

RELATIONSHIPS BETWEEN CRUCIAL SOIL VARIABLES AND SOIL MICROBIAL BIOMASS IN ANNUAL AND PERMANENT FARMING CULTIVATION SYSTEMS IN CENTRAL EUROPE

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Abstract

Soil is the key resource for agriculture and horticulture. Most of our food production depends on this resource. The aim of the research is to evaluate the state of the soils and their fertility in fruit and vegetable field cultivation in central Europe. To achieve this goal, the status of 77 soil samples from 18 pilot farms was recorded. We investigated the relationship between different soil properties and analysed the influence of two types of field cultivation on soil microbial biomass. We differentiate between permanent cultures (apple orchards, PF) and yearly changing vegetable and arable cultures (AF). The results obtained indicate differences in the soil properties. Deficits regarding soil fertility could be observed. Soil pH values range from 3.9 to 7.5 in arable crops and from 5.3 to 7.3 in apple crops. The fluctuation range of the soil chemical and physical parameters is larger in the soils of the annual crops. No significant difference could be detected between the content of organic matter; both the total microbial biomass and the bacterial and fungal biomass in the soil organic carbon (SOC) were significantly higher in permanent crops. A high negative correlation was found between microbial biomass and sand content. The correlation analysis showed that SOC and total nitrogen (TN) were strongly correlated ($R^2 = 0.71$). Pb and Cu show a negative correlation with sand but a positive correlation with adsorption on silt and clay. We suggest that the soil organic matter was the main reason for the increase in microbial biomass. It influences the soil physicochemical properties, especially nutrient availability and heavy metal content. Based on the determined current status, the derivation of individual area-specific measures should maintain and increase soil fertility and biodiversity. These measures are to be implemented in pilot farms, and their success in improving and maintaining good soil vitality is to be analysed and documented in the future.

Keywords: soil properties, PLFA analysis, microbial biomass, soil organic carbon, land use, vegetable, food production, fruits

1. INTRODUCTION

Agricultural land worldwide is under increased production pressure. Soil is an important factor for effective crop production. In addition to cereals, large areas of land are also used for the cultivation of vegetables and fruit. Intensive anthropogenic use as well as natural processes leads to nutrient losses and soil degradation over the long term. Our research aims to analyse soil vitality with the help of different soil properties over a large area in Central Europe.

Following the project "Healthy Soil - Healthy Plants - Healthy Vegetables", the current state of soil fertility in different farms of vegetable and fruit production should be investigated. During this project, numerous soil samples were collected at various locations in Germany, Poland and the Czech Republic. These results serve as the basis for the investigation of correlations between different soil parameters. Thus, a large dataset of soil parameters of different soils of Central Europe is available.

Soil health in general focuses on the soil as a living system with optimal ecological functions. Soil quality is the ability of a soil to maintain biological productivity, sustain environmental quality, and promote plant and animal health within ecosystem boundaries (Svoray et al. 2015). Soil property is determined by parent material, topography, and climate (Doran et al. 1996).

Soil health is best assessed by measuring physical, chemical, and biological variables that are sensitive to changes in management systems (Doran et al. 1996).

Soil quality depends on its inherent composition, which is derived from soil-forming factors, and its responses to the introduction of different soil management practices (Goh et al. (2001). Liddle et al. (2020) evaluated soil microbial biomass as affected by naturally occurring variations in soil organic carbon (SOC), clay content, and local topography. The study's pastures differed in historical land use for crops or forage seeding.

Soil fertility, on the other hand, is the ability of soils to serve as a site for plants and is related to management effects and yield. Important soil parameters for this are soil structure, water and air balance, and nutrient supply. According to Mäder et al. (2002), a fertile soil must provide enough essential nutrients for plant growth and have an active biological community and a capacity for undisturbed decomposition.

The content, quantity and quality of the humus are decisive in this respect. It influences soil physical, chemical and biological properties, such as water and nutrient balance, cation exchange capacity, pH value and mineralization (Thiel, E. and Kolbe, H. (2011)).

Bailey et al. (2008) assesses the extent of the problem of fertility of agricultural soils in parts of Papua New Guinea. Due to population pressure, there is a reduction in the fertility of arable soils with sweet potato (Bailey et al. 2008). Guo et al. (2019) studied soils by analysing the interaction between soil nutrients and microorganisms, which contribute greatly to soil fertility. The study by Y. El-Ladan and A. Maiwada (2014) was designed with the aim of investigating the influence of land use practices on soil fertility status.

Site vegetation or cultivated crops are also relevant to soil fertility. The influence of land use practices on the fertility status of some soils has already been studied, among others by Asadu et al. (1997).

Within the framework of our research project, soils of different regions and cultivation are investigated with regard to numerous factors of soil fertility. The focus is on soils with permanent crops (apple orchards, PF) and with yearly crop rotation (vegetable crops, AF).

Studies on permanent crops have been conducted mainly in forestry (Joergensen (1996), Zhao et al. (2013)). Hassink (1992) studied the effects of soil texture and structure on carbon and nitrogen mineralization in grassland soils. Three different production systems for apple orchards with grassland in New Zealand were compared in terms of chemical and biological quality parameters and their effects on soil physics (Goh et al. 2001). Microbial properties in permanent apple crops were also addressed by Wang et al. (2009).

Since soil biological state variables are sensitive to changes, they are considered suitable indicators of environmental stresses to adequately complement soil physicochemical properties (Wang 2009). Research on agricultural fields led (Lu et al. (2021), Mishra et al. (2020), Joergensen (1996), Bulluck et al. (2002)), among others.

According to Joergensen (1996), studying soils that have developed under similar vegetation cover and climatic conditions is a meaningful way to measure the relationship between microbial biomass and soil properties. The interaction between soil nutrients and microorganisms contributes greatly to soil quality in fragile ecological environments (Guo et al. 2019).

Land use changes have significant impacts on soil quality, ecological processes, and soil functions due to changes in soil physical, chemical, and biological properties (Mishra et al. 2020).

Soil is also a major source of C sequestration. Globally, it plays a key role in the carbon cycle. When an ecosystem is disturbed by land use change, the original equilibrium of soil carbon storage is disturbed, and a new equilibrium is created. Management activities are one of the main factors causing the loss of SOC in orchards.

Qin et al. (2014) investigated the influence of vegetation restoration on topsoil organic carbon in a small catchment in China. The objective of this study was to quantify the current soil organic carbon density of different land uses, such as cropland, fallow land, forest, and orchard. Often, trimmed branches and litter are removed from orchards, which may result in fewer organic compounds entering the soil (Qin et al. 2014).

The results show that orchard management systems significantly affected soil physical, chemical, and biological properties (Goh et al. 2001). However, according to Goh et al. (2001), very little is known about the effects of soil management practices on soil quality parameters.

The supply of nutrients, especially N, P, and K, from minerals or fertilizer to the soil affects the availability of other nutrients. In turn, the input of a nutrient alters soil biogeochemical cycling.

The commonly studied chemical indicators of soil fertility are pH, Na, K, P, EC, Mg, Ca, and Zn (Gregorich et al. 1994). Numerous state variables were determined as part of this project. We focus on relevant soil physical and chemical parameters, with an emphasis on the content of various nutrients and heavy metals, CEC, grain size, and pH.

Biological processes are also used to estimate soil health influenced by agricultural activity. In our case, these are selected soil biological parameters, such as soil organic matter, C/N value, and microbial biomass.

CEC is an important indicator for assessing soil fertility, plant growth, and the distribution and transport of contaminants in soils. CEC measures the basic physical and chemical properties of soils, pH, SOC, and grain size composition. Chemical properties influence plant growth as well as microbiological processes in the soil and can indicate C and nutrient availability as well as soil acidity (Svoray et al. 2015).

Previous studies have shown that soil physical and chemical properties, such as SOC, pH, and particle size composition, have significant effects on CEC. Clay, sand, pH and soil OM are important influencing factors for predicting topsoil CEC in Nigerian soils (yunan et al. 2018)). Dutta et al. (2011) studied the effects of physical and chemical soil properties, including pH, organic carbon and CEC, on the adsorption of lead in soil. Many studies on correlations between different soil properties already exist. Among them, yunan et al. (2018) addressed the correlations of soil parameters in 100 agricultural soil samples from 23 Chinese provinces.

Moreover, soil organic matter is considered an important factor of soil health. Lu 2021 mentioned that small changes in soil organic carbon (SOC) have a significant impact on climate change. A major driver of SOC turnover is microorganisms. Microorganisms promote the formation of macroaggregates to physically protect carbon. Microbial biomass also plays a critical role in influencing the SOC pool (Zhang et al. 2013). Generally, up to 5% of the total organic carbon and nitrogen is in the soil microbial biomass. A change in microbial biomass can affect the cycling of soil organic matter.

As an important source of soil nutrients, soil microbial biomass is involved in most chemical processes that occur in soil organisms. Microorganisms play an essential role in soil carbon by affecting various ecosystem processes, including organic matter mineralization, soil formation, and nutrient availability (He et al. (2020), Lin et al. (2019)).

Hassink (1995) addressed organic matter and microbial biomass as predictors of C and N mineralization, and Murphy et al. (1998) stratified microbial biomass C and N and gross N mineralization with soil depth in two contrasting agricultural soils in western Australia. McGonigle und Turner (2017) differentiated soils between grassland and cropland in his research.

In addition, soil microbes are sensitive to variations in soil fertility, land use changes, and ecosystem disturbances (Zhao et al. 2013). Heavy metals in soil are key limiting factors for soil life. Heavy metal cations can be introduced into agricultural soils through the application of fertilizers, lime materials, sewage sludge, compost, and other industrial and urban waste materials (Gomes et al. 2001).

Very few studies have focused on the interaction of management practices with soil properties. Most studies have focused on only one ecosystem without linking changes in soil properties to other factors. The influence of different types of land use on soil microbial properties and soil quality is still largely unknown (Zhao et al. 2013). It has been suggested that agriculture can significantly affect soil organic matter dynamics, soil C and N cycles, and soil biological properties, thus altering soil quality and function (Page et al. 2020).

Therefore, differences between the soil properties of permanent crops and annually changing agricultural soils will be elaborated in our study. Despite numerous studies, there are still large gaps in our knowledge of variations between the soil properties of vegetable and fruit crops. To fill this research gap, we analysed the effects of different management methods on the quality of soil properties between cropland as annual management system and apple orchards as permanent management system. We investigated the properties of soils of different uses and analysed possible relationships. Differences in crop composition directly and/or indirectly influence litter decomposition rates and their relationships with changes in soil properties. However, the influence of soil properties on microbial biomass remains unclear (Liddle et al. 2020). It is of great importance for the mechanistic understanding of plant–soil interactions. We are trying to determine initial approaches to correlations. To date, there is no dataset on this scale from vegetable and fruit crops in Central Europe. Therefore, this work represents a first overview of the differences between vegetable and fruit production areas. Our aim is to improve the understanding of the relationships between microbial biomass and soil properties under vegetable and fruit cultivation.

The aim of the project is to develop a set of measures to increase soil fertility and vitality in outdoor fruit and vegetable production. To achieve this goal, further scientific monitoring of pilot farms is planned. After recording the actual state of the prevailing soils and management measures, the evaluation of the effectiveness of area-specific proposed measures on soil vitality will be conducted.

In the context of this article, the status of soils is presented in terms of the contents of basic essential elements, including organic carbon, total nitrogen, available phosphorus, pH and cation exchange capacity.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Survey location and characteristics

The present study was conducted in central Europe, located between 48° 43' and 54° 1' N latitude and 8° 28' and 21° 12' E longitude, in Germany, Poland and Czech Republic. The research area has a continental climate, with an average annual temperature between 8.5 and 10.0 °C. The average annual rainfall varies from a minimum of 660 mm to a maximum of 800 mm, which occurs equally in the whole year. However, in recent years, rainfall has varied widely and occurs locally.

Most agriculture is conducted in the mid-altitude range of 100 to 500 m, largely on valley floors and ground moraines. In general, soils in the studied area are defined as sandy loam according to the USDA texture classification system. The soil types are distinct varieties of Fluvisol, Luvisol, Cambisol and Chernozem. However, there were still differences in grain size, land use and cover types.



Fig. 1. Geographical location of the soil samples

Different locations were considered due to their heterogeneity. For the present study, a total of 77 soil samples were collected from 18 locations (Figure 1). They were divided into annual farming (AF) and permanent crops (PF). 13 companies with vegetable and/or crop cultures (AF) and 5 companies with apple trees as permanent farming (PF).

2.1.2. Soil sampling

The soil samples were collected outside the growing season between January and March as well as between October and November 2021. Eighteen sites were selected with the two different land use types: permanent farming (PF) with apples and annual farming with vegetables (AF). At each site, three to five fields were sampled at a depth of 0-30 cm. If the field history was different, the fields were also divided, mostly into two sections with a maximum of three sections. A total of 51 plots with vegetable and arable land use (AF) and 26 plots in apple production (PF) were taken and analysed. The sampling of the permanent crops (apple orchards) was conducted in 4 rows, divided into interrow greening and tree planting with sampling gap of approx. 20 cm from the trunk. The composite soil subsamples of 30 cores were selected at 0.2 m from the apple tree trunk (after removing the litter layer) and in the alley.

Soil sampling in the vegetable fields was performed on a selected area of approximately 2 ha of the field, depending on the field size. In each field, 16-20 samples from 0-30 cm depth were sampled with a borstick.

Soil samples were mixed and homogenized for each plot and divided into two subsamples. One subsample was used for the chemical and physical analyses, and the other was stored in plastic bags at 4 °C until microbial biomass and microbial function diversity analyses were performed.

2.2. Methods

For sample preparation, the samples were dried and ground before analysis. For grain size, the analysis ÖNORM L1061-2 (pipette method) was used. The particle size distribution is clay (< 2 µm), silt (63-2 µm) and sand (2000-63 µm). Soil pH was determined with CaCl₂ (DIN ISO 10390). Electrical

conductivity was analysed using a conductivity metre (edge™ HI2020-02 HANNA Instruments srl) with a solution ratio of 1:2.5. The concentration of soil nutrient reserves was determined using an extract with ammonium lactate, pH 3.75 (Egner, H. & H. Riehm 1955). The CAT extraction of Mg, B, Mn, Cu and Zn was carried out by VDLUFA. The soluble fraction extracting agent of the nutrient fractions was a 1:5 water extract. DM 13/09/1999 SO n° 185 GU n° 248 21/10/1999 Met XIII.2 were used to obtain data about the potential CEC.

Total carbon (TC), total nitrogen (TN) and total inorganic carbon (TIC) were assessed using an elemental analyser. The samples were ground, and 4 replicate analyses were performed for each sample. All soil samples for TC and TN analysis were pyrolyzed at 1400 °C for analysis. Soil samples for TIC were heated at 130 °C and determined with phosphoric acid.

Total Organic Carbon (TOC): TC-TIC

Humic substance = TOC*1,72

C/N-ratio= TOC/TN

To determine the soil organic matter, we used the method of Eurofins Agro accredited by RvA (NIRS (TSC®)).

The CaO reserve is the sum of the exchangeable Ca ions and the soluble, carbonated Ca ions in the extract. Heavy metal analysis is based on DIN EN 15763 and DIN EN ISO 17294-2:2017-01 and is performed by pressure digestion followed by determination by ICP-MS.

We recorded fungal and bacterial biomass C measured using methods such as phospholipid fatty acids (PLFAs). The PLFA was the most widely used and likely the most appropriate approach for estimating the FBC and BBC simultaneously (He et al. 2020). Microbial biomass is a quantified total of a large number of fatty acids. Fungi and bacteria make up the largest proportion but do not contain the entire microbial biomass. The biomass of fungi, bacteria and microbial biomass in mg C/kg soil was calculated using a conversion factor known from the literature (Eurofins Agraranalytik Germany).

Table 1. Overview of the abbreviations

Abbreviation	Parameter
SOC	soil organic carbon, Corg
EC	electrical conductivity
pCEC	potential cation exchange capacity
pH	pH-value
TN	total nitrogen
C/N	
K ₂ O-Res	K ₂ O-reserve
P ₂ O ₅ -Res	P ₂ O ₅ -reserve
Mg-CAT	Mg with Calciumchlorid/DTPA-extract
B-CAT	B with Calciumchlorid/DTPA-extract
Na-s	sodium soluble
CaO-Res	calcium oxide reserve
Humic	humic substance
MBC	soil microbial biomass carbon (Cmic)

BBC	bacterial biomass carbon
FBC	fungal biomass carbon
Pb	lead
Cd	cadmium
Cu	copper
Hg	mercury
TIC	total inorganic carbon
TC	total carbon
TOC	total organic carbon
C	carbon

The standard soil tests were carried out in the laboratory of ECORECYCLING KG Winfried Felderer Italia, and the heavy metal analysis was performed at Analytica Alimentaria GmbH, Germany. Eurofins Agraranalytik Germany GmbH determined the microbiological properties of the soil substrates in Wageningen.

2.3. Statistical analysis

Pearson correlations were used to check the correlation between different measured parameters. For the determination of the relevant influencing variables on the target variable microbial biomass, stepwise multiple regression was used. For the reduction of the influencing variables, the significance approach was chosen. For comparison of selected datasets, Student's T test for independent samples with $p < 0.05$ was calculated. All analyses were conducted using Statistica-version 13.5.0.17, TIBCO Software Inc.

3. RESULTS

3.1. Soil properties and metal contents

The soil substrates investigated are very different. This difference is shown by the fact that the soil properties (Table 2) vary greatly. We observed significant differences in soil physical properties between annual and permanent crops. Both the coefficients of variation (cv-%) of the annual crops and the permanent crops of apple often assume values above 50%. Only for the parameters pH and C/N was the cv rather low, as expected, in the range between 6.3 and 17.8. The cv of the nitrogen and humus contents ranged between 33 and 42% in annual farming and 22 and 28% in permanent farming.

In the studied soils, sand contents vary from 5 to 93% in annual crops (vegetables, AF) and from 8 to 76% in permanent crops (apple, PF). Soil pH values ranged from 3.9 to 7.5 in arable soils and from 5.3 to 7.3 in permanent farming.

The maximum soil EC was observed in annual farming soil, with 630 $\mu\text{S}/\text{cm}$ in arable/vegetable crops and only 325 $\mu\text{S}/\text{cm}$ in soils with apple cultivation. Maximum values of CaO reserve of 6,766 mg/100 g were observed in the arable crops. Soils of permanent apple crops had a maximum of half of these contents. The minimum values were 11 mg/100 $\times$ g for vegetable crops and 78 mg/100 $\times$ g for apple crops.

In both types of cultivation, Mg-CAT contents varied between 1.8 and 24.7 mg/100 g. In contrast, large differences appear between them in the content of the micronutrient boron. In the arable crops,

the values ranged from 0.6 to 14.8 mg/100 g. The range of variation in apple crops was smaller, with values between 1.7 and 9.9 mg/100 g.

The CEC of soils ranges from 4.4 meq/100 g to 33.9 meq/100 g in annual crops and 2.68 to 23.2 meq/100 g in permanent crops. The mean value is lower for vegetable crop soils at 11.9 meq/100 g than for apple crop soils at 13.9 meq/100 g.

For most of the soil chemical properties (CEC, pH, and Corg, most nutrient concentrations), no significant differences between annual and permanent farming were detected. Only for phosphorus are the values of permanent crops significantly lower. In contrast, the values for copper are significantly higher in the apple crops. Significant differences between the arable crops (vegetables, AF) and the permanent crops (apple, PF) are especially pronounced in the microbial area and the heavy metal contents. Cadmium shows high contents of maximum values of 18.6 mg/kg DM, especially in arable crops. These are in the permanent crop contents below 0.9 mg/kg DM.

Corg content has roughly equal ranges of approximately 0.5 to 2.3% in both categories. The median is smaller than the mean for the arable crops but larger for the apple plants. The C/N values are approximately 8.7 for the apple crops and 9.0 for the arable crops. As expected, the range is larger for annual crops, varying from 6.5 to 13.7.

Table 2. Soil physiochemical and microbial properties of the soils

variable	units	Annual farming					Permanent farming				
		Mean	Median	Min	Max	Cv %	Mean	Median	Min	Max	cv %
sand	%	61.1	65.0	5.1	93.0	43.7	35.0	30.5	7.9	76.0	74.4
silt	%	26.3	23.0	3.7	72.0	75.6	47.5	49.5	17.0	73.0	40.9
clay	%	12.7	10.0	1.7	43.0	75.0	17.6	18.0	5.5	36.0	53.0
SOC	%	1.17	1.10	0.50	2.30	41.9	1.40	1.45	0.80	2.20	28.2
EC	μS/cm	150.5	144.0	42.0	630.0	65.9	140.6	120.5	64.0	325.0	46.3
pCEC	meq/100 g	11.90	9.80	4.40	33.90	55.4	13.92	14.35	2.80	23.20	43.3
pH	-	6.43	6.50	3.90	7.50	14.5	6.34	6.35	5.30	7.30	8.9
TN	%	0.14	0.12	0.07	0.28	33.7	0.16	0.17	0.10	0.21	22.1
C/N	-	9.1	8.9	6.5	13.7	17.8	8.7	8.7	7.8	9.5	6.3
K ₂ O-Res	mg/100 g	23.0	20.0	7.0	65.0	51.6	30.2	24.0	13.0	108.0	76.7
P ₂ O ₅ -Res	mg/100 g	43.5	38.0	16.0	114.0	53.4	29.2	20.5	11.0	91.0	70.7
Mg-CAT	mg/100 g	10.1	9.7	1.8	24.7	45.1	12.5	11.8	4.8	22.9	44.4
B-CAT	mg/100 g	5.3	5.2	0.6	14.8	66.7	5.2	5.4	1.7	9.9	45.9
Na-s	mg/100 g	0.99	0.84	0.18	5.19	82.9	0.54	0.49	0.23	1.16	41.0
CaO-Res	mg/100 g	811	271	11	6766	191.4	590	283	78	3303	143.9
Humic	%	2.14	2.00	0.90	4.80	38.0	2.37	2.55	1.40	3.30	26.0
MBC	mg C/kg	144.8	125.0	58.0	365.0	46.7	265.3	283.0	97.0	580.0	45.0
BBC	mg C/kg	61.0	52.5	23.0	161.0	48.8	112.1	114.0	42.0	248.0	47.7
FBC	mg C/kg	46.3	39.0	15.0	147.0	57.3	100.0	102.0	38.0	256.0	51.2
Pb	mg/kg	14.5	12.0	5.4	38.9	52.2	17.2	16.0	8.7	29.0	36.6
Cd	mg/kg	0.6	0.1	0.0	18.6	466.1	0.2	0.2	0.1	0.9	78.6

Cu	mg/kg	9.8	6.0	2.3	29.5	72.0	23.0	22.4	3.7	51.7	46.4
Hg	mg/kg	0.03	0.02	0.00	0.19	132.9	0.04	0.04	0.01	0.06	34.7

Organic parameter, Heavy metals

3.2. Soil microbial biomass

Bacteria and fungi, representing two major groups of soil microorganisms, play an important role in global nutrient biogeochemistry. Biogeographic patterns of bacterial and fungal biomass are fundamental to the mechanistic understanding of nutrient cycling. We analysed phosphorous lipid fatty acid-derived fungal biomass C (FBC), bacterial biomass C (BBC), and total topsoil microbial biomass (0-30 cm) from the 77 sites.

It is noticeable that soil microbial characteristics differ significantly between arable and permanent crops (Fig. 2). Although no significant difference can be demonstrated between the organic matter content, both the total microbial biomass and the breakdown by bacterial and fungal biomass in the SOC fraction are significantly higher in the permanent crops; the apple crops in our experiment. The maximum values of microbial biomass are 365 mg C/kg in annual crops but 580 mg C/kg in permanent crops. The minimum values were 58 and 97 mg C/kg, respectively.

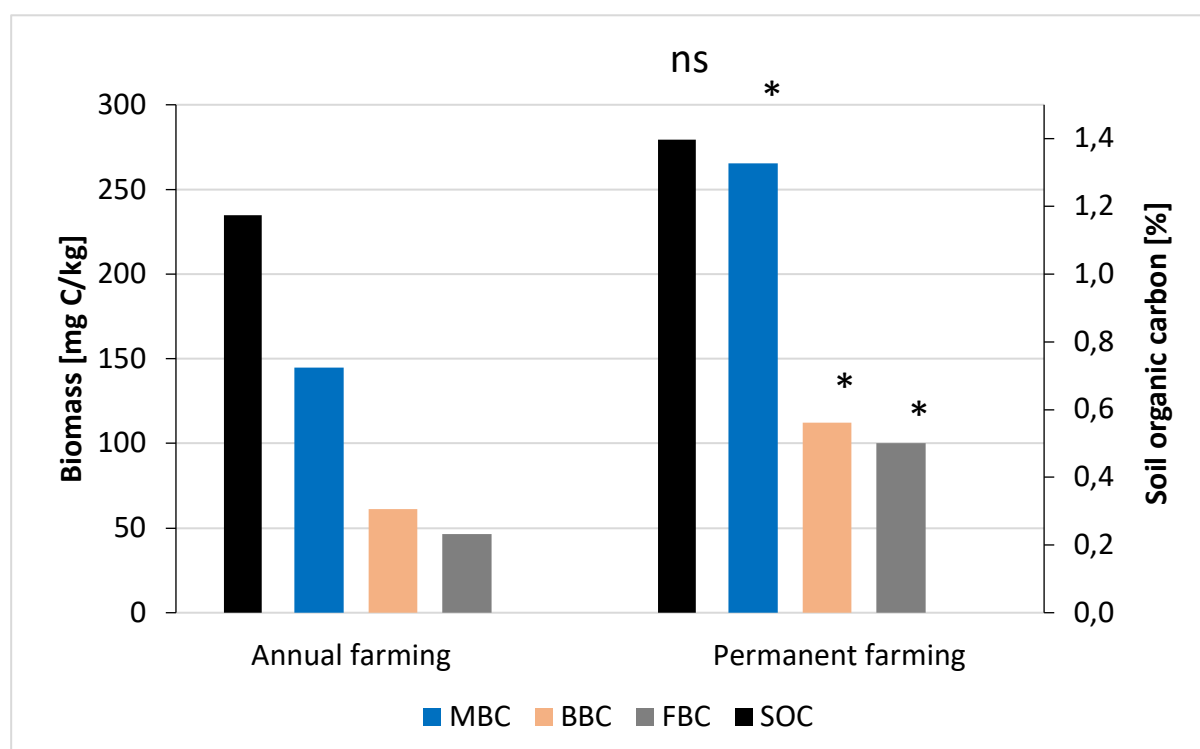


Fig. 2. Soil organic carbon and microbial biomass in analysed farming types, *significantly different between farming types, ns = nonsignificant.

3.3. Relationship between soil properties

In Tables 3 and 4, the relationships between soil properties are shown separately for annual crops (Table 3) and permanent crops (Table 4), with only slight differences in correlation coefficients. However, more significant correlations between individual parameters were detected in the soils of the permanent crops.

In general, sand content is negatively correlated not only with pH, TN, conductivity and microbial parameters but also with heavy metal contents of copper and lead. Accordingly, these are positively correlated with clay content. However, no significant linear correlation was found between the sand content and the SOC or humus content in the crops that changed annually.

The potential CEC is negatively correlated with sand in both management types. Cation exchange capacity is a measure of exchangeable cations and thus represents the number of negative binding sites of cation exchangers in the soil. As expected, it is positively correlated with organic carbon content and clay content. Both parameters provide an important contribution to the CEC, which is confirmed by our analyses. The content of nitrogen shows a high positive correlation with the CAC, especially in the annual crops of vegetable cultivation.

The differential effect of pH on microbial biomass carbon mentioned by Sawada 2009 is only detectable in apple permanent plots in our studies. In contrast, different vegetable or arable crops require different pH values, independent of organic carbon content and microbial biomass.

In apple crops, there is also a close relationship between SOC, TN, and microbial biomass (MBC). The content of Pb also shows a high correlation value with MBC. Copper correlates mainly with B, TN and, for the vegetable crop soils, microbial biomass.

The high correlations between microbial biomass and magnesium and boron CAT contents are also of interest.

However, despite the importance of the soil microbial community for soil fertility, the effects of boron are still unknown (Vera et al. 2019). Boron has a noticeable effect on the soil nitrogen (N) cycle, as shown by an increase in the water-soluble N content in studies by Vera et al. (2019). According to their study, the analysis of phospho-lipid fatty acids (PLFAs) showed that the effect of B on soil microbial biomass was dependent on the chemical form of fertilizers used. The correlation coefficients between boron and TN in our samples were 0.63 in vegetable crops and 0.85 in fruit crops.

According to Vera (2019), high B doses reduce soil microbial respiration, and fungal diversity is reduced. This was confirmed by our analyses, and the correlation between boron and fungal biomass in carbon was between 0.54 (AF) and 0.41 (PF).

However, microbial biomass in permanent and annual crops correlates strongly (0.59-0.62) with Mg-CAT content. According to Yang et al. (2021), who studied the short-term application of Mg fertilizers on soil microbial biomass and functions, the application of $MgSO_4$ significantly increases the microbial biomass carbon. The composition of the soil bacterial community is shaped by the concentrations of exchangeable Mg and sulfate, pH, and electrical conductivity (EC).

In our soil substrates, no correlation could be identified in the conductivity, potassium, phosphorus, lime and soluble sodium parameters.

Table 3. Correlation between soil microbial characteristics and physicochemical properties in soils of annual farming (vegetable cultures)

	sand	silt	clay	SOC	EC	pCEC	pH	TN	K ₂ O	K ₂ O-Res	P ₂ O ₅	Mg-CAT	B-CAT	Na-s	CaO-Res	Humic	MBC	BBC	FBC	Pb	Cd	Cu	Hg
silt	-0.95	1																					
clay	-0.80	0.58	1																				
SOC	-0.17	0.03	0.42	1																			
EC	-0.43	0.34	0.49	0.00	1																		
pCEC	-0.69	0.48	0.93	0.69	0.41	1																	
pH	-0.62	0.54	0.59	-0.10	0.50	0.47	1																
TN	-0.52	0.33	0.74	0.87	0.31	0.91	0.26	1															
K ₂ O-Res	-0.38	0.33	0.36	-0.06	0.54	0.29	0.50	0.20	1														
P ₂ O ₅ -Res	0.06	-0.10	0.04	0.13	-0.01	0.14	0.23	0.11	0.37	1													
Mg-CAT	-0.41	0.25	0.60	0.36	0.24	0.59	0.35	0.54	0.19	0.10	1												
B-CAT	-0.69	0.59	0.69	0.30	0.42	0.71	0.75	0.60	0.49	0.19	0.41	1											
Na-s	-0.50	0.29	0.80	0.46	0.49	0.80	0.31	0.65	0.13	-0.01	0.68	0.44	1										
CaO-Res	-0.42	0.31	0.53	0.35	0.23	0.51	0.48	0.44	-0.03	-0.17	0.07	0.49	0.27	1									
Humic	-0.18	0.02	0.45	0.95	0.03	0.70	-0.11	0.88	-0.03	0.16	0.40	0.27	0.47	0.27	1								
MBC	-0.62	0.44	0.78	0.61	0.27	0.82	0.42	0.81	0.08	-0.05	0.59	0.53	0.64	0.53	0.64	1							
BBC	-0.61	0.43	0.78	0.61	0.29	0.83	0.44	0.82	0.09	-0.05	0.56	0.54	0.64	0.57	0.64	1.00	1						
FBC	-0.63	0.49	0.72	0.51	0.27	0.74	0.47	0.74	0.11	-0.04	0.60	0.54	0.58	0.49	0.55	0.97	0.96	1					
Pb	-0.53	0.44	0.57	0.08	0.23	0.47	0.44	0.31	-0.07	-0.07	0.36	0.37	0.46	0.37	0.18	0.55	0.54	0.51	1				
Cd	-0.28	0.30	0.16	0.01	0.02	0.12	0.15	0.06	0.01	-0.02	0.16	0.04	0.08	0.02	-0.02	0.12	0.10	0.13	0.09	1			
Cu	-0.68	0.55	0.74	0.25	0.42	0.69	0.51	0.54	0.24	0.08	0.48	0.60	0.60	0.26	0.33	0.53	0.52	0.49	0.74	0.24	1		
Hg	-0.37	0.27	0.45	0.09	0.15	0.41	0.29	0.25	-0.19	0.00	0.27	0.20	0.43	0.19	0.20	0.42	0.41	0.34	0.85	0.09	0.73		

units of the parameters; see Table 1, limits: 0,55; 0,70; 0,85

Table 4. Correlation between soil microbial characteristics and physicochemical properties in soils of permanent farming (apple culture)

	Sand	silt	clay	SOC	EC	pCEC	pH	TN	K ₂ O	K ₂ O-Res	P ₂ O ₅	Mg-CAT	B-CAT	Na-s	CaO	Humic	MBC	BBC	FBC	Pb	Cd	Cu	Hg
silt	-0.96	1																					
clay	-0.81	0.61	1																				
SOC	-0.75	0.74	0.57	1																			
EC	-0.35	0.19	0.58	0.21	1.00																		
pCEC	-0.81	0.66	0.93	0.59	0.55	1																	
pH	-0.67	0.52	0.80	0.42	0.68	0.73	1																
TN	-0.86	0.79	0.79	0.73	0.54	0.86	0.73	1															
K ₂ O-Res	-0.21	0.11	0.33	0.08	0.83	0.31	0.43	0.40	1														
P ₂ O ₅ -Res	-0.07	0.11	-0.03	0.02	0.30	0.09	0.33	0.28	0.48	1													
Mg-CAT	-0.85	0.81	0.67	0.61	0.29	0.63	0.52	0.68	0.24	0.02	1												
B-CAT	-0.77	0.75	0.59	0.47	0.53	0.65	0.66	0.81	0.59	0.41	0.67	1											
Na-s	-0.40	0.26	0.60	0.24	0.88	0.55	0.64	0.51	0.75	0.15	0.47	0.58	1										
CaO-Res	-0.44	0.23	0.77	0.36	0.42	0.65	0.70	0.48	0.13	0.03	0.44	0.18	0.40	1									
Humic	-0.86	0.80	0.77	0.78	0.52	0.82	0.74	0.98	0.41	0.33	0.68	0.79	0.49	0.50	1								
MBC	-0.85	0.77	0.79	0.78	0.36	0.77	0.63	0.80	0.10	-0.11	0.62	0.52	0.30	0.47	0.80	1							
BBC	-0.85	0.77	0.77	0.78	0.31	0.73	0.60	0.77	0.06	-0.15	0.64	0.48	0.27	0.48	0.78	0.99	1						
FBC	-0.79	0.74	0.68	0.77	0.25	0.67	0.55	0.72	-0.02	-0.14	0.55	0.41	0.19	0.39	0.73	0.98	0.98	1					
Pb	-0.86	0.86	0.62	0.62	0.16	0.61	0.38	0.64	0.02	-0.17	0.73	0.53	0.22	0.23	0.60	0.70	0.71	0.65	1				
Cd	-0.43	0.39	0.41	0.34	0.17	0.52	0.26	0.44	-0.10	-0.14	0.20	0.20	0.03	0.22	0.34	0.44	0.41	0.39	0.62	1			
Cu	-0.56	0.59	0.34	0.45	0.18	0.52	0.48	0.58	0.06	0.39	0.33	0.47	0.18	0.24	0.62	0.43	0.39	0.44	0.35	0.28	1		
Hg	-0.55	0.49	0.50	0.34	-0.03	0.33	0.25	0.28	-0.11	-0.36	0.64	0.24	0.22	0.31	0.28	0.40	0.45	0.38	0.56	-0.03	-0.03		

units of the parameters; see Table 1, limits: 0,55; 0,70; 0,85

4. DISCUSSION

4.1. Soil properties and their relationships

The soil results revealed deficits with regard to soil fertility. Thus, very low pH values occur in part both in the annual hole changing arable crops and in the apple permanent crops. Minima here are 3.9 in arable crops and 5.3 in apple crops. This can have numerous consequences on soil dynamics, such as ionic bonds and microorganism activities. Svoray 2015 found that land management factors control the spatial variability of most soil variables. It was concluded that liming could be an effective tool to improve soil nutrient retention.

Low pH may reduce Mg uptake and reduce available organic phosphorus. Our correlation results could not provide confirmation of this. Very low levels of SOC, reservoirs of CaO and various nutrients could also be observed. Due to these deficiencies, measures to improve these soils are necessary to ensure soil fertility in the long term.

According to yunan et al. (2018), in general, the soils with CEC > 20 cmol/kg, 10-20 cmol/kg, <10 cmol/kg have relatively high fertility and medium and weak fertility, respectively. The studied soils in Germany, Poland and the Czech Republic have ranges of potential CEC from 2.8 to 33.9 meq/100 g. With mean values of 11.9 meq/100 g (AF) and 13.9 meq/100 g (PF), they are in the medium range with a tendency towards low values.

Soil CEC shows a significant positive correlation with clay, silt and organic matter and has an obvious negative correlation with sand, which have the greatest influence on CEC (yunan et al. 2018). In our soil samples, CEC was also positively correlated with SOC and silt and clay content and negatively correlated with sand. According to Asadu et al. (1997), the contributions of clay, silt and organic matter to effective CEC are important. In this context, organic matter is more important than granularity as a nutrient reserve, and silt, however, is more important than clay. In terms of correlation analysis of our soil samples, this is also true for potential CEC.

Various studies have shown that agricultural intensification, heavy metal pollution, and herbicide and pesticide pollution reduce microbial diversity and activity. The amount of soil nitrogen in fields with conventional production systems correlated negatively with soil microbial components, while soil nitrogen in fields with organic production positively correlated with soil microbial components (Gunapala und Scow 1998).

In the results of Gomes et al. (2001), Cr, Pb, and Cu were the most adsorbed heavy metal cations among all soils, while Cd, Ni, and Zn were the least adsorbed. Correlation analysis showed that soil characteristics that may have affected heavy metal adsorption, represented by the distribution coefficients, were pH and cation-exchange capacity for Cd and Cr and organic carbon and clay contents for Cu.

The total copper content shows significantly higher values in the permanent crops. A possible cause is the necessary use of appropriate plant protection products in apple orchards. Over a longer period of time, accumulations can be observed. Copper-based fungicides have been used in apple orchards for a long time, which has led to an increase in Cu concentration in the soil. Mixtures of Cu sulfate and lime (Bordeaux mixture) have been used for over 100 years in pome and stone fruit orchards and vegetable crops to control fungal diseases (Wang et al. 2009).

Lead and mercury levels correlate with each other in both permanent and arable crops. Possible causes could be natural occurrences in the region or the use of appropriate pesticides or fertilizers. Nickel could not be detected in our samples of vegetable and fruit crops. Pb and Cu show a negative correlation with sand but adsorption to silt and clay.

As fungicides are used to control fungal diseases, they also affect beneficial soil fungi and other soil organisms. Therefore, there is increasing concern in many regions of the world that Cu in orchards

may reach concentrations that are toxic or even phytotoxic to soil organisms (Wang et al. 2009). Although the total soil Cu concentration is a useful indicator of soil vitality, it does not provide sufficient information on environmental effects. Soil Cu concentrations in orchards tended to increase with the increase in years following the use of the Cu-containing fungicide (Bordeaux mixture) (Wang et al. 2009).

4.2. Soil microbial biomass and organic

Microbial biomass is an early indicator of changes in total soil organic carbon (SOC) (Limbu et al. 2020). In the analysis from them in pastures in Nepal, soil microbial biomass MBC ranged from 220 to 988 mg/kg and increased with decreasing grazing. Our analytical results of soil samples in annual cropland crops showed lower contents ranging from 58 to 365 mg C/kg. This decreased content amount can be explained by the annual removal of organic structures due to the harvest of vegetables, intensive tillage, and significantly lower organic fertilization. In contrast, the permanent crops had higher values, up to 580 mg C/kg. Liddle et al. (2020) evaluated the biomass of microbes in the soil, which is influenced by naturally occurring variations in organic carbon (SOC), clay content, and local topography. In our analyses, microbial biomass carbon (MBC) was positively correlated with SOC, 0.61 in annual crop soils and 0.78 in permanent crop plots. The soil organic carbon and total nitrogen revealed a significant positive correlation ($R^2 = 0.71$, $p = 0.01$), which increased as the total nitrogen content and soil organic carbon increased (Figure 3). The regression coefficients of annual and permanent farming are not significantly different, so the presentation is independent of farming.

Soil TN and SOC contents are also influenced by climate. In the regions of our studied soils, conditions are approximately the same as in the annual average temperatures (8.5-10.0 °C) as well as precipitation (660-800 mm). Soil moisture, soil organic matter quality, and soil pH are among the most important factors affecting soil microbial community composition (Amelung et al. 2018). The C/N ratio of organic matter is important for soil quality. Organic matter with a high carbon to nitrogen ratio often has unstable soil organic matter. There is intense competition among microorganisms for available soil nitrogen (Mabuhay et al. 2004).

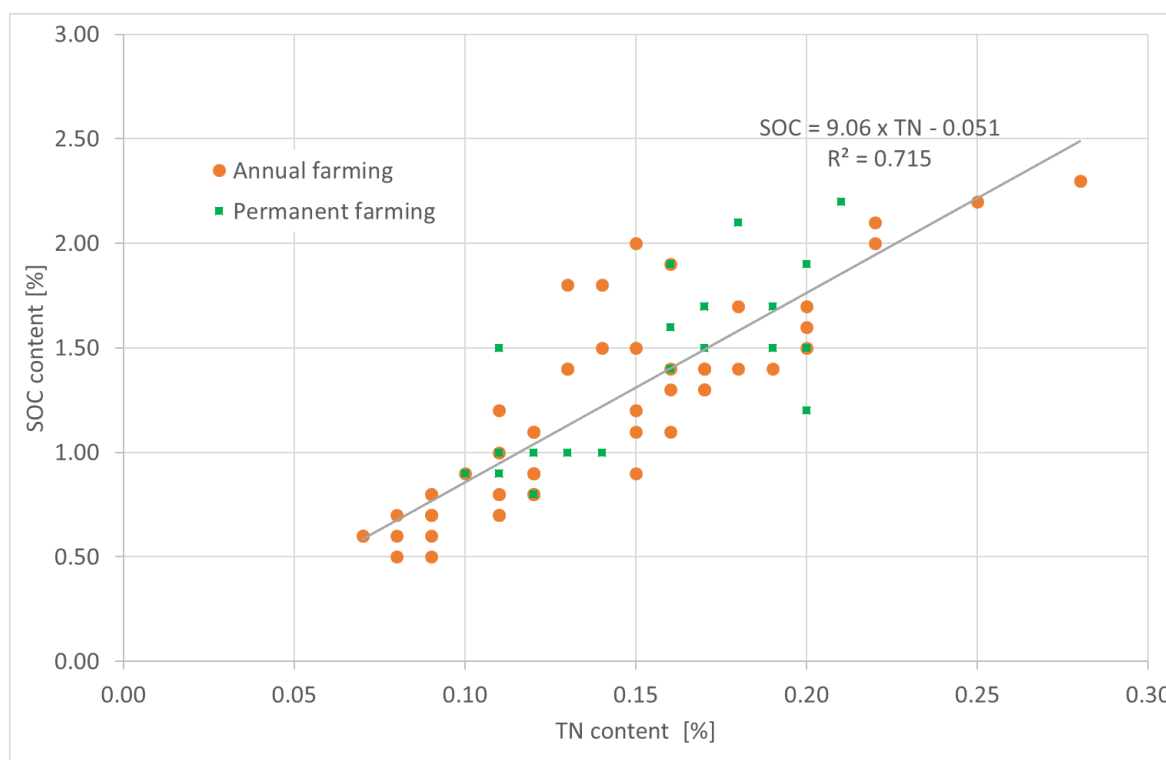


Fig. 3 Relationship of topsoil soil organic carbon SOC and total nitrogen content TN

Amelung et al. (2018) states frequent C/N ratios for soils in the range of 9-11. Thus, the values of the soil samples of our research present a good average (Table 2). Only in soil with annually changing crops have ratios of 6.5 also been found. This result may be due to the different vegetable crops grown and the corresponding removal of organic matter. In the apple crops, a C/N of 7.8 is obtained.

The linear correlation analysis between SOC and TN showed a good correlation, with a coefficient of determination of 0.71 (Fig. 3). A similar correlation is also detectable in studies by Abrar et al. (2021). The linear functions of the management forms are very similar, differing only in their range. This is lower for both SOC and TN for permanent crops.

In addition, the larger C/N ratio, Ni concentration, and organic matter pool along with higher pH contributed to the increase in microbial functional diversity in urban soils (Zhao et al. 2013). Soil microbial activities were strongly correlated with the chemical properties measured in the soil.

Multiple studies (Abrar et al. (2021), Qin et al. (2014)) have analysed the relationship between Corg and microbial biomass. Sparling (1992) studied the ratio of carbon from microbial biomass to soil organic carbon as a sensitive indicator of changes in soil organic matter. Cmic generally comprised 1-4% Corg, with the ratio under pasture consistently greater than the corresponding soil under native forest or cropland. However, absolute values differed markedly among soils and were strongly influenced by texture, mineralogy, and Corg content. Cmic and the Cmic/Corg ratio are useful measures for monitoring soil organic matter.

However, the microbial characteristics of orchard soils remain poorly understood. In the analysis of Wang et al. (2009), the soil Cmic values varied from 43.6 to 116 mg/kg in orchard soils. The ratio of soil Cmic to total organic C (Corg) increased with decreasing orchard age (Wang et al. 2009). Our analyses showed much higher Cmic values, ranging from 58 to 365 mg C/kg (AF) and 97 to 580 mg C/kg (PF).

Lin et al. (2019) showed that the microbial community is sensitive to increases in available nutrients with organic matter application. Microbial biomass is influenced by factors that alter the soil water regime or carbon content and include soil type, climate, and management practices. Soil properties that affect microbial biomass are clay, soil pH, and organic carbon. A soil pH near 7.0 is best for microbial biomass (Eurofins).

Lu et al. (2021) mentioned that few studies have investigated the mechanisms linking aggregate size and SOC turnover microbial properties. In our analyses, permanent crops had higher correlations between microbial biomass and these parameters (SOC and clay) than arable crops, with at least 0.64. No correlations were found with pH. Soils with more clay generally have higher microbial biomass because they store more water and often contain more organic C. Lu et al. (2021) also mentioned that long-term fertilization changes soil microbiological properties and then affects the soil organic carbon (SOC) pool. In contrast, these vary little in the permanent crops of apple orchards.

Liddle et al. (2020) mentioned that soil microbial biomass can immobilize and mineralize nutrients. MBC accounts for only 1-3% of soil organic carbon.

The relationship of MBC to soil physical and biogeochemical properties is variable. An increase in MBC in response to higher soil pH may or may not occur (Sawada et al. 2009). No correlations occurred in our samples, which highlights this inhomogeneity. Regarding the response of MBC to increasing clay content, some studies have found a positive correlation, while others have found a negative correlation (Liddle et al. 2020). In our analyses, a positive correlation was detected (0.78).

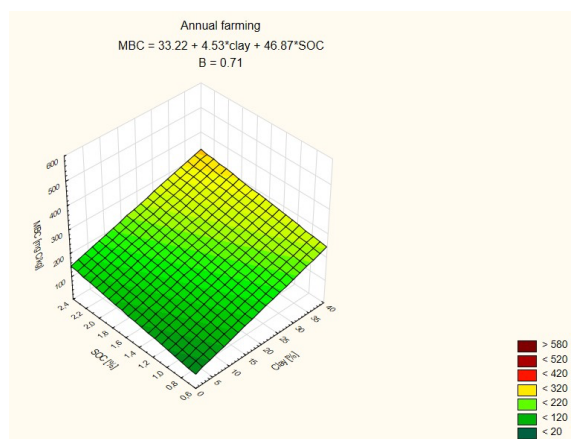


Fig. 4. Relationship between microbial biomass with clay and organic in soils with annual farming

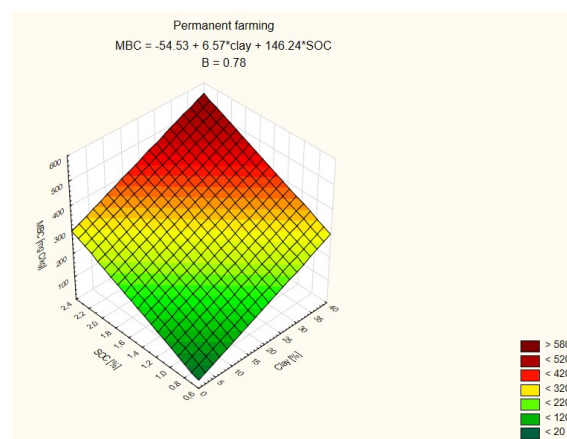


Fig. 5. Relationship between microbial biomass with clay and organic in soils with permanent farming

The results of the stepwise multiple regressions in terms of microbial biomass remained the influencing variables of clay and SOC (Figures 4 and 5). The higher the contents of clay and organic matter are, the higher the microbial biomass.

Thus, for annual crops, approximately 2/3 of the change in microbial biomass can be explained. For the permanent crops of apple cultivation, this is even higher than 3/4 because of the lower soil disturbances in the apple crops. In the annually changing crops, a strong intervention in the soil dynamics occurs with the harvest of vegetables and during ploughing. On the one hand, the lack of tillage and the supply of root exudates leads to higher biological activity in permanent crops.

Soil microbial biomass is considered a transforming agent of soil organic matter and a labile pool for plant nutrients. Therefore, the change in soil microbial biomass could lead to a change in the rate of nutrient cycling and the size of the nutrient pool (Wang et al. 2009). The negative relationship between MBC and clay content mentioned by Liddle et al. (2020) indicates that clay minerals physically protect SOC from microbial attack. Organic compounds can adhere to clay particles. Thus, SOC associated with the small pore sizes associated with clay minerals could be shielded from microorganisms. This is not the case in our soils after evaluating the correlations.

However, the microbial community includes a wide range of individual species that can respond very heterogeneously to changes in the environment. Microorganisms may lose their resistance to ecosystem disturbances and become unable to carry out their normal processes of nutrient cycling and maintenance of soil structure (Mabuhay et al. 2004).

5. CONCLUSIONS

The pH, SOC, particle size composition, and CEC values of the 62 soils collected varied widely. The different management and cultivated crops significantly affect the microbial biomass and soil characteristics. Our study partly revealed a deficiency of nutrients, mainly B as well as Mg, in the soil.

The revealed relationship between SOC and MBC highlights the important role of SOC in soil fertility, such as nutrient availability and the contribution of microorganisms to soil structure. Specifically, soils with SOC enrichment have more microbes to promote nutrient availability and soil structure development (Liddle et al. 2020). However, there was spatial variability in MBC due to the different land use histories of the regions.

In the future, measures will be implemented on a subplot, and their effect on soil properties will be compared. Thus, studies with altered management practices and the influence of micronutrient

fertilizers, limes, and organic soil amendments are planned. The derivation of individual area-specific measures to maintain and increase soil fertility and biodiversity is to be based on the actual state determined here.

In this context, changes in the characteristics of soil organisms can be used to monitor soil quality. Overall, the addition of organic matter could contribute to higher C storage by enhancing the fungal community and enzyme activity rather than changing the diversity of the microbial community in macroaggregates (Liddle et al. 2020).

Soil organic carbon is an important parameter that determines soil fertility and maintains soil health. SOC stabilization mechanisms have not been extensively studied, especially in response to slow-release fertilizer (Abrar et al. 2021). Chemical fertilization alters the soil nutrient status, which indirectly affects the soil carbon balance, while organic fertilization replenishes the soil carbon balance by directly adding organic carbon to the soil.

Orchards should be managed with conservation practices, such as grass or legumes, mulching, and the use of organic fertilizers. This could also reduce soil erosion and improve SOC content. Various measures will be implemented on pilot farms, and their success in improving and maintaining good soil vitality will be analysed and documented.

Maintaining and improving soil quality requires an understanding of how soils respond to agricultural and horticultural practices over time and the ability to quantitatively measure or monitor changes (Goh et al. 2001).

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