nearly 40%), dehydrogenase (by nearly 50%), catalase (by more than 10%) and fluorescein diacetate (by 10%) in the cultivation of spring wheat, particularly in combination with moderate doses of N fertilizer. Both catch crops induced a similar increase in the activity of acid phosphatase, dehydrogenase and fluorescein diacetate, whereas catalase activity was higher in soils enriched with field peas than with oilseed radish. Field peas and grass grown as catch crops were also found to stimulate the activity of protease (by 35-200%), acid phosphatase (about 5%), nitrate reductase (above 20%) – Piotrowska, Wilczewski (2012), dehydrogenase and urease (by 15-50%) – Chirinda et al. (2010), Janušauskaitė et al. (2013). Abdallahi and N'Dayegamiye (2000) demonstrated that catch crops with a narrow C:N ratio promoted a rapid increase in microbial biomass, alkaline phosphatase and urease activity, and N mineralization.

A greater increase in microbial biomass was observed when catch crops were incorporated into the soil in spring than in autumn (Piotrowska-Długosz, Wilczewski 2014*a*). When green manure is applied in spring, it increases the availability of N during the growing season and minimizes N leaching (Thorup-Kristensen, Dresbøll 2010).

The introduction of catch crops in crop rotation increases earthworm density and biomass, and the density of earthworm channels in soil. Earthworms decrease soil compaction, improve soil structure, increase the content of humic substances and nutrients, improve soil aeration, increase water content and soil capillary action (Riley et al. 2008).

The size of earthworm populations and their activity are influenced by the volume and quality of catch crop biomass, root exudates produced by catch crops, soil parameters (organic matter content, texture, compaction, pH, temperature, moisture content) and climate (Palm et al. 2013). Organic matter rich in N (legume plants) is a particularly valuable source of nutrients for earthworms. Frøseth et al. (2014) demonstrated that earthworm density increased when grass and *Trifolium pratense* were left in the field as mulch. These catch crops contributed to the survival of old earthworms and the development of young individuals. In the cited study, the number of earthworms increased 1.4- to 2.6-fold and earthworm biomass increased 1.2- to 3.3-fold in the first year after mulching relative to the control treatment without catch crops. Similar results were reported by Riley et al. (2008) who found that the number and biomass of earthworms was several times higher in an organic system with Italian ryegrass as the catch crop than in a conventional system without catch crops.

BUCK et al. (2000) demonstrated that in treatments with lupine catch crops, *Lumbricus terrestris* and *Octolasion cyaneum* increased the content of water-stable aggregates (WSA) by more than 70%. The influence of earthworm secretions on WSA is largely determined by the chemical composition of plant foods (content of carbohydrates, adhesives and fiber, C:N ratio). In the cited study, cast production by *Lumbricus terrestris* ranged from 280 to 431 mg DM g^{-1} per day, and cast production by *Octolasion cyaneum* – from 852 to 1305 mg DM g^{-1} per day. It should be noted that nearly all N in earthworm casts is fixed and protected against leaching.

Gas exchange is also a robust indicator of soil biological activity (N'DAYEGAMIYE, TRAN (2001). Barley and oilseed rape mulch nearly doubled microbial respiration in soil in comparison with the treatment without catch crops. Microbial respiration is directly linked with the carbon content of catch crop biomass (SANZ-COBENA et al. 2014). CHIRINDA et al. (2010) demonstrated that the incorporation of perennial ryegrass and a mixture of ryegrass, chicory and clover into the soil increased CO_2 emissions by 30% in winter wheat relative to the treatment without catch crops. Carbon dioxide emissions increased with a rise in the proportion of catch crops in crop rotation. In the cited study, catch crops did not influence N_2O emissions. SANZ-CORBENA et al. (2014) found that vetch and barley mulch increased CO_2 and N_2O emissions by 75% and 47%, respectively. Catch crops abundant in N were responsible for higher N_2O emissions. However, CHIRINDA et al. (2010) argued that catch crops have a negligent influence on N_2O emissions in the temperate climate. Contrary results were presented by BAGGS et al. (2000), who demonstrated that catch crops reduced N_2O emissions from 61 g ha^{-1} to 23-44 g ha^{-1} in 19 days. In a study by SANZ-COBENA et al. (2014), catch crops did not affect NH_4 emissions.

CONCLUSIONS

Catch crops exert a beneficial influence on the soil environment and plant health, therefore they are an important agronomic factor and an element of environmentally friendly agricultural programs (Rural Development 2014-2020). Catch crops prevent the migration of nutrients, mainly N and P, into deeper soil horizons by up to 70%. Catch crops promote the sequestration of atmospheric CO_2 and N_2 (legumes) and increase the content of humic substances in soil. Catch crops decrease soil compaction (by up to 20%), increase soil moisture content, temperature and porosity, and improve soil structure. The incorporation of plant biomass into the soil increases the content of soil-dwelling microorganisms (by 20-80%), earthworms (1.4- to 2.6-fold) and soil enzymatic activity (even two-fold). Catch crops promote the exchange of CO_2 between the soil and the atmosphere. Their effects on denitrification vary subject to local habitat conditions. A wide variety of plant species can be grown as catch crops in all climates, soils and farming systems.

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