Acta Sci. Pol. Hortorum Cultus, online first, 1–12

https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 https://doi.org/10.24326/asphc.2025.5553

ORIGINAL PAPER

Received: 2.06.2025
Accepted: 5.08.2025
First published online: 3.10.2025

MICROBIAL AND PHYSICO-CHEMICAL RESPONSES OF THE SOIL TO INTENSIVE ONION AND PEPPER CROPPING

Magdalena Szczech[1]✉, Beata Kowalska[1], Jacek Nowak[2], Małgorzata Kunka[2], Robert Maciorowski[3]

[1] Department of Microbiology and Rhizosphere, The National Institute of Horticultural Research, Konstytucji 3 Maja 1/3, 96-100 Skierniewice, Poland

[2] Department of Plant Cultivation and Fertilization, The National Institute of Horticultural Research, Konstytucji 3 Maja 1/3, 96-100 Skierniewice, Poland

[3] Scientific Planning and Multiannual Program Department, The National Institute of Horticultural Research, Konstytucji 3 Maja 1/3, 96-100 Skierniewice, Poland

ABSTRACT

Vegetable cropping systems are high-input and generally require large quantities of fertilization, protection, frequent irrigation, and repeated tillage operations. Consequently, an increase in vegetable production may have serious impact on soil health and functions. The aim of the study was to assess microbiological, chemical and physical indicators of soil fatigue in two of the most intensive vegetable crops in Poland: onions and peppers, to identify which cultivation practices are most responsible for the adverse changes. The results have shown, that the most reliable indices in cultivation of these vegetables occurred dehydrogenase activity, organic matter content and soil physical properties. The other studied parameters such as pH, nutrients availability and microbial abundance seem to be less sensitive factors. In all soils, where the onion and pepper were produced, the dehydrogenase activity was significantly lower as compared to non-cultivated soil. It corresponded with reduced content of organic matter. In onion production numerous runs by agricultural machinery during field operations lead to soil compaction, breakdown of its structure and organic matter reduction. Moreover, poor crop rotation and low surface coverage with vegetation accelerate these effects and deteriorate the biological functioning of the soil. In turn, in pepper cultivation, monoculture with high mineral fertilization, cause soil acidification and adverse effect on microorganisms, decreasing their activity, but increasing the proportion of fungi in microbial community. Intense mineral input, resulting in high concentration of nutrients in soil, may be a reason of reduced organic carbon content, despite application of organic manures.

Keywords: onion, pepper, dehydrogenase, organic matter, soil structure, microorganisms, nutrients

INTRODUCTION

Soil is a natural, non-renewable resource, which has fundamental functions to our existence as a source of food and energy. Decomposition of organic matter and circulation of nutrients, essential for the continuity of life, take place in the soil. It also plays an important role in climate regulation e.g. through carbon sequestration and water retention. However, in the 21st century, the progressive degradation of soils is a serious problem. Intensive agriculture cause a strong pressure on soil environment and negatively affects its functioning. In consequence, soil is subject to accelerated erosion, compaction, acidification, salinization,

✉ magdalena.szczech@inhort.pl

decline in organic matter and depletion of organic carbon reserves, elemental imbalance and loss of nutrients, loss of biodiversity and accumulation of soil-borne pathogens [Lal 2015, Bonanomi et al. 2016, Bayata 2024]. According to global estimates, about 38% of soils have been degraded, including those used for agricultural purposes [Goździewicz-Biechońska 2018], and at least 60–70% of soils in the European Union [Midler 2022, European Environment Agency 2024]. Changes to cropping systems are required to prevent these adverse trends. In order to do this, however, it is necessary to know which factors have a decisive impact on soil health in specific crops.

In the food supply chain vegetables play very important role. Sales of fresh produce – vegetables and fruits, has increased dramatically (by 30%) in the past few decades [Stea et al. 2020], as their consumption is intensively promoted worldwide to prevent many civilisation's diseases. However, growing vegetables is demanding in terms of nutrition, protection and irrigation. In spite of improved varieties, the pressure of pathogens and pests requires systematic control, and achieving satisfactory yields encourages farmers to use intensive fertilization and agro-technical practices with heavy equipment. This intensification of production leads to environmental pollution, residual toxicity towards microorganisms and humans, development of plant pathogen resistance and biodiversity loss [De Corato 2020], which results in serious crop problems and losses that farmers face for years. In Poland, vegetable producers complain that they have to apply more and more fertilizers and pesticides to achieve satisfactory yields, which exacerbates the detrimental processes in the soil.

Onion and pepper are the crops, which production is very intensive, with high input of chemicals and limited crop rotation. Onion occupies the first place in Poland in terms of the area of vegetable cultivation. The annual production in 2024 was around 700,000 tonnes. After the Netherlands and Spain, Poland is the third producer of onion in the EU, and the share of our country in the EU production of onion is about 10% [Statistics Poland 2024]. Pepper in Poland is the third vegetable grown under cover after tomatoes and cucumbers. The specificity of this crop lies in the fact, that the peppers are grown in plastic tunnels, in the soil, on the same site for up to a dozen years. In both cases, the production is associated with many difficulties, and growing conditions are getting worse. In order to try to solve these problems, it is necessary to know which soil parameters have been most severely altered by these crops.

Numerous chemical, physical, microbiological and biochemical indicators are used to asses soils condition [Bastida et al. 2008]. Among them pH, nutrients availability, soil organic matter (SOM) content and soil physical indices such as bulk density, soil porosity and field water capacity are considered as important for soil function [Chaudhry et al. 2024, Kahsay et al. 2025]. Of great importance are also microbial indices [Raiesi and Behesthi 2015]. Soil microorganisms plays an important role in organic matter decomposition and govern the balance of carbon cycling between SOM and atmospheric C pool, and microbial biomass contributes to SOM [Anthony et al. 2020]. Microorganisms are also responsible for nutrient cycling, soil structure building, promotion of plant growth and suppression of pathogens [Jacobsen and Hjelmsø 2014, Wolińska et al. 2018, Mayer et al. 2019]. The diversity of their metabolic activities makes them participate in practically all processes and stages of nutrient transformations in the soil [Bonanomi et al. 2016, Mahala et al. 2020]. According to Trivedi et al. [2016], changes in microbial populations and activity can precede detectable changes in soil physico-chemical properties, providing an early sign of soil degradation. Populations of bacteria, actinomycetes, fungi and soil enzyme activities are still the most commonly studied indicators in order to assess the performance of various soil management techniques [Tian et al. 2015, Wolińska et al. 2018]. Essential microbial function of processing and acquisition of nutrients from organic matter, requires the activity of extracellular enzymes [Raiesi and Behesthi 2015, Qu et al. 2020]. Among the soil enzymes, the activity of dehydrogenases (DHA) provides information about the biologically active microbial population in the soil [Gil-Sotres et al. 2005].

The aim of this study was to assess the condition of soils in intensive production of onion and pepper, as an attempt to try to solve the problems with soil degradation in cultivation of these vegetables. The evaluation was based on microbiological, chemical and physical indices of soil condition.

MATERIALS AND METHODS

Origin and sampling of soil

Soil samples were collected from Polish farms situated mainly in central Poland, where intensive, long-term vegetable cultivation is carried out. The farms for sampling were selected based on crop history, where in many cases the vegetables were grown in monoculture over several years. The best example is the cultivation of pepper in the soil, in PE film tunnels, on the same site for several years (even for 20 years). The crops were treated with intensive mineral fertilization, chemical plant protectants and mechanical cultivation using heavy equipment (except for peppers in tunnels). Soil samples were taken in the middle of vegetation period for crop plants. At the same time, comparative samples were taken from fallow soils in close proximity to the agricultural soils. Four combined soil samples were taken for each site. One combined sample, comprising approx. 2 kg of soil, was collecting from a randomly selected area of 25 m^2 (square 5 × 5 m). The sub-samples were taken with a Egner's tool from a depth of about 0–20 cm. These samples were taken for microbiological, chemical and biochemical analyses. From the same areas, the soil samples were collected to evaluate physical soil parameters using four stainless cylinders (diameter 5 cm, height 5 cm), closed on both sides with a tightly fitting plastic caps.

In total, arable and fallow soil samples (in four replicates) were taken from 28 farms: 18 from onion crops, 10 from pepper crops. During the farms visits, the farmers were asked to fill a questionnaire, in which the information about fertilization practices (the type of fertilizers used and time of their application) and on the crop rotation systems were collected.

Microbiological analyses

All combined soil samples were thoroughly mixed and sieved to remove stones and big particles. Then, 10 g subsamples were added to 100 ml 0.85% NaCl water solution and mixed on a rotary shaker for 20 min. The soil dilution plating method on selective media was used to quantify the population of selected groups of microorganisms. Total bacteria, including actinomycetes, were determined on soil extract medium [Dhingra and Sinclair 1995]. The number of fluorescent *Pseudomonas* was determined on the S1 medium under UV light [Gould et al. 1985]. Rose Bengal medium [Martin 1950] was used to enumerate fungi and yeasts. The number of spore-forming bacteria was determined on 10% trypticase soy agar medium (TSA), after pre-heating of the soil suspension for 10 minutes at 80 °C. Copiotrophs and oligotrophs were evaluated according to Hattori and Hattori method [1980]. The number of microorganisms was expressed as a $\log_{10}$ of colony forming units (cfu) g^{-1} of soil dry weight.

Enzyme dehydrogenases activity

Dehydrogenases activity (DHA) was measured according to Cassidy procedure described by Alef and Nannipieri [1995] and Brzezińska and Włodarczyk [2005]. Briefly, 3 g of sieved soil was placed in the 15 ml dark tube to restrict light, and added successively with: 1.8 ml of sterile deionized water, 600 µl of 1% glucose suspension and 600 µl of 3% water solution of 2,3,5-triphenyltetrazolium chloride (TTC). The mixture was incubated for 24 hours at 30 °C in the darkness. During incubation TTC was reduced enzymatically to water-insoluble TPF (1,3,5-triphenylformazane). The reaction was stopped by addition 12 ml of 96% ethanol, and the mixture was agitated for next hour in dark. Then, the samples were centrifuged (12 000 rpm/min.) for 8 minutes, at 4 °C. The supernatant was used for spectrophotometric measurements of TPF concentration at λ = 485 nm, with the use of spectrophotometer (UVLINE 9600). The obtained values were related to the standard curve (with known TPF concentration). Finally, the mean dehydrogenases activity was expressed in units of dehydrogenases activity, as the amount of TPF produced by 1 gram of soil during 24 hours (µg TPF/g s.d.w. 24 h) [Casida et al. 1964].

Chemical analyses of the soil

Sieved soil samples were subjected to chemical analysis. Total nitrogen was determined through mineralization in concentrated sulfuric acid [Walinga et al. 1995]. A Kjeldahl digestion kit and unit (Vapodest, Gerhardt GmbH, Konigswinter, Germany) were used to determine total nitrogen (N) content by titration. Macro- and micronutrients (P, K, Ca, Mg, Na, S, Fe, Mn, Cu, Zn, B) were isolated by the microwave digestion in the concentrated nitric acid, in a closed system

[Ostrowska et al. 1991]. Qualitative and quantitative analyses of the above elements were done by the plasma spectrometry, atomic absorption spectroscopy and colorimetric methods called "segment flow system" [Antweiler et al. 1996]. The pH was measured in 1 N KCl in air-dried soil, using a 1 : 5 v/v soil suspension.

Soil physical properties measurements

The physical properties of the soils were determined according to the method adopted by the European Union [PN-EN 13041: 2002]. Designations were made in the cylinders with a diameter of 5 cm and a height of 5 cm. The water-air capacity was determined with the 'Eijkelkamp' sand apparatus at a vacuum corresponding to a negative pressure of –3.2 cm H_2O. Water holding capacity, bulk density and porosity were calculated in accordance with PN-EN 13041 [2002]. The organic matter content was determined after sample incinerating in accordance with PN-EN 13039 [2002].

Statistical analysis

Data concerning statistical differences between intensively cultivated and fallow soil were tested by means of the Student two tailed test separately for each crop. If the homogeneity criterion of the variance tested by the Lavene'a method was not met, a modified generalisation of the test, the so-called Welch test, was used. The calculation were done using Statistica package v. 13.1 (Dell Inc. 2016).

RESULTS

Microorganisms and microbial activity in soils

Analyses of microbial groups in soil samples showed small differences between studied microorganisms, determined in intensively cultivated and fallow soils. The greatest differences were found in the case of onion cultivation, where the total number of fungi, bacteria and actinomycetes were significantly lower in the soil samples from under cultivation than in the fallow soils (Tab. 1). For other groups of studied microorganisms there were no differences between arable and fallow soils. In contrast, many years of intensive pepper cultivation had no effect on the total abundance of culturable microbial groups compared to the neighboring uncultivated soils. However, it was observed that "pepper's" soils indicated tendency to reduced number of overall bacteria, and especially fluorescent *Pseudomonas*, compared to soils from onion cultivation.

The studies of dehydrogenases showed a reduction in the activity of microorganisms in the soils with onion and pepper crops compared to the adjacent fallow land (Fig. 1). The highest difference was observed for onion cultivation, where DHA was determined on average at the level of 17.74 and 89.89 µg TFP g^{-1} of soil dry weight for intensive cultivated soil and fallow respectively. In the case of both types of the soils sampled in pepper production, the differences were not significant (34.81 and 46.29 µg TFP g^{-1}). Howev-

Table 1. The number of microorganisms in soils used for intensive vegetable cropping (intensive) and not cultured soils (fallow) presented as $\log_{10}$ cfu g^{-1} ± SE

Microorganisms	Onion		Pepper	
	intensive	fallow	intensive	fallow
Total fungi	5.1 ±0.3 b	5.3 ±0.4 a	5.3 ±0.3 a	5.4 ±0.4 a
Bacteria	7.4 ±0.4 b	7.6 ±0.3 a	7.2 ±0.4 a	7.2 ±0.2 a
Actinomycetes	6.6 ±0.4 b	6.9 ±0.3 a	6.6 ±0.3 a	6.7 ±0.3 a
Copiotrophs	10.1 ±0.5 a	10.0 ±0.5 a	10.4 ±0.7 a	10.3 ±0.5 a
Oligotrophs	9.3 ±0.9 a	9.1 ±0.9 a	9.3 ±0.7 a	9.4 ±0.6 a
Spore-forming bacteria	6.4 ±0.4 a	6.4 ±0.3 a	6.1 ±0.5 a	6.2 ±0.5 a
Fluorescent *Pseudomonas*	4.2 ±0.4 a	4.4 ±0.3 a	3.8 ±1.2 a	3.8 ±0.9 a

Means for cropping and fallow soils indicated by the same letter do not differ significantly according to Student test at p = 0.05

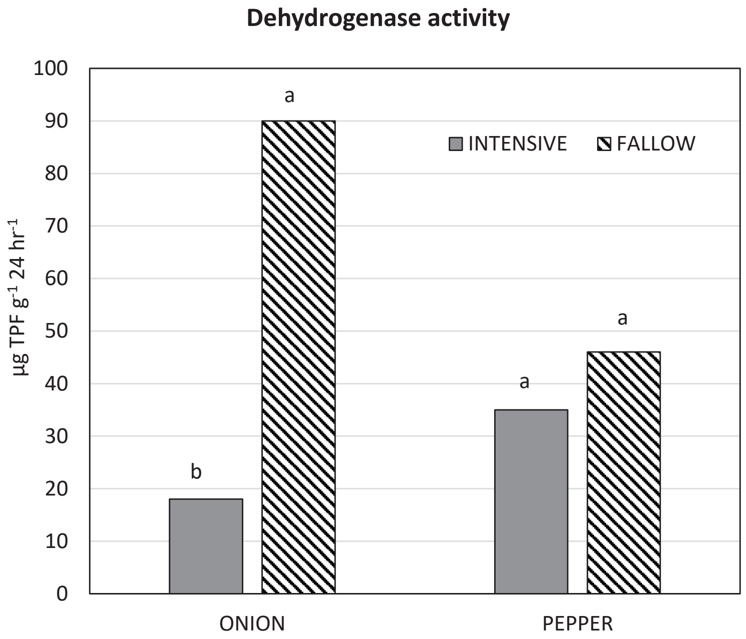

Fig. 1. Enzyme dehydrogenase activity in soils cropped with onion or pepper compared to the fallow land adjacent to these crops. Different letters above the bars indicated significant differences between means according to Welch test at p = 0.05, separately for each crop

er, the tendency to increased dehydrogenase activity in not cultivated soil, taken in the neighbourhood of growing tunnels, was observed. It was also noticed, that enzymes activity in pepper producing farms was markedly lower than in not cultivated soils adjacent to the fields of onion.

Chemical parameters of the soils

Soil management had no significant effect on pH (Tab. 2). However, there were differences between fields of onion and soils sampled in pepper production, which had distinctly lower pH (pH 6.4). In general, chemical parameters of soils from this type of produce (in tunnels) were different comparing to field cultivation of onion. The soil sampled in pepper tunnels characterized high salinity (EC 0.75 mS cm^{-1}), i.e. significantly higher than in control fallows and in the other examined soils (EC range 0.29–0.47 mS cm^{-1}). Similar effect was observed for nitrogen and phosphorus contents. Concentrations of N-NO_3 was in average 99.7 mg dm^{-3} of soil, while for onion this was 75.0 mg dm^{-3}. In the case of P the values were: 212.6 and 122.7 mg dm^{-3} for pepper and onion cultivated soils respectively. The opposite effect was observed for calcium whose contents were lower in pepper crops (1419 mg dm^{-3}) than in field crops of onion (1813 mg dm^{-3}).

Comparing nutrients concentrations between arable soils and fallows in studied crops, the most significant differences were again in the case of pepper followed by onion. The soils, where pepper was cultivated, contained significantly more N-NO_3, P, Ca, Cu and Zn than adjacent fallows, but less Fe. In onion cultivation salinity and nitrogen content were significantly higher, but K and Mg were lower than in not cultured soils. According to micronutrients the differences between cultivated soils and fallows were not significant.

Physical properties of the soils

The differences in the physical properties between arable soil and fallow were established for the cultivation of onions (Tab. 3). Cultured soil characterized significantly higher bulk density 1.4 g cm^{-3} and lower soil porosity about 46%, compared to fallow, where soil bulk density was 1.1 g cm^{-3} and soil porosity ranged 55–56%. In the pepper producing farms there were no significant differences between cropped soil and soils in the vicinity of the tunnels. It was observed, that soil in the tunnels was less compact than in field vegetable production. Whereas fallow soil, taken in the vicinity of the tunnels, was more compacted – opposite to other fallows. In the case of water holding capacity, there were not significant differences between both types of soil use.

It was found that fallow soils characterized significantly higher organic matter content (SOM ranged 3.78–3.80%) than in soils used for vegetable cultivation (SOM ranged 2.24–2.82%) – as in Figure 2. The higher differences were determined for onion. In the case of pepper, the difference in SOM content between not cultivated soil and "tunnel" soil was not that much bigger, but still relevant.

Fertilization practices and crop rotation

On the basis of the surveys carried out in the visited farms, it was found that in field production of onion mineral fertilization prevailed (Fig. 3). In opposite, in pepper production combined mineral-organic fertilization was mainly used (in 60% of monitored farms). In the case of organic fertilizers cattle manure was the

Table 2. Concentration of nutrients (means in mg dm^{-3} of soil ± SE) in soils under intensive vegetable production and in fallow soils

Nutrients	Onion		Pepper	
	intensive	fallow	intensive	fallow
pH	6.8 ±1.2 a	7.2 ±1.0 a	6.4 ±0.7 a	6.3 ±0.8 a
EC (mS cm^{-1})	0.47 ±0.24 a	0.36 ±0.24 b	0.75 ±0.43 a	0.29 ±0.22 b
N-NO_3	75.0 ±76.3 a	40.4 ±32.4 b	99.7 ±87.0 a	29.6 ±15.4 b
P	122.7 ±75.1 a	116.6 ±65.6 a	212.6 ±115.5 a	73.4 ±50.9 b
K	139.8 ±74.8 b	184.9 ±123.4 a	120.6 ±82.6 a	119.8 ±75.8 a
Ca	1813 ±1467 a	2449 ±1731 a	1419 ±862 a	839 ±519 b
Mg	128.5 ±48.5 b	177.5 ±82.8 a	131.8 ±52.7 a	90.4 ±31.6 b
Fe	103.4 ±79.9 a	91.9 ±83.5 a	106.8 ±49.8 b	145.9 ±68.2 a
Mn	20.8 ±24.2 a	11.4 ±11.9 a	9.0 ±3.6 a	8.0 ±4.7 a
Cu	2.5 ±1.6 a	2.6 ±2.6 a	1.8 ±0.6 a	1.3 ±0.4 b
Zn	4.1 ±2.6 a	12.4 ±30.4 a	9.8 ±4.7 a	6.4 ±3.0 b
B	0.7 ±0.3 a	0.9 ±0.6 a	1.0 ±0.6 a	0.8 ±0.4 a

Means for cropping and fallow soils indicated by the same letter do not differ significantly according to Student or Welch test at p = 0.05

Table 3. Physical properties of studied soils (means ± SE)

Parameter	Onion		Pepper	
	intensive	fallow	intensive	fallow
Soil bulk density (g cm^{-3})	1.41 ±0.15 a	1.13 ±0.20 b	1.33 ±0.10 a	1.25 ±0.19 a
Soil porosity (%)	45.6 ±5.8 b	56.0 ±7.9 a	48.7 ±3.9 a	51.0 ±7.1 a
Water holding capacity (%)	41.6 ±4.2 a	44.3 ±8.2 a	45.7 ±2.9 a	46.6 ±3.6 a

Means for cropping and fallow soils indicated by the same letter do not differ significantly according to Student test at p = 0.05

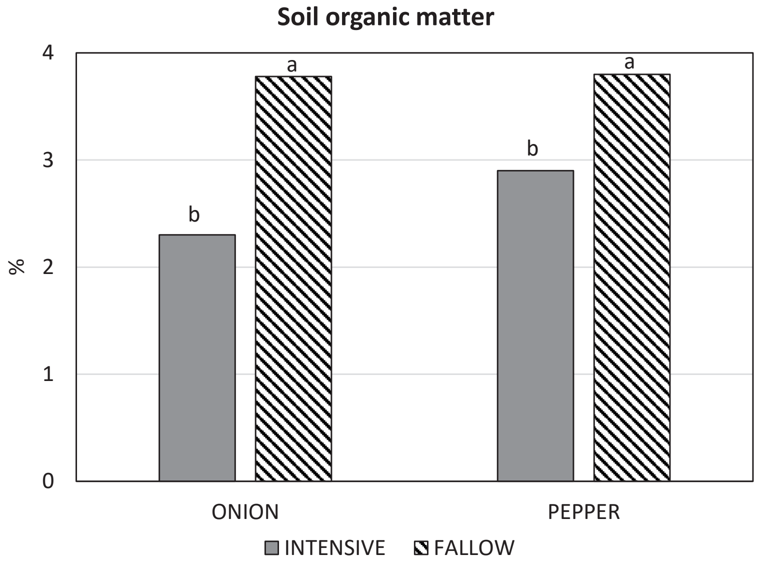

Fig. 2. Organic matter content (% vol.) in soils cropped with onion, cabbage or pepper compared to the fallow land adjacent to these crops. Different letters above bars indicated significant differences between means according to Student test at p = 0.05, separately for each crop

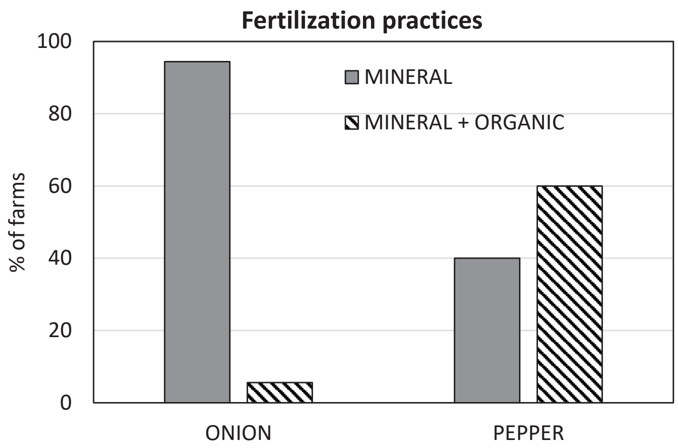

Fig. 3. Comparison of the rate of mineral and mineral-organic fertilization in production of onion and pepper

most frequently used. However, in pepper cultivation chicken dung applied in autumn, after harvest was also applied.

Analysis of the farmers' data has shown that rotation studied crops was very simplified. Onion in most cases was grown in monoculture or in rotation with potato and carrot, and occasionally with celery, lettuce or wheat. The most simplified rotation was in the cultivation of pepper. In eight out of ten visited farms, the crop was grown in a monoculture that lasts for several years or more (in one case it was 22 years). In one farm pepper was rotated with cucurbits and bean, and in second with barley. In two sites pepper was intercropped with radish or dill and lupine as green manure.

DISCUSSION

The investigations performed in this work show the effects of intensive onion and pepper cultivation on soil's biotic and abiotic characters, and indicate which of studied parameters are the most sensitive to practices employed in both crops production. The research showed significant functional degradation of cultivated soils expressed by reduced enzymatic microbial activity and organic matter content. Soil physical properties deteriorated the most in the field cultivation of onions. These factors may be considered as reliable indicators of soil health in vegetable production. The other studied parameters such as pH, nutrients availability and microbial abundance seems to be less sensitive. However, the evaluation of their values supported the hypotheses about the reasons for soil degradation in each of the crops studied.

Although soil quality deteriorated in both crop types, the causes were different. The most adverse soil conditions were found in onion cultivation. The studies have shown, that commonly applied agrotechnical system for this vegetable production has a strong negative impact on the biological status of the soils, as indicated by the low activity of dehydrogenases DHA and decreased organic matter contents in contrast to fallows. Moreover, these soils characterized the highest bulk density and the lowest porosity, and water holding capacity compared to non-cultivated soils, but also to the soil in the tunnels with pepper.

The activity of dehydrogenases, as a group of enzymes acting intracellularly, informs about the biologically active microbial population in soil [Wolińska and Stępniewska 2012, Błońska et al. 2017]. Therefore, measurements of the activity of these enzymes are used to assess soil quality and the impact of soil use and degradation/regeneration rates, and their higher activity indicates higher functional diversity and soil fertility [Gil-Sotres 2005, Raiesi and Behesthi 2015]. There are several factors that may have impact on soil dehydrogenases activity. Among them the most important are SOM content, soil moisture, soil aeration [Wolińska et al. 2015].

The amount of organic matter is one of the most important indicators of soil fertility [Scotti et al. 2015, Bashir et al. 2023]. A high content of OM is a factor stabilising the structure, reducing the susceptibility of soil to compaction, erosion and degradation. The relationship between DHA and SOM and worsened soil physical soil properties are also clearly visible in our research. The highest DHA and SOM content were in the soil collected form fallows. These values strongly decreased in cultured soils. Organic matter enhances soil physical and chemical properties and promotes biological activity [Chakraborty et al. 2011], affecting the supply of energy for microbial growth and enzyme production [Fontaine et al. 2003]. As dehydrogenase activity reflects metabolic activity of the soil [Mohammadi et al. 2011], it may be considered to be proportional to the biomass of the microorganisms [Wolińska et al. 2015]. In our studies, in onion production, the number of fungi bacteria and actinomycetes in cultivated soils was significantly lower than in fallows. Similarly, Bonanomi et al. [2011] compared the biological characteristics of soils collected from different agricultural farms and found a drastic reduction of soil microbial biomass and enzymatic activities in soils having small organic C content and under intensive agriculture, without use of organic amendments. In turn Lu et al. [2021] concluded that excessive application of mineral fertilizers in vegetable production has led to the substantial soil enrichment of P, K, Ca and Mg and soil acidification at 0–60 cm depths, and resulted in rapid decrease of SOC content, followed by decline in soil physical and biological properties. In our case over-fertilisation was not observed in onion cultivation. The concentrations of nutrients in cultivated soils and in fallows were comparable, and soil acidification did not occur. It suggests, that the farmers fertilized the crops according to plant requirements, recommended by the local extension services. However, it was reported that low humus reserves in Polish soils are also related to its intensive mineralization, removal of organic residues, while limiting the supply of organic material to the soil [Jończyk et al. 2008, Smreczak and Jadczyszyn 2017]. Onion is one of such crops, where organic residues are minor and mostly transferred from the field. Moreover, the soil in onion production for the most time is not covered with vegetation. Weeds are intensively controlled with herbicides, because onion is very sensitive for competition with other plants. Intensive control of weeds, pests and pathogens, split-dose fertilisers application [Jarecka-Boncela et al. 2017] and growing need for irrigation require numerous passes by heavy equipment. This led to soil compaction, its structure degradation, and in consequence to increase organic matter mineralization and lower carbon sequestration [Jakab et al. 2023]. This is repeated year after year, especially that such production is often practised in monoculture.

In pepper cultivation, despite of less "invasive" tillage (the use of heavy equipment is not possible under tunnels) and more frequent application of organic manures (Fig. 3), the situation was not much better compared to onion production. Soil compaction in tunnels was less severe, but SOM content was comparable to soils from onion production. Moreover, excessive application of mineral fertilizers caused high concentration of macro-elements resulting in high salinity and acidification of the soil. Conditions in tunnels are favorable for pests and diseases. Therefore, intensive pepper monoculture leads to an accumulation of pathogens and pests, and the resulting increased use of pesticides. Microbial communities are also strongly affected by fumigants and pesticides usage [Jacobsen and Hjelmsø 2014]. Ciarkowska and Sołek-Podwika [2012] reported that long-term growing of vegetables in monoculture, in foil tunnels reduces urease activity in soil reflecting the changes in soil environment, and have pointed out the hampering effect of frequently used pesticides. Intensive mineral fertilization and pesticide management are also listed as a factors inhibiting dehydrogenase activity [Chang et al. 2007, Luo et al. 2015], what was observed in our studies.

Mar Guerrero et al. [2014] have found, that soil fatigue caused by continuous cropping of pepper plants at the same site is highly specific towards this crop, and does not apply to other plant species cultivated in this soil. Whereas, according to Liang et al. [2013] intensive re-cropping of the same vegetables may negatively affect soil organisms communities changing their metabolism. They showed that repetitive cropping of cucumbers enhanced population of fungi in the soil. In presented studies, the number of fungi in pepper tunnels did not differ compared to other soil samples. However, markedly lower abundance of bacteria was observed. Thus, the proportions of fungi in the microbial community increased in these soils. This could be effect of long-term, repeated mineral fertilizers application, especially nitrogen inputs, which lead to acidification and suppress soil microorganisms [Tian et al. 2015], causing adverse changes in microbial communities, favoring fungi and increasing fungal biomass in relation to bacterial biomass. The soil from pepper production contained also the lowest abundance of *Pseudomonas* bacteria, recognised as beneficial to plants [Mehmood et al. 2023]. These results suggest that, although, generally no significant changes in total microbial abundance were observed in studied soils, the adverse alterations may have occurred in microbiota composition and biodiversity. However, it needs more detailed studies with the use of culture-independent molecular techniques such as next generation sequencing (NGS) to characterize the differences in soil microbiome's composition.

CONCLUSIONS

The results showed that intensive cultivation of economically important vegetables grown in Poland such as onion and pepper, has detrimental effect on soil environment. Despite of each crop management affect the soil *via* different factors, the most significant adverse effects were reduction of DHA and SOM content. Both of them may be considered as reliable indicators of soil health condition in vegetable production. However, in order to understand the causes of the phenomena, other soil parameters also need to be thoroughly investigated.

In onion production, multiple operations with the use of agricultural equipment lead to a breakdown of soil structure. This effect is exacerbated by the poor surface coverage with vegetation related to intensive weeds control with herbicides, and minor supply of organic material to soil. Despite the use of rational mineral fertilization, these factors led to soil compaction, reduced water infiltration, surface erosion, decrease of soil organic matter, suppression of the biological functioning, and in consequence degradation of the soil. The situation is worsened by onion re-cropping for several years. Therefore reduction of tillage practices, intercrops implementation and regular crop rotation should be recommended in onion production.

In turn, in pepper cultivation, frequent cropping of the same plant for years on the same site, chemical soil disinfection frequently applied against soil-borne pathogens, with high mineral fertilizer application rates causes soil acidification and adverse effect on soil microorganisms, increasing the proportion of fungi in microbial community. Even substantial application of organic manuring in pepper monoculture did not reduce this detrimental effect. High mineral input in pepper production may cause an increase of soil organic matter mineralization. Therefore, more precise and reasonable application of fertilizers and disinfectants should be recommended. One of the solution could be also to break pepper monoculture by rotation with other crops, which can be cultivated under cover. The results indicate that future sustainable vegetable cropping systems should include a more efficient crop rotation, with fewer tillage operations and the implementation of practices leading to an increase in organic matter resources

SOURCE OF FUNDING

Study carried out within the research task PW3.2 entitled ”Development of sustainable fertilisation of horticultural plants and prevention of soil degradation and groundwater contamination”, in the Multiannual Programme (2015–2020) “Measures to improve the competitiveness and innovation of the horticultural sector taking into account food quality and safety and environmental protection”, funded by the Polish Ministry of Agriculture and Rural Development.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Alef, K., Nannipieri, P. (1995). Enzyme activities. In: K., Alef, P., Nannipieri (eds), Methods in applied soil microbiology and biochemistry. Academic Press London, New York, San Francisco.

Anthony, M.A., Crowther, T.W., Maynard, D.S., van den Hooden, J., Averill, C. (2020). Distinct assembly processes and microbial communities constrain soil organic carbon formation. One Earth, 2(4), 349–360. http://doi.org/10.1016/j.oneear.2020.03.006

Antweiler, R.C., Patton, C.J., Taylor, E. (1996). Automated colorimetric methods for determination nitrate plus nitrite, nitrite, ammonium and orthophosphate ions in natural water samples. In: U.S. Geological Survey, Open-File Report 93–638. Denver, Colorado, 1–28.

Bashir, H., Zafar, S.A., Rehman, R.S., Khalid, M.N., Amjad, I. (2023). The importance of soil organic matter (SOM) on soil productivity and plant growth. Biol. Agric. Sci. Res. J., 11. http://doi.org/10.54112/basrj.v2023i1.11

Bayata, A. (2024). Soil degradation: contributing factors and extensive impacts on agricultural practices and ecological systems – systematic review. J. Agric. Environ. Sci., 13, 16–34. http://doi.org/10.15640/ijhs.v13a2

Bastida, F., Zsolnay, A., Hernández, T., García, C. (2008). Past, present and future of soil quality indices: a biological perspective. Geoderma, 147, 159–171. http://doi.org/10.1016/j.geoderma.2008.08.007

Błońska, E., Lasota, J., Zwydak, M. (2017). The relationship between soil properties, enzyme activity and land use. For. Res. Pap., 78(1), 39–44. http://doi.org/10.1515/frp-2017-0004

Bonanomi, G., D’Ascoli, R., Antignani, V., Capodilupo, M., Cozzolino, L., Marzaioli, R., Puopolo, G., Rutigliano, F.A., Scelza, R., Scotti, R., Rao, M.A., Zoina, A. (2011). Assessing soil quality under intensive cultivation and tree orchards in Southern Italy. Appl. Soil Ecol., 47(3), 184–194. http://doi.org/10.1016/j.apsoil.2010.12.007

Bonanomi, G., De Filippis, F., Cesarano, G., La Storia, A. (2016). Organic farming induces changes in soil microbiota that affect agroecosystem functions. Soil Biol. Biochem., 103, 327–336. http://doi.org/10.1016/j.soilbio.2016.09.005

Brzezińska, M., Włodarczyk, T. (2005). Enzymy wewnątrzkomórkowych przemian redoks (oksydoreduktazy) [Enzymes of intracellular redox metabolism (oxidoreductases)]. Acta Agroph., Rozpr. Monogr., 3, 11–26.

Casida, L., Johnson, J., Klein, D. (1964). Soil dehydrogenase activity. Soil Sci., 98, 371–376.

Chakraborty, A., Chakrabarti, K., Chakraborty, A., Ghosh, S. (2011). Effect of long-term fertilizers and manure application on microbial biomass and microbial activity of a tropical agricultural soil. Biol. Fertil. Soils, 47, 227–233. http://doi.org/10.1007/s00374-010-0509-1

Chang, E.H., Chung, R.S., Tsai, Y.H. (2007). Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population. Soil Sci. Plant Nutr., 53, 132–140. http://doi.org/10.1111/j.1747-0765.2007.00122.x

Chaudhry, H., Vasava, H.B., Chen, S., Saurette, D., Beri, A., Gillespie, A., Biswas, A. (2024). Evaluating the soil quality index using three methods to assess soil fertility. Sensors, 24, 864. http://doi.org/10.3390/s24030864

Ciarkowska, K., Sołek-Podwika, K. (2012). Influence of intensive vegetable cultivation in ground and under foil tunnels on the enzymatic activity of the soil. Pol. J. Environ. Stud., 21(6), 1571–1575. https://www.researchgate.net/publication/289043250 [date of access: 21.02.2025]

De Corato, U. (2020). Agricultural waste recycling in horticultural intensive farming systems by on-farm composting and compost-based tea application improves soil quality and plant health: a review under the perspective of a circular economy. Sci. Total Environ., 738, 139840. http://doi.org/10.1016/j.scitotenv.2020.139840

Dhingra, O.D., Sinclair J.B. (1995). Basic plant pathology methods. CRC Press, Inc. London, Tokyo.

European Environment Agency, Arias-Navarro, C., Baritz, R., Jones, A. (2024). The state of soils in Europe – fully evidenced, spatially organised assessment of the pressures driving soil degradation. Publications Office of the European Union, https://data.europa.eu/doi/10.2760/7007291 [date of access: 30.05.2025].

Fontaine, S., Marotti, A., Abbadie, L. (2003). The priming effect of organic matter: a question of microbial competition. Soil Biol. Biochem., 35, 837–843. http://doi.org/10.1016/S0038-0717(03)00123-8

Gil-Sotres, F., Trasar-Cepeda, C., Leiros, M.C., Seoane, S. (2005). Different approaches to evaluating soil quality using biochemical properties. Soil Biol. Biochem., 7, 877–887. http://doi.org/10.1016/j.soilbio.2004.10.003

Gould, W.D., Hagedorn, C., Bardinelli, T.R., Zablotowicz, R.M. (1985). New selective media for enumeration and recovery of fluorescent pseudomonads from various habitats. Appl. Environ. Microbiol., 49, 28–32.

Goździewicz-Biechońska, J. (2018). Przeciwdziałanie degradacji ziemi i gleby jako globalne wyzwanie dla prawa [Dealing with land and soil degradation as a global legal challenge]. Przegl. Prawa Rol., 1(22), 41–57.

Hattori, R., Hattori, T. (1980). Sensitivity to salts and organic compounds of soil bacteria isolated on diluted media. J. Gen. Appl. Microbiol. 26, 1–14.

Jacobsen, C.S., Hjelmsø, M.H. (2014). Agricultural soils, pesticides and microbial diversity. Curr. Op. Biotech., 27, 15–20. http://doi.org/10.1016/j.copbio.2013.09.003

Jakab, G., Madarász, B., Masoudi, M., Karlik, M., Király, C., Zacháry, D., Filep, T., Dekemati I., Centeri, C., Al-Graiti, T., Szalai, Z. (2023). Soil organic matter gain by reduced tillage intensity: storage, pools, and chemical composition. Soil Till. Res., 226, 105584. http://doi.org/10.1016/j.still.2022.105584

Jarecka-Boncela, A., Anyszka, Z., Doruchowski, G., Felczyński, K., Grzegorzewska, M., Kałużna, M., Komorowska, B., Ptaszek, M., Wrzodak, R. (2017). Metodyka integrowanej ochrony cebuli [Methodology for integrated onion protection]. Instytut Ogrodnictwa, Skierniewice.

Jończyk, K., Jadczyszyn, J., Filipiak, K., Stuczyński, T. (2008). Przestrzenne zróżnicowanie zawartości materii organicznej w glebach Polski w kontekście ochrony gleb i ich rolniczego wykorzystania [Spatial differentiation of organic matter content of Polish soils in the context of soil protection and its agricultural use]. Stud. Rap. IUNG – PIB, 12, 133–142. http://opr.iung.pulawy.pl/publikacje/Jo%C5%84czyk,%20Jadczyszyn,%20Filipiak,%20Stuczy%C5%84ski%202008.pdf [date of access: 12.05.2025].

Kahsay, A., Haile, M., Gebersamuel, G., Mohammed, M. (2025). Developing soil quality indices to investigate degradation impacts of different land use types in Northern Ethiopia. Heliyon, 11, e41185. http://doi.org/10.1016/j.heliyon.2024.e41185

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7, 5875–5895.

Liang, Y., Lin, X., Yamada, S., Inoue, M., Inosako, K. (2013). Soil degradation and prevention in greenhouse production. Proc. Inter. Conf. Combating Land Degradation an Agricultural Areas, Zi'An City, PR China, 11–15 October 2010. SpringerPlus, 2(Supl. 1), S10. http://www.springerplus.com/content/2/S1/S10 [date of access: 21.02.2025].

Lu, M., Powlson, D.S., Liang, Y., Yao, Z., Chadwick, D.R., Long, S., Liu, D., Chen, X. (2021). Significant soil degradation is associated with intensive vegetable cropping in subtropical area: a case study in southwest China. Soil, 7, 333–346. http://doi.org/10.5194/soil-7-333-2021

Luo, P., Han, X., Wang, Y., Han, M., Shi, H., Liu, N., Bai, H. (2015). Influence of long-term fertilization on soil microbial biomass, dehydrogenase activity, and bacterial and fungal community structure in a brown soil of northeast China. Ann. Microbiol., 65, 533–542. http://doi.org/10.1007/s13213-014-0889-9

Mahala, D.M., Maheshwari, H.S., Yadar, R.K., Prabina, B.J., Bharti, A., Reddy, K.K., Kumawat, C., Ramesh, A. (2020). Microbial transformation of nutrients in soil: an overview. In: S.K., Sharma, U.B., Singh, P.K., Sahu, H.V., Singh, P.K. Sharma, (eds), Rhizosphere microbes. Microorganisms for sustainability. Springer, Singapore, 175–211. http://doi.org/10.1007/978-981-15-9154-9_7

Mar Guerrero, M., Guiaro, P., Martinez-Lluch, C., Tello, J.C., Lacasa, A. (2014). Soil fatigue and its specifity towards pepper plants in greenhouses. Spanish J. Agric. Res., 12(3), 644–652. http://doi.org/10.5424/sjar/2014123-5701

Martin, P. (1950). Use of acid, rose Bengal and streptomycin in the plate method for estimating soil fungi. Soil Sci., 69, 215–232.

Mayer, Z., Sasvári, Z., Szentpéteri, V., Pethöné Rétháti, B., Vajna, B., Posta, K. (2019). Effect of long-term cropping system on the diversity of the soil bacterial communities. Agronomy, 9, 878. http://doi.org/10.3390/agronomy9120878

Mehmood, N., Saeed, M., Zafarullah, S., Hyder, S., Rizvi, Z.F., Gondal, A.S., Jamil, N., Iqbal, R., Ali, B., Ercisli, S., Kupe, M. (2023). Multifaceted impacts of plant-beneficial *Pseudomonas* spp. in managing various plant diseases and crop yield improvement. ACS Omega. http://doi.org/10.1021/acsomega.3c00870

Midler, E. (2022). Environmental degradation: impacts on agricultural production. Institute for European Environmental Policy. Available: https://ieep.eu/wp-content/uploads/2022/12/Policy-brief_Environmental-degradation.-Impacts-on-agricultural-production_IEEP-2022.pdf [date of access: 15.05.2025].

Mohammadi, K., Gholamreza, H., Khalesro, S., Sohrabi, Y. (2011). Soil management, microorganisms and organic matter interactions: a review. Afr. J. Biotech., 10(84), 19840–19849. http://doi.org/10.5897/AJBX11.006

Ostrowska, A., Gawliński, S., Szczubiałka, Z. (1991). Metody analizy i oceny właściwości gleb i roślin [Methods of analysis and evaluation of soil and plant properties]. Instytut Ochrony Środowiska, Warszawa.

PN-EN 13041: 2002. Soil improvers and growing media. Determination of physical properties – Dry bulk density, air volume, water volume, shrinkage value and total pore space. Polish Standards, PKN, Warszawa.

PN-EN 13039: 2002. Soil improvers and growing media. Determination of organic matter content and ash. Polish Standards, PKN, Warszawa.

Qu, Y., Tang, J., Li, Z., Zhou, Z., Wang, J., Wang, S., Cao, Y. (2020). Soil enzyme activity and microbial metabolic function diversity in soda saline-alkali rice paddy fields of northeast China. Sustainability, 12, 10095 http://doi.org/10.3390/su122310095.

Raiesi, F., Beheshti, A. (2015). Microbiological indicators of soil quality and degradation following conversion of native forests to continuous croplands. Ecol. Indic., 50, 173–185. http://doi.org/10.1016/j.ecolind.2014.11.008

Scotti, R., Bonanomi, G., Scelza, R., Zoina, A., Rao, M.A. (2015). Organic amendments as suitable tool to recovery fertility in intensive agricultural system. J. Soil Sci. Plant Nutr., 15(2), 333–352. http://doi.org/10.4067/S0718-95162015005000031

Smreczak, B., Jadczyszyn, J. (2017). Badania właściwości gleb użytkowanych rolniczo w latach 1992–1997 i ich wykorzystanie w ocenach rolniczej przestrzeni produkcyjnej [Studies on the properties of agriculturally used soils from 1992 to 1997 and their use in assessments of agricultural production space]. Stud. Rap. IUNG – PIB, 51(5), 41–56. http://doi.org/10.26114/sir.iung.2017.51.03

Statistics Poland. Production of Agricultural and Horticultural Crops in 2024. Available online: https://stat.gov.pl/en/topics/agriculture-forestry/agricultural-and-horticultural-crops/production-of-agricultural-and-horticultural-crops-in-2024,2,9.html [date of access: 28.07.2025].

Stea, T.H., Nordheim, O., Bere, E., Stornes, P., Eikemo, T.A. (2020). Fruit and vegetable consumption in Europe according to gender, educational attainment and regional affiliation – A cross-sectional study in 21 European countries. PLoS ONE 15(5), e0232521. http://doi.org/10.1371/journal.pone.0232521

Tian, W., Wang, L., Li, Y., Zhuang, K., Li, G., Zhang, J., Xiao, X., Xi, Y. (2015). Responses of microbial activity, abundance, and community in wheat soil after three years of heavy fertilization with manure-based compost and inorganic nitrogen. Agric. Ecosyst. Environ., 213, 219–227. http://doi.org/10.1016/j.agee.2015.08.009

Trivedi, P., Delgado-Baquerizo, M., Anderson, C., Singh, B.K. (2016). Response of soil properties and microbial communities to agriculture: implications for primary productivity and soil health indicators. Front. Plant Sci., 7. http://doi.org/10.3389/fpls.2016.00990

Walinga, J., van der Lee, J.J., Houba, V.J.G., van Varak, W., Nowozamsky, I. (1995). Plant analysis manual. Kluwer Academic Publishers, Dordrecht.

Wolińska, A., Stępniewska, Z. (2012). Dehydrogenase activity in the soil environment. In: R.A. Canuto (ed.), Dehydrogenases. IntechOpen. http://doi.org/10.5772/2903

Wolińska, A., Stępniewska, Z., Pytlak, A. (2015). The effect of environmental factors on total soil DNA content and dehydrogenase activity. Arch. Biol. Sci. Belgrade, 67(2), 493–501. http://doi.org/10.2298/ABS140120013W

Wolińska, A., Banach, A., Szafranek-Nakonieczna, A., Stępniewska, Z., Błaszczyk, M. (2018). Easily degradable carbon – an indicator of microbial hotspots and soil degradation. Inter. Agroph. 32, 123–131. http://doi.org/10.1515/intag-2016-0098

Wolińska, A., Kuźniar, A., Zielenkiewicz, U., Banach, A., Błaszczyk, M. (2018). Indicators of arable soil fatigue – bacterial families and genera: a metagenomic approach. Ecol. Indic., 93, 490–500. http://doi.org/10.1016/j.ecolind.2018.05.033