Journal of Elementology ISSN 1644-2296

Żuk-Gołaszewska K., Wanic M., Orzech K. 2019.
*The role of catch crops in field plant production – A review.*
J. Elem., 24(2) 575-587. DOI: 10.5601/jelem.2018.23.3.1662



RECEIVED: 10 April 2018
ACCEPTED: 19 October 2018

REVIEW PAPER

# THE ROLE OF CATCH CROPS IN FIELD PLANT PRODUCTION – A REVIEW*

**Krystyna Żuk-Gołaszewska[1], Maria Wanic[2], Krzysztof Orzech[2]**

**[1] Department of Agrotechnology, Agricultural Production Management and Agribusiness**
**[2] Department of Agroecosystems**
**University of Warmia and Mazury in Olsztyn, Poland**

### Abstract

Sustainable farming systems have recently gained significant interest, which reflects the need to protect biodiversity and maintain environmental balance. One of the strategies involves the use of catch crops. Catch crops can be grown in all agricultural systems, but they are particularly recommended for organic and sustainable farming. The aim of this review article was to discuss the functions performed by catch crops, with particular emphasis on their role in weed and disease control, effects on soil fertility, and the yield and chemical composition. Many plant species can be used as catch crops, which should be characterized by rapid growth in early stages of development and allelopathic properties. Popular catch crop species are *Sinapis alba*, *Phacelia tanacetifolia* and *Lupinus luteus* L., *Vicia faba* L., *Vicia villosa* Roht., *Trifolium pratense* L., *Trifolium repens* L., *Medicago lupulina* – plants from the family Leguminosae. Intercropping contributes to lower weed pressure and improves plant health by decreasing the incidence of stem base, leaf and spike diseases. Therefore, catch crops can help minimize the use of pesticides, and alleviate the adverse effects of cereal monoculture. The effectiveness of catch crops is influenced by the main crop, the type and plants of catch crops, the type of pathogen/pest and weed species, habitat conditions. Catch crop biomass incorporated into the soil improves crop efficiency and quality by increasing the availability of biogenic elements required for the growth and development of main crops.

**Keywords:** species, catch crops, pathogens, pests and weeds, yield, chemical composition.

Krystyna Żuk-Gołaszewska, assoc. prof., Department of Agrotechnology, Agricultural Production Management and Agribusiness, University of Warmia and Mazury in Olsztyn, ul. Oczapowskiego 8, 10-719 Olsztyn, Poland, phone: 48 89 523 47 13, e-mail: kzg@uwm.edu.pl

* This study was financed by funds allocated to the statutory research at University of Warmia and Mazury in Olsztyn.

## INTRODUCTION

Biodiversity plays a key role in sustainable agriculture (Jaskulski, Jaskulska 2011*a,b*). Catch crops are an important element of sustainable farming. In agricultural production, catch crops are defined as additional plant species that (1) are grown for biomass between successive plantings of the main crop (intercrops), (2) are sown in spring together with the main crop, such as spring barley, or are sown into winter cereals in spring or after the emergence of spring cereals (undersown catch crops). After the main crop is harvested, undersown crops are left in the field until late fall (such as serradella undersown in rye) or until the following season, such as small seed legumes (e.g. red clover) sown into spring cereals, e.g. spring barley (Wanic et al. 2004, Šarūnaitė et al. 2010, Talgre et al. 2011).

Catch crops exert a positive influence on field production, and they used in both specialized and simplified crop rotation systems, including zero-till direct seeding systems (Kordas et al. 2000), as an additional source of nutrients for the main crop. Intercropping is also an important element of agricultural and environmental programmes in the European Union (Jaskulska, Gałęzewski 2009). Catch crops protect soil and act as a source of nutrients in soil conservation practices. Intercropping minimizes weed pressure and decreases the risk of disease and pests, which increases productivity and improves the quality of the final product in agricultural production (Płaza et al. 2007, Rinnofner et al. 2008, Askegaard et al. 2011, Wanic et al. 2012, Ulla et al. 2014).

Plant species grown as catch crops have to be characterized by rapid development in early stages of the growth and the ability to generate large quantities of biomass. A good example is *Synapsis alba* L., which can produce 12-15 t ha$^{-1}$ of biomass under favourable conditions. Other popular catch crops are species from the family Leguminosae, including *Lupinus luteus* L., *Vicia faba* L., *Vicia villosa* Roht., *Trifolium pratense* L., *Trifolium repens* L., *Medicago lupulina* L., *Ornithopus sativus* L. and *Melilotus albus* L., which are intercropped with cereals (Pałys et al. 2009, Šarūnaitė et al. 2010).

This study discusses the role of catch crops in plant production, including their ability to control pathogens, pests and weeds, and their influence on the yield and quality of major food crops.

## CATCH CROPS VS. WEED INFESTATION AND PLANT HEALTH

Environmentally friendly methods of pathogen, pest and weed control play a very important role in sustainable agriculture, in particular in the production of field crops. Intercropping minimizes weed pressure and improves plant health. The effectiveness of catch crops is influenced by the type of pathogen/pest and weed species, habitat conditions, the type and species of catch crops, the main crop, its health and competitiveness. Catch crops are more effective in controlling weeds than pathogens and pests (WOJCIECHOWSKI 2009, ULLA et al. 2014). ULLA et al. (2014) demonstrated that the incorporation of white mustard, oilseed radish and annual grasses (Italian ryegrass and westworlds ryegrass) into the soil decreased the number and biomass of weeds such as *Apera spica-venti, Matricaria maritima* and *Capsella bursa-pastoris*. The best results were reported when white mustard was grown as a catch crop. In a study by WOJCIECHOWSKI (2009), white mustard grown as a catch crop was more effective than legumes and oats in inhibiting the growth of weeds in winter wheat. DERYŁO and PAWŁOWSKI (1992) reported that white mustard and oilseed radish planted into stubble decreased several times the number and biomass of weeds in cereals, which indicates that these catch crops exert allelopathic effects. White mustard and oilseed radish released allelopathic compounds into the soil, thus inhibiting the growth of many weed species. In a study by KRETSCHMER and BERGER (1990), catch crops also contributed to weed control, and their influence was determined by the amount of the produced biomass. WACŁAWOWICZ et al. (2006) reported that catch crops planted into stubble not only inhibited weed growth, but also decreased their soil seed bank. Undersown red clover and Italian ryegrass effectively minimized the number and biomass of weeds. Their positive influence resulted from increased stand density, ability to effectively compete with weeds for growth factors (space, light, water and biogenic elements) and chemical interactions between plants (JASKULSKI et al. 2000, WANIC et al. 2004), which are observed in mixed-species stands (JASKULSKI et al. 2000). Similar results were reported by PAWŁOWSKI and WOŹNIAK (2000) from their study where the number and biomass of weeds in winter triticale was significantly higher after the ploughing-in of manure than after the incorporation of westworlds ryegrass and serradella biomass into the soil. Serradella was more effective in controlling weeds than ryegrass. RASMUSSEN et al. (2006) demonstrated that spring barley undersown with grasses and clover was less infested with weeds than when pure sown. The ability of undersown clover to reduce weed infestation was confirmed by JASTRZĘBSKA (2009) and WANIC et al. (2004, 2005). In turn, undersown clover in oats and spring wheat did not reduce the number of annual weeds, but it decreased their soil seed bank (WACŁAWOWICZ et al. 2006, SJURSEN et al. 2012). According to ORZECH (2013), undersown crops inhibited the growth of weeds in barley stands, but were less effective than herbicides. This way of cultivation is not as effective as chemical control agents, but it can curb weed growth to a level that does not affect crop yields. However, RASMUNSSEN et al. (2006) demonstrated that undersown crops exerted a minor influence or no influence on weed growth. In a study by HRUSZKA and BRZOZOWSKA (2008), catch crops insufficiently protected the main crop against weeds, and they could contribute to an increase in the soil seed bank. BOGUZAS et al. (2006)

and Stupnicka-Rodzynkiewicz et al. (1998) demonstrated that catch crops increased the number of weeds, in particular in fields where post-harvest cultivation was abandoned.

The results of studies investigating the influence of intercropping on disease control in cereals were inconclusive. Catch crops were more effective in eliminating pathogens colonizing stems than leaves and spikes. Wanic et al. (2012) demonstrated that undersown crops had no influence on the severity of net blotch, Septoria leaf blotch, Fusarium head blight and stem-base diseases (*Fusarium* spp. and *Tapesia yallundae*) in spring barley. Powdery mildew, scald, leaf strip and diseases caused by *Rhizoctonia* fungi were more prevalent in barley undersown with Italian ryegrass and red clover. Askegaard et al. (2011) found that the severity of stripe rust was lower in spring barley intercropped with grasses and clover than in treatments without catch crops. Similar results were reported by Skuodiene and Nekrosiene (2012), who demonstrated that ploughed-in red clover, white clover and alfalfa, grown as catch crops, decreased the severity of Septoria leaf blotch and tan spot in triticale and barley. However, the above catch crops were less effective than timothy-grass in reducing the rates of infections caused by *Drechslera teres* and *Drechslera sorokiniana,* which suggests that these fungal pathogens thrive in soils that are more abundant in nitrogen. Pawłowski and Woźniak (2000) observed that triticale undersown with Italian ryegrass was more susceptible to fungal stem-base diseases, whereas serradella was more effective in controlling the development of these pathogens. Kraska and Mielniczuk (2012) also demonstrated that undersown westworlds ryegrass increased the prevalence of stem-base infections caused by *Fusarium culmorum* in spring wheat, whereas red clover undersown into a stand and white mustard and blue phacelia planted into cereal stubble inhibited the growth of fungal pathogens. In cereal monocultures, catch crops planted into stubble decreased the prevalence of stem-base diseases (Parylak, Kita 2000). However, according to Andrzejewska (1999), grasses should not be grown as catch crops in crop rotations with a high share of cereals because they contribute to the transmission of cereal pathogens. In studies by Jastrzębska (2009), Thorup-Kristensen et al. (2012) and Kunellus et al. (1992), catch crops had a minor influence on the health of the main crop. The catch crops did not inhibit the spread of most diseases affecting spring barley and winter wheat. The prevalence of stem-base infections caused by *Fusarium* fungi increased in cereals undersown with Persian clover (Jastrzębska 2009). In a study by Kunellus et al. (1992), undersown red clover and Italian ryegrass had no effect on the severity of leaf diseases in spring barley.

# CATCH CROPS AS A SOURCE OF NUTRIENTS

Catch crops incorporated into the soil in autumn are a source of organic matter (in particular on farms with a manure deficit) which increases nutrient concentrations in soil (Thomson, Christensen 2004, Pałys et al. 2009, Wanic et al. 2013). In a study by Dzienia et al. (2006), catch crops significantly improved the soil nitrogen balance, and their root residues increased the effectiveness of mineral fertilizers. The ploughed-in green matter of catch crops is a more available source of nitrogen than incorrectly fermented manure, and it can replace manure fertilization (Płaza et al. 2007). Wilczewski et al. (2006) and Balkcom et al. (2011) demonstrated that catch crops accumulated 50 to 110 kg ha$^{-1}$ N in unfertilized treatments. Legume catch crops are particularly effective because they accumulate about two to times more nitrogen in biomass than white mustard and common buckwheat (Wojciechowski, Wermińska 2016).

Intercropping can increase soil pH and nutrient concentrations in soil, which contributes to the growth and development of the main crop by improving nutrient availability (Orzech 2013). The catch crop species analyzed by Wojciechowski and Wermińska (2016) supplied the following amounts of nutrients to the soil: N: 24.0-60.4, P: 3.3-9.4 and K: 23.4-62.0, depending on the amount of the produced biomass. In a study by Stavridou et al. (2012), catch crops released 4-29 kg S ha$^{-1}$ and 65-3263 kg Se ha$^{-1}$ into the soil. According to Pałys et al. (2009), undersown catch crops also improve the chemical composition of light soil.

At present, catch crops are used mainly to mitigate N losses, in particular in sandy soils where N leaching frequently occurs (Meissner et al. 1995). Catch crops, in particular species that accumulate large amounts of P, are incorporated into the soil to increase the availability of P for the main crop (Liu et al. 2015). These plants accumulate P even in soils that are not abundant in this element. Their extensive root systems penetrate the soil and take up nutrients from deeper horizons. Plants that accumulate large amounts of P include phacelia. The release of P from decomposing organic matter is a complex process, which is influenced by P levels in soil and biomass, the N:P ratio of organic matter, the rate of P mineralization and P circulation (Eichler-Löbermann et al. 2008). Decomposing organic matter of phacelia and serradella increased the P content of soil and P uptake by the main crop. Soil is supplied with available forms of P during the growth (root secretions which dissolve phosphorus compounds, mycorrhiza) and decomposition of catch crops. The amount of plant-available P is also significantly influenced by catch crop species. Phacelia and ryegrass are characterized by similar P uptake, but they exert a different influence on the amount of plant-available P in soil and its uptake by the main crop. Phosphorus and nitrogen are mobilized in soil mainly by legume plants. Eichler-Löbermann (2008) demonstrated that phacelia and serradella increased the concentration of P in soil and its uptake by the main crop. In contrast, ryegrass grown as a catch crop immobilized P and decreased its content in soil. According to Schomberg and Steiner (1999), P is immobilized when organic matter deficient in this element is incorporated into soil. The above is also observed in soils with a wide C:P ratio (Singh, Jones 1976), and/or when the P content of biomass is below the mineralization threshold of 200 to 300 mg 100 $g^{-1}$ DM. The extensive root system of ryegrass plants is abundant in lignin, a substance which is resistant to biochemical decomposition and which contributes to the immobilization of P (Rasse et al. 2006). Eichler-Löbermann et al. (2008) demonstrated that aerial parts of catch crops accumulated 3-6 kg P $ha^{-1}$. Catch crops can thus reduce P leaching with rain water and minimize erosion.

Talgre et al. (2011) observed that legumes, pea and faba bean, accumulated the highest amounts of nutrients. In years with the most favourable growth conditions, these legumes accumulated 50-100 N, 7-10 P and 40-60 K kg $ha^{-1}$. These nutrients were released directly to soil and made available to the main crop when legume biomass was decomposed by soil-dwelling microorganisms. The main disadvantage of legume plants as catch crops is the high price of seeds. Catch crops did not decrease the content of $N\text{-}NO_3$ and $NH_4$ in soil relative to treatments without catch crops. Catch crops reduced N leaching by up to 90%, but their effectiveness was determined by soil type and weather conditions. In a study by Askegaard et al. (2005), catch crops decreased N leaching by 26-38%.

## CATCH CROPS VS. CROP YIELD AND QUALITY

Sustainable fertilization relies on the diversification of agricultural production systems where catch crops exert the greatest influence on the yield potential of the main crop (Płaza et al. 2009, Šarūnaitė et al. 2010, Talgre et al. 2011, Talgre et al. 2012). It is well known that catch crops act as biofertilizers in organic farms with no livestock production. In organic farming, catch crops should cover at least 50% of sown area. Post-harvest residues act like mulch by preserving high levels of soil productivity, enhancing the biological activity of soil and protecting soil against chemical contamination (Dzienia et al. 2006).

There is evidence to indicate that catch crops improve the physical properties of soil in crop rotation systems with a very high share of cereals (Sharratt 2002). Catch crops increase soil moisture content and minimize water deficit (Wanic et al. 2013). Their influence on soil moisture content is determined by farming intensity and the main crop species (Jaskulski, Jaskulska 2004). Majchrzak and Skrzypczak (2010) observed that white clover grown as a catch crop increased the moisture content of soil, and Orzech (2013) reported similar results in the top 0-30 cm soil horizon where spring barley was undersown with Italian ryegrass. Krężel et al. (1988) demonstrated that undersown catch crops and catch crops planted into stubble increased the water resistance of granular soil aggregates and increased the capillary water capacity of soil. In a study by Šarūnaitė et al. (2010), spring wheat (*Triticum aestivum* L.) was intercropped with grain legumes for increased production in an organic crop rotation system. The productivity of spring wheat sole crop and intercrops depended on the species of grain legumes – *Pisum sativum* L., *Lupinus angustifolius* L., *Vicia faba* L. and *Vicia sativa* L. The yield of spring wheat intercrops with pea lupin and bean decreased from 15 to 21% compared with wheat cultivated as a sole crop. In turn, in the study N'Dayegamiye and Tran (2001) yield of spring wheat increased from 13 to 68% (Table 1).

Various opinions have been expressed in the literature regarding the effects of catch crops on the yield of subsequent crops. Crop yields have been

Table 1

Influence of catch crops on yield of main crops

| Main crops | Catch crops | Increase (+)/ /decrease (-) | Authors |
|---|---|---|---|
| Spring wheat | clover, millet, buckwheat, colza, mustard | +13-68 | N'Dayegamiye and Tran (2001) |
| Spring wheat | faba bean, fodder radish, white mustard, oilseed rape, Italian ryegrass | +5-28 | Talgre et al. (2011) |
| Oats or spring wheat (1st year ) | red clover, bird's-foot, lucerne, hybrid lucerne, white melilot | +0.4-42 | Talgre et al. (2012) |
| Spring barley (2st year ) | | +12-34 | |
| Cats (3st year ) | | +5-17 | |
| Spring wheat | pea, lupine, bean | - 15-21 | Šarūnaitė et al. (2010) |
| Spring barley | pea, yellow lupine, white mustard, oilseed rape, phacelia, sunflower | +3-16 | Jaskulski et al. (2000) |
| Potato | white mustard, phacelia | +13-61 | Płaza et al. (2009) |
| Spring barley | pea | +9 | Wilczewski (2014) |
| | phacelia, white mustard, sunflower | no influence | Wrzesińska et al. (2017) |
| Oilseed rape, spring barley, spring wheat | phacelia | +4.2 | Eichler-Löbermann et al. (2008) |
| | buckwheat, ryegrass, serradella, oil radish | no influence | |

found to increase, decrease or remain unchanged under the influence of catch crops. Majchrzak (2015) demonstrated that white mustard significantly increased (by more than 20%) the grain yield of spring wheat, mainly due an increase in spike density and the number of kernels per spike. Besides, Majchrzak (2015) reported that wheat grain from stands intercropped with white mustard was characterized by a higher content of starch (4%), fat (6%) and ash (20%) – Table 2, and its protein content was similar to that of grain from treatments without catch crops.

Table 2

The effect of catch crops on the chemical composition of main crops

| Main crops | Catch crops | Increase(+) decrease (-) % | | Authors |
|---|---|---|---|---|
| Winter wheat | winter pea | protein | +13-15 | Bedoussac and Justes (2010) |
| Spring wheat | pea, lupin, bean, vetch | | + 0-7 | Šarūnaitė et al. (2010) |
| Spring wheat | white mustard | starch | +4 | Majchrzak (2015) |
| | | ash | +20 | |
| | | fat | +6 | |
| Spring barley | red clover, bird's-foot, lucerne, hybrid lucerne, white meliloti | P | +29-71 | Talgre et al. (2012) |
| | | K | +7-27 | |
| Carrot | phacelia, vetch | N | +2-3 | Kwiatkowski et al. (2015) |
| | | P | +25-32 | |
| | | K | +9-12 | |
| | | Mg | +25-36 | |
| | | Na | +10-24 | |

An increase in the grain yield of spring barley was reported by Kwiatkowski (2009) when the main crop was grown after white mustard and a legume mix as catch crops, and by Talgre et al. (2012) when barley was grown after red clover, white melilot and alfalfa. The positive residual effects of catch crops were observed for three years after they had been discontinued (Talgre et al. 2012), yield increased about 5-20% (Table 1).

In a study by Jaskulski et al. (2000), all legume and non-legume catch crops improved spring barley yields by increasing spike density, the number of kernels per spike and 1000-kernel weight. According to Wilczewski (2014), spring barley was characterized by significantly higher grain yields when grown after peas as a catch crop, compared with the treatment without catch crops about 9%. The observed increase resulted from a significantly higher number of spikes per unit area. Płaza et al. (2009) demonstrated that the fertilizer value (expressed by potato tuber yield) of white mustard biomass was similar to that of manure when incorporated into soil in fall or somewhat lower than manure when used for mulching in spring, whereas phacelia (a rich source of macronutrients) was a better fertilizer than manure. Phacelia also induced the highest increase (61%) in the yield of large potato tubers with a diameter above 60 mm. Similar results were noted by Talgre et al. (2012).

Contrary results were reported by Wrzesińska et al. (2017) from an experiment established on light soil, where none of the evaluated catch crops (phacelia, white mustard, sunflower) influenced the yield or the yield components of spring barley. In contrast, Szafrański and Kulig (2001) reported a decrease in spring wheat yield under the influence of white clover that had been left in the field in winter and ploughed-in before wheat was sown in spring. The yield and quality of crops grown after catch crops are generally influenced by the type, species and biomass yield of catch crops, the C:N ratio, the date on which organic matter is incorporated into the soil, as well as habitat, soil and weather conditions (Wojciechowski 2009). Kuś et al. (1993) demonstrated that weather conditions had a greater influence on barley yields than catch crops (white mustard). According to the cited authors, the varied effects of catch crops across years can be attributed to changes in soil water content and prolonged decomposition of organic matter under drought stress. The influence of catch crops planted into stubble on the length of spring wheat spikes differed across years. Spikes from treatments with ploughed-in serradella were longer than spikes from control treatments. Wheat grain protein concentration was significantly higher in intercrops than in sole crops (14% on average) because more N was remobilized into wheat grain due to a lower number of spikes per unit area and a similar amount of available soil N as in sole crops due to a high rate of pea $N_2$ fixation in intercrops (Bedoussac, Justes 2010).

In a study by Šarūnaitė et al. (2010), the crude protein content of grain was higher when wheat was grown in intercrops than as the sole crop. The fat content of spring wheat grain was higher in treatments with mustard and phacelia grown as catch crops (Kraska 2011*a*). Kraska (2011*b*) observed that the incorporation of red clover, Westworlds ryegrass, blue phacelia and white mustard into the soil increased the concentrations of zinc, iron and copper in wheat grain. Talgre et al. (2012) reported an increase in the nitrogen, phosphorus and potassium content of spring barley grain, particularly in stands intercropped with alfalfa and white melilot (Table 2). The above can be attributed to the gradual release of nutrients from decomposing organic matter and the resulting increase in the content of plant-available nutrients in soil (Talgre et al. 2012). The rate at which nutrients are released from organic matter is determined by their concentration in biomass and their C:N ratio (Sorensen, Thorup-Krystensen 2011). In a study by Kraska (2011*b*), catch crops decreased the content of potassium, magnesium and iron in wheat grain. In contrast, Tendziagolska and Parylak

(2004) did not observe significant changes in the chemical composition of winter triticale grain from treatments with white mustard grown as a catch crop. Kwiatkowski et al. (2015) reported higher levels of P, K, Ca, Mg, Na and phenolic compounds (antioxidants) in carrot roots grown after tansy phacelia and spring vetch + field peas as catch crops (Table 2).

## CONCLUSIONS

Catch crops are increasingly used in sustainable agriculture. There is a wide array of potential catch crop species. Catch crops should be characterized by rapid growth in early stages of development and the ability to produce large amounts of biomass that can be incorporated into the soil. Soil enriched with organic matter supports the growth and development of the main crop. Catch crops minimize weed pressure and improve plant health. Their biomass is a reservoir of valuable nutrients which increase the yield and quality of main crops. However, catch crops can limit water for the next crop or aggravate a wet soil condition.

### REFERENCES


Andrzejewska J. 1999. *Intercrops in cereal crop rotations*. Post. Nauk Rol., 1: 19-31. (in Polish)

Askegaard M., Olesen J.E., Kristensen K. 2005. *Nitrate leaching from organic arable crop rotations: effects of location, manure and catch crop*. Soil Use Manage., 21: 181-188. DOI: 10.1079/SUM2005315

Askegaard M., Thomsen I.K., Berntsen J., Hovmøller M.S., Kristensen K. 2011. *Performance of spring barley varieties and variety mixtures as affected by manure application and their order in an organic crop rotation*. Acta Agr. Scan., B 61: 421-430. DOI: 10.1080/09064710.2010.501340

Balkcom K.S., Massey J.M., Mosjidis J.A., Price A.J., Enloe S.F. 2011. *Planting date and seeding rate effects on sunn hemp biomass and nitrogen production for a winter cover crop*. Int. J. Agron., 2011: Article ID 237510, 8 pages. DOI: 10.1155/2011/237510

Bedoussac L., Justes E. 2010. *The efficiency of a durum wheat-winter pea intercrop to improve yield and wheat grain protein concentration depends on N availability during early growth*. Plant Soil, 330: 19-35. DOI: 10.1007/s11104-009-0082-2

Boguzas V., Kairyte A., Jodaugiene D. 2006. *Weed and seed-bank response to tillage systems, straw and catch crops in continuous barley*. 23rd German Conference on Weed Biology and Weed Control. 07-09 Mar. Stuttgart, Germany. J. Plant Dis. Prot., 297304.

Deryło S., Pawłowski F. 1992. *The effect of stubble catch crops on weed infestation in winter wheat and spring barley stands in crop rotations with a different proportion of cereal*. Ann. UMCS, Sect. E, 47: 7-12. (in Polish)

Dzienia S., Zimny L., Weber R. 2006. *The newest trends in soil tillage and techniques of sowing*. Fragm. Agron, 23(2): 227-241. (in Polish)

Eichler-Löbermann B., Köhne S., Kowalski B., Schnug E. 2008. *Effect of catch cropping on phosphorus bioavailability in comparison to organic and inorganic fertilization*. J. Plant Nutr., 31: 659-676.

Hruszka M., Brzozowska I. 2008. *Effectiveness of proecological and chemical methods of regulating weed infestation in crop rotation*. Acta Agrophys., 12(2): 347-355. (in Polish)

Jaskulska I., Gałęzewski L. 2009. *Role of catch crops in plant production and in the environment*. Fragm. Agron., 26(3): 48-57. (in Polish)

Jaskulski D., Jaskulska J. 2004. *Effect of fertilization with straw, stubble intercrops, and varied tillage on some properties of soil in the crop-rotation link: winter wheat-spring barley*. Acta Sci. Pol., Agricultura, 3(2): 151-163. (in Polish)

Jaskulski D., Jaskulska I. 2011*a Share of agricultural land in spatial variation in plant cover of Kujawy and Pomorze Province*. Pol. J. Environ. Stud., 20(3): 571- 579.

Jaskulski D., Jaskulska I. 2011*b*. *Diversity and dominance of crop plantations in the agroecosystems of the Kujawy and Pomorze region in Poland*. Acta Agric. Scand., Sect. B – Soil Plant Sci., 61(7): 633-640.

Jaskulski D., Tomalak S., Rudnicki F. 2000. *Regeneration of the stand after winter wheat for spring barley with catch crop plants*. Zesz. Probl. Post. Nauk Rol., 490: 49-57. (in Polish)

Jastrzębska M. 2009. *Cultivar mixtures of winter wheat and spring barley in cereal crop rotations*. UWM in Olsztyn, Diss. Monogr., 151: 5-172. (in Polish)

Kordas L., Wacławowicz R., Białczyk W. 2000. *The effect of stubble catch crops on weed infestation in winter wheat and spring barley stands in crop rotations with a different proportion of cereals*. Inż. Rol., 6: 147-152. (in Polish)

Kraska P. 2011*a*. *Conservation tillage and catch crops as factors creating the grain yield of spring wheat cv. Zebra cultivated in monoculture*. Ann. UMCS, Sect.E, 66(1): 8-23. (in Polish)

Kraska P. 2011*b*. *Tillage systems and catch crops as factors creating physical and chemical properties of spring wheat grain cultivar Zebra*. Acta Agroph., 17(1): 117-133. (in Polish)

Kraska P., Mielniczuk E. 2012. *The occurrence of fungi on the stem base and roots of spring wheat (Triticum aestivum* L.*) grown in monoculture depending on tillage systems and catch crops*. Acta Agrobot., 65(1): 79-90.

Kretschmer H., Berger G. 1990. *Zwischenfruchtanbau zur Reduktion von N-Restgehalten nach Getrede*. FZB-Raport, 118-120.

Krężel R., Gandecki R., Kordas L., Zimny L. 1988. *The effect of specialistic crop-successions on yielding of plants and properties of light soil*. Part II. *Selected physical properties of soil*. Fragm. Agron., 5(4): 29-36. (in Polish)

Kunellus H.T., Johnston H.W., Macleod J.A. 1992. *Effect of undersowing barley with Italian ryegrass or red clover on yield, crop composition and root biomass*. Agr. Ecosyst. Envirron., 38(3): 127-137. DOI: org/10.1016/0167-8809(92)90138-2

Kuś J., Siuta A., Mróz A., Kamińska M. 1993. *Mitigating the negative effects of site conditions on spring barley yields*. Pam. Puł., 103: 133-143. (in Polish)

Kwiatkowski C. 2009. *Studies on the fielding of naked and husked spring barley in crop rotation and monoculture*. Wyd. UP Lublin, Rozpr., 336: 5-117. (in Polish)

Kwiatkowski C., Haliniarz M., Kolodziej B., Harasim E., Tomczyńska-Mleko M. 2015. *Content of some chemical components in carrot (Daucus carota* L.*) roots depending on growth stimulators and stubble crops*. J. Elem., 20(4): 933-943. DOI: 10.5601/jelem.2014.19.4.812

Liu J., Bergkvist G., Ulen B. 2015. *Biomass production and phosphorus retention by catch crops on clayey soils in southern and central Sweden*. Field Crop Res., 171: 130-137. DOI: org/10.1016/j.fcr.2014.11.013

Majchrzak L. 2015. *Influence of white mustard cover crop and method of tillage on soil properties, growth and yielding of spring wheat*. Rozpr., 480, Wyd. UP Poznań, 113. (in Polish)

Majchrzak L., Skrzypczak G. 2010. *The influence of tillage system on physical soil properties and yielding of spring wheat*. Ann. UMCS, Sect. E., 65(2): 1-8. (in Polish)

Meissner R., Rupp H., Seeger J., Schonert P. 1995. *Influence of mineral fertilizers and different soils types on nutrient leaching: results of lysimeter studies in East Germany*. Land Degrad. Rehabil., 6: 163-170.

N'Dayegamiye A., Tran T.S. 2001. *Effects of green manures on soil organic matter and wheat yields and N nutrition*. Can. J. Soil Sci., 81(4): 371-382. DOI: org/10.4141/S00-034

Orzech K. 2013. *Spring barley in pure sowing and witch catch crops in crop rotations*. Wyd. UWM in Olsztyn, Dissert. Monogr., 180, 122. (in Polish)

Pałys E., Kuraszkiewicz R., Kraska P. 2009. *The residual effect of undersown crops and nurse crops on chemical properties of light soil*. Ann. UMCS Sect. E., 64(4): 81-92. (in Polish)

Parylak D., Kita W. 2000. *Effect of eco-friendly measures in winter triticale monoculture on the reduction of infection by steam base diseases*. Prog. Plant Prot., 40(2): 627-630. (in Polish)

Pawłowski F., Woźniak A. 2000. *The influence of underplant crop and organic fertylization on yield, weed infestation and health state of winter triticale grown in monoculture*. Zesz. Probl. Post. Nauk Rol., 470: 83-89. (in Polish)

Płaza A., Ceglarek F., Próchnicka M. 2009. *The influence of stubble catch crop on the yield and yield structure of potato tubers*. Fragm. Agron., 26(3): 137-145. (in Polish)

Rasmussen I.A., Askegaard M., Olesen J.E., Kristensen K. 2006. *Catch crop: Long term experiment. Manure, mechanical weed control, organic farming, weed management*. Agric. Ecosyst. Environ., 113(1-4): 184-195.

Rasse D.P., Digrac M.F., Bahri H., Rumpel C., Mariotti A., Chenu C. 2006. *Lignin turnover an agricultural field: from plant residues to soil-protected fractions*. Eur. J. Soil Sci., 57: 530-538. DOI: 10.1111/j.1365-2389.2006.00806.x

Rinnofner T., Friedel J.K., de Kruijff R., Pietsch G., Freyer B. 2008. *Effect of catch crops on N dynamics and following crops in organic farming*. Agron. Sustain. Dev., 28: 551-558. DOI: 10.1051/agro:2008028

Šarūnaitė L., Deveikytė I., KADŽIULIENĖ Z. 2010. *Intercropping spring wheat with grain legume for increased production in an organic crop rotation*. Žemdirbystė-Agriculture, 97(3): 51-58.

Schomberg H.H., Steiner J.L. 1999. *Nutrient dynamics of crop residues decomposing on a fallow no-till soil surface*. Soil Sci. Soc. Am. J., 63: 607-613.

Singh B.B., Jones J.P. 1976. *Phosphorous sorption and desorption characteristics of soil as affected by organic residues*. Soil Sci. Soc. Am. J., 40(3): 389-394.

Sjursen H., Brandsaeter K.O., Netland J. 2012. *Effects of repeated clover undersowing, green manure ley and weed harrowing on weeds and yields in organic cereals*. Acta Agr. Scan., B, 62: 138-150. DOI: org/10.1080/09064710.2011.584550

Sharratt B.S. 2002. *Corn stubble height and residue placement in the northern US Corn Belt II Spring microclimate and wheat development*. Soil Till. Res., 64: 253-261.

Skuodiene R., Nekrosiene R. 2012. *The effect of perennials as green manure on cereal productivity and disease incidence*. Span. J. Agric. Res., 10(1): 44-54.

Sorensen J.N., Thorup-Kristensen K. 2011. *Plant-based fertilizers for organic vegetable production*. J. Plant Nutr. Soil Sci., 174: 321-332. DOI: org/10.17660/ActaHortic.2010.852.23

Stavridou E., Young S.D., Thorup-Kristensen K. 2012. *The effect of catch crop species on selenium availability*. Plant Soil, 351: 149-160. DOI: 10.1007/s11104-011-0940-6

Stupnicka-Rodzynkiewicz E., Łabza T., Hochol T. 1998. *Changes in the group of rarely occurring cereal weeds at selected constant fields in the Miechow upland*. Acta Univ. Lodz., Fol. Bot., 13: 241-246. (in Polish)

Szafrański W., Kulig B. 2001. *Spring wheat yielding and content of soil mineral N depending on the timing of ploughing in catch crop biomass, and nitrogen fertilization*. Zesz. Nauk. AR Kraków, 76(1): 267-272. (in Polish)

Talgre L., Lauringson E., Makke A, Lauk R. 2011. *Biomass production and nutrient binding of catch crops*. Zemdirbyste, 98(3): 251-258.

Talgre L., Lauringson E., Roostalu H., Astover A., Makke A. 2012. *Green manure as nutrient source for succeeding crops*. Plant Soil Environ., 58(6): 275-281.

TENDZIAGOLSKA E., PARYLAK D. 2004. *Tillage method for winter triticale in monoculture and intensity of stem base diseases.* Ann. UMCS, Sect E, 59(3): 1105-1111. (in Polish)

THOMSON I.K., CHRISTENSEN B.T. 2004. *Yields of wheat and soil carbon and nitrogen contents following long-term incorporation of barley straw and rye-grass catch crops.* Soil Use Manage., 20: 432-438. DOI: org/10.1111/j.1475-2743.2004.tb00393.x

THORUP-KRISTENSEN K., DRESBŘLL DB., HANNE L. KRISTENSEN H.L. 2012. *Crop yield, root growth, and nutrient dynamics in a conventional and three organic cropping systems with different levels of external inputs and N re-cycling through fertility building crops.* Europ. J. Agron., 37: 66- 82. DOI: 10.1016/j.eja.2011.11.004

ULLA M., DITON E., KOLSETH A.K., WIDMARK D., PERSSON P. 2014. *Cover crop residues – Effects on germination and early growth of annual weeds.* Weed Sci., 62(2): 294-302. DOI: 10.1614/ /WS-D-13-00117.1

WACŁAWOWICZ R., WOJCIECHOWSKI W., ZAWIEJA J. 2006. *Number and species composition of weed seeds as affected by percentage of oats in crop rotation.* Prog. Plant Prot., 46(2): 229-232. (in Polish)

WANIC M., KOSTRZEWSKA M.K., JASTRZĘBSKA M., BRZEZIN G.M. 2004. *Role of intercrop sowing in weeds control for spring barley in cereal crops rotation systems.* Fragm. Agron., 21(1): 85-102. (in Polish)

WANIC M., JASTRZĘBSKA M., NOWICKI J. 2005. *Intercropping and weeds growth in spring barley cultivated on different lots.* Fragm. Agron., 22(2): 238-248. (in Polish)

WANIC M., MAJCHRZAK B., NOWICKI J., WALERYŚ Z., ORZECH K. 2012. *Role of undersown catch crops and crop rotation in state of health of spring barley.* Acta Sci. Pol., Agricultura, 11(1): 113-124.

WANIC M., KOSTRZEWSKA M. K., MYŚLIWIEC M., BRZEZIN G. 2013. *Influence of undersown catch crops and crop rotation on some physical and chemical properties of the soil.* Fragm. Agron., 30(1): 121-132. (in Polish)

WILCZEWSKI E., LEMAŃCZYK G., SKINDER Z., SADOWSKI CZ. 2006. *Effect of nitrogen fertilization on the yielding and health status of selected non-papilionaceous plant species grown in stubble intercrop.* EJPAU, Ser. Agron., 9(2): 04. http://www.ejpau.media.pl/volume9/issue2/art-04.html

WILCZEWSKI E. 2014. *Effect of cultivation intensity and stubble catch crop on spring barley yield.* Fragm. Agron., 31(1): 95-112. (in Polish).

WOJCIECHOWSKI W. 2009. *The importance of catch crops for optimizing nitrogen fertilization of quality spring wheat.* Wyd. UP Wrocław Rozpr., 76: 7-122. (in Polish).

WOJCIECHOWSKI W., WERMIŃSKA M. 2016. *Yielding and fertilization value of cover catch crops cultivated in accordance with the principles of agri-environmental scheme.* Fragm. Agron., 33(2): 103-109. (in Polish).

WRZESIŃSKA E., PUŻYŃSKI S., NURKIEWICZ G. 2017. *The impact of stubble crop on yielding of spring barley.* Fragm. Agron., 34(2): 115-123. (in Polish)