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Changes in soil physico-chemical and biological quality after two decades of forest soil conversion to agricultural land

Ayoub ALLAM[1], Mohamed ZOUIDI[2], Abdelkrim KEFIFA[3], Amine Habib BORSALI[4],
Sid Ahmed AOUADJ[5], Samira NEGRICHI[1], Anne Marie FARNET da SILVA[6],
Catherine RÉBUFA[6]

[1]Centre de Recherche en Technologies Agroalimentaires (CRTAA),
Campus Universitaire Tergua Ouzemour
06000 Bejaia, Algeria
E-mail: ayoub.allam@crtaa.univ-bejaia.dz

[2]Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane
Route de Ain el Bey, 25000 Constantine, Algeria

[3] University of Dr Moulay Taher,
Laboratory for Biotoxicology, Pharmacognosy and Biological Valorization of Plants
Saida, Algeria

[4]University of Dr Moulay Taher, Laboratory of Water Resources and Environment
Saida, Algeria

[5]Abu Bakr Belkaid University of Tlemcen,
Laboratory of Ecology and Management of Natural Ecosystems
Tlemcen, Algeria

[6]Aix Marseille Université, CNRS, IRD, Avignon Université, IMBE, UMR 7263
Campus l'Etoile, 13397 Marseille, Cedex 20, France

Abstract

The development of agriculture to the detriment of the forest is one of the strongest pressures, essentially anthropogenic. The particularity of this study was that the traditional agricultural practice used was low intensity agriculture (fallow period) since the first conversion. The experiment was conducted in the Keroua forest, Saïda Province, north-western Algeria. Soil samples from two experimental areas were collected at depths ranging from 0 to 10 cm. The findings came from the statistical analysis of the data, some of which revealed the sensitivity of this ecosystem. The conversion of the forest soil to agricultural land increased the alkalinity of the soil (pH_{H2O} increased by 0.16 units), and the acidification of the soil with a significant decrease in pH_{KCl} values (by 0.24 units). Moreover, the organic matter content in the converted soil decreased by more than 50%, while the physical characteristics changed slightly with a decrease in moisture content and water holding capacity and an increase in bulk and real density. Meanwhile, the permeability and total porosity did not change in the two areas. For biological properties, basal respiration and microbial biomass decreased by more than 45% in the converted soil compared to the forest soil.

Keywords: soil properties, conversion, ploughing, degradation, western Algeria.

Introduction

Native and cultivated grasslands are an important part of the global ecosystem, covering 37% of the world's land area (FAOSTAT, 2014). Most forest environments worldwide have suffered significant losses in their floristic composition (Cardoso et al., 2013). Increasing population numbers and human activities are impacting forests (Allam et al., 2020) and changing globally the landscape through afforestation and deforestation (Zhou et al., 2018). The acceleration of the fragmentation and degradation of these fragile ecological environments

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(Ayoub et al., 2019) leads to strong land degradation (Chen et al., 2022). Regarding environmental degradation and global climate change, the change in the use of natural environments (forests and grasslands) and their conversion into agricultural land is currently one of the main concerns on a global scale (Kooch et al., 2016).

The conversion of forest soil to agricultural land is an action that is practiced all over the world. Therefore, several studies have been conducted on this topic to show the effect of this practice on soil properties, some of which have focused on changes in the surface horizon, while others have studied these changes at various depths. The studies done by Saha and Kukal (2015) and Mohmmadi et al. (2020) on two 0–15 and 15–30 cm horizons showed that conversion of forest soil to agricultural land increased pH and bulk density, while decreasing overall organic matter, electrical conductivity, macroporosity, and water retention in both horizons. Contrariwise, according to Adugna and Abegaz (2016) and Aneesh et al. (2020), this conversion increased bulk density, total porosity, and electrical conductivity, while decreasing pH and organic matter content. The results obtained by the different studies show differences depending on the experimental areas, the depth of sample collection, the time elapsed after conversion, and the mode of use. In addition to the use of physicochemical properties as indicators of changes in soil quality, other rapidly changing parameters such as microbial biomass, soil respiration, microbial biomass carbon, and microbial biomass nitrogen play an essential role in soil nutrient cycling and quality, making these properties valuable indicators for comparing soil qualities (Maharjan et al., 2017).

To enrich information and documentation on this fragile semi-arid environment and taking into consideration their environmental importance as well as the aggravation of degradation risk on the qualitative and quantitative level, the general objective of this study was to determine changes in the physical, chemical, and microbiological properties of Keroua forest soil 20 years after its conversion to agricultural land.

Material and methods

Experimental site was in a semi-arid bioclimatic stage area: the Keroua forest massif, part of the municipality of Ouled Khaled in Saïda province in north-western Algeria (Table and Figure 1), reaching an average altitude of 880 meters and receiving an amount of rainfall of 345.16 mm yr^{-1} during the year on average.

Table. The relative geographic location of each station in the experimental (agricultural and forest) area

Station No.	Agricultural area			Forest area		
	longitude (E)	latitude (N)	altitude m	longitude (E)	latitude (N)	altitude m
1	0°7.693″	34°55.004″	867	0°7.832″	34°55.194″	834
2	0°7.637″	34°54.907″	871	0°7.839″	34°55.029″	834
3	0°7.546’	34°55.809″	871	0°7.673″	34°55.166″	881
4	0°7.453″	34°54.842″	880	0°7.444″	34°55.159″	941
5	0°7.347″	34°54.747″	880	0°7.502″	34°55.031″	914

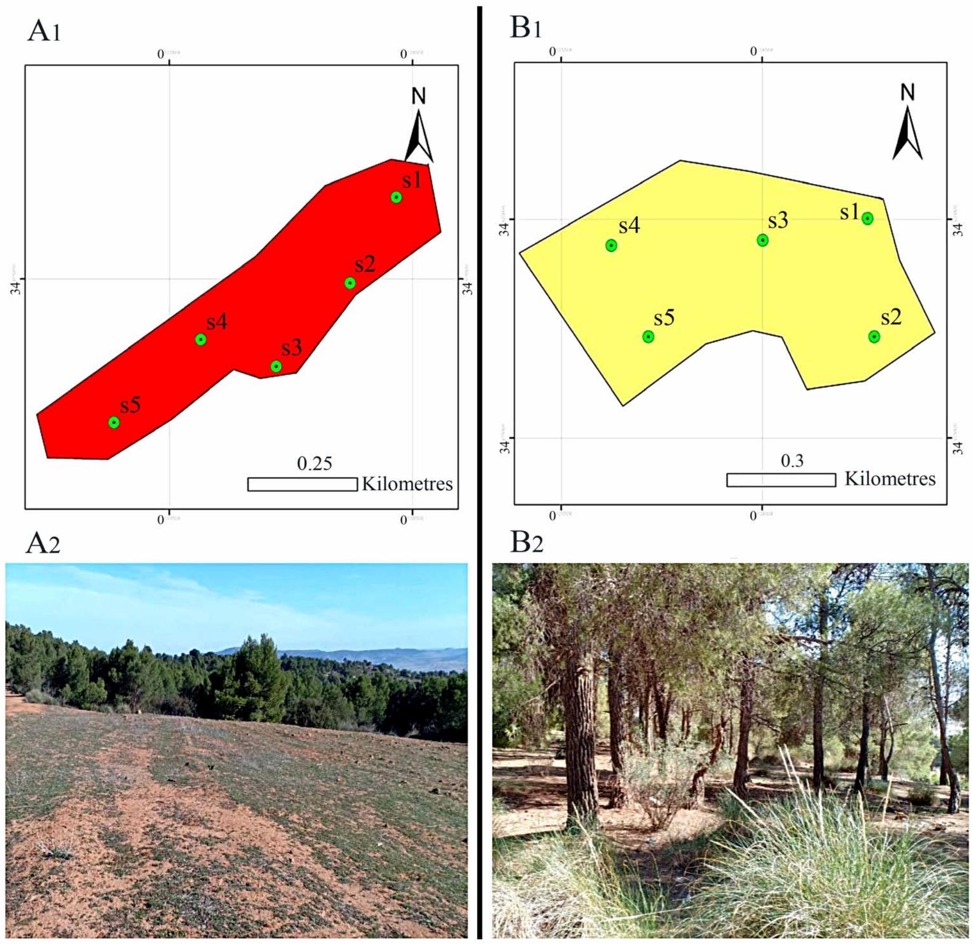
The experimental areas have a high biodiversity of forest species such as the mastic tree (*Pistacia lentiscus* L.), prickly juniper (*Juniperus oxycedrus* L.), and olive tree (*Olea europaea* Mill.) with the dominance of the Aleppo pine (*Pinus halepensis* Mill.). However, these species have undergone extensive degradation during the latter few decades, essentially wood cutting.

In the absence of other income-generating activities, the population has converted these cleared soils into agricultural area, which is a source of income. A protected forest that covers 36.7 ha served as a control area, while the agricultural area is an undivided parcel covering a surface of 16.5 ha that has been converted over the last 20 years.

The ancient forest landscape has completely changed, and there are several types of land use (ploughed fields, pastures, leisure places) taking up small areas compared to those occupied by the forest. The most common cropping system is the cultivation of durum wheat and common wheat with two years of fallow.

The experimental areas are orographically homogenous (slope and exposure). Fersiallitic soil (red) is present in both the control and transformed areas. The soil profile consists of three horizons. Horizon 1 (0–10 cm) represents the humus layer (litter + humus), horizon 2 (10–40 cm) represents the poorly differentiated layer resulting from the alteration of the bedrock, and horizon 3 (< 40 cm) represents the unweathered bedrock. Except for the horizon 1, which is nearly absent in the converted soil given the incorporation of vegetation debris into the soil by ploughing, the thickness of each horizon in the forest soil and in the converted soil is almost the same. Due to dependence on annual rainfall, farmers no longer practice crop rotation in this area. They practice fallow and change the choice of crop type between durum wheat, soft wheat, and barley each year. Furthermore, the soil's properties have deteriorated over the years due to poor agricultural practices and the non-use of either mineral or organic fertilisers.

In addition, conventional tillage of the soil is adopted by the region's farmers. The first ploughing



A1 – geographic map locating the five stations in the agricultural area, A2 – photographs of the agricultural area, B1 – geographic map locating the five stations in the forest area, B2 – photographs of the forest area

Figure 1. Location of experimental areas

(deep ploughing, more than 30 cm) is conducted in spring during the rest year using a 3-disc plough. The second ploughing is done in autumn to prepare the seedbed (depth < 20 cm), while the third ploughing is done after sowing the seeds to cover them with a thin layer of soil (depth < 5 cm). For the two last ploughings, a 16-disc plough is used.

Soil sampling methods. This experience was made at the beginning of winter 2019 after completing 20 years of forest soil conversion into agricultural land. Except for the organic horizon, soil samples were collected in two experimental areas: 1) in the control area under the forest, where soil properties were well preserved, and 2) in the cleared and cultivated area before ploughing. In each area, 25 samples were randomly collected from 0–10 cm depth with a shovel from five stations with five replicates and were used for physicochemical and biological analyses.

Soil analyses. *Chemical analysis*. pH_{H2O} and soil electrical conductivity (EC) were estimated from a 1: 2.5 soil and water mixture. The measurement of pH_{KCl} was performed with potassium chloride (KCL) solution at the same ratio (1:2.5). The organic matter was measured by the mass loss of the dry sample at calcination at a temperature of 550°C for 16 hours. The total amount of limestone ($CaCO_3$) was estimated by the Bernard calcimeter method.

Physical analysis. Bulk density (ρv) was measured by the cylinder method of Wertebach et al. (2017) by the equation:

$$\rho v \ (g \times cm^{-3}) = \frac{W_B}{V} \quad (1),$$

where W_B is dry weight of the soil (g); V is cylinder volume (cm^3); $V = \pi \times r^2 \times h$, where h is height of cylinder (cm).

The real density (ρ) was calculated according to Pétard (1993):

$$\rho \ (g \times cm^{-3}) = \frac{W_B}{V} \quad (2),$$

$$V = \frac{(W_{B1} + W_B) - W_{B2}}{\rho_B} \quad (3),$$

where V is volume of soil used; W_B = 10 g of dried soil in an over at 105°C; W_{B1} is weight of the pycnometer filled with benzene to the mark (g); W_{B2} is weight of the pycnometer that contains the 10 g of soil and filled with benzene to the mark after the disappearance of the air bubbles (g); ρ_B is benzene density.

The porosity (ρ) was determined by the equation:

$$p\,(\%) = \frac{\rho - \rho v}{\rho} \times 100 \qquad (4).$$

Retention capacity was obtained by the protocol described by Wang et al. (2014). Soil moisture and permeability were measured according to the protocol of Mohamed et al. (2019).

Biological analysis. Basal respiration (*Br*) and microbial biomass (*Mb*) were measured according to the protocol of Anderson and Domsch (1978). The induced respiration values were converted to a microbial biomass value using the equation of Beare et al. (1990). The metabolic quotient (qCO_2) was calculated by the equation:

$$qCO_2 = \frac{Br}{Mb} \qquad (5).$$

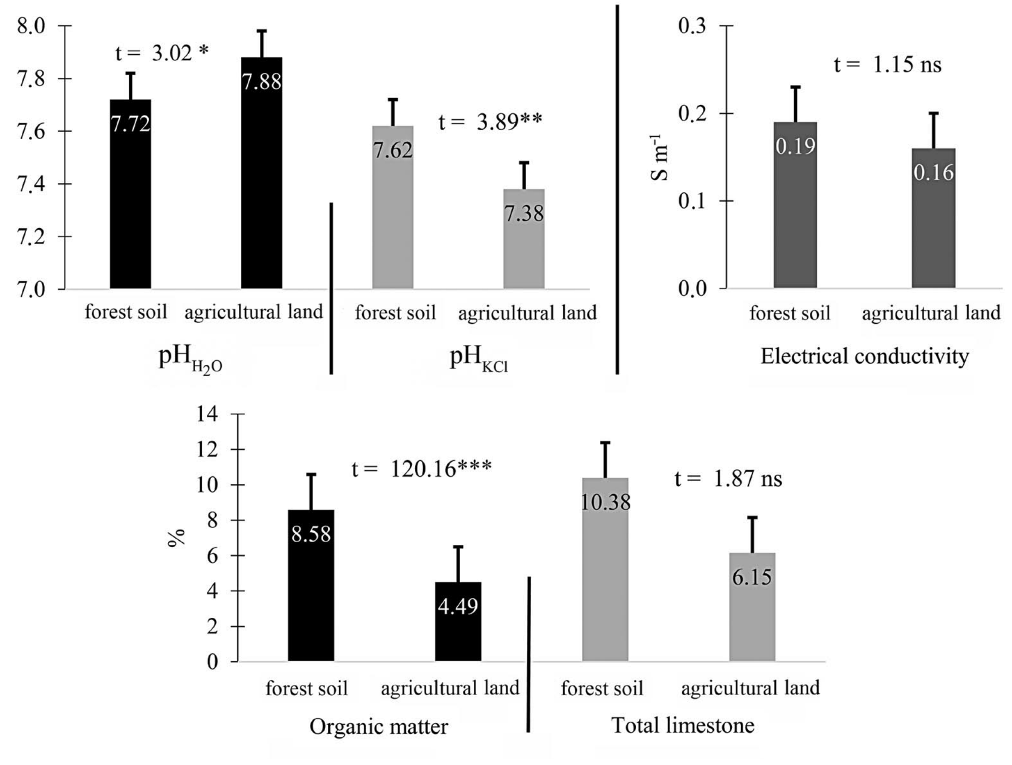
Statistical analysis. Data were analysed using the statistical software Minitab 17 (Minitab LLC, USA). The 5% threshold comparison test was used to compare means by the Student's *t*-test: * – $p < 0.05$ (significant), ** – $p < 0.01$ (very significant), *** – $p < 0.001$ (highly significant), ns – not significant.

Results

Soil chemical properties. The results obtained in this study showed that the conversion of forest soil to agricultural land negatively affected some chemical properties, where a significant increase in pH_{H2O} by 0.16 units was recorded. As recognised for the measurement of pH_{KCL}, a decrease of the latter was recorded in both areas in the same direction, but with a significant difference of about 0.24 units (7.62 for the forest soil and 7.32 for the converted soil). Also, the organic matter was reduced by more than 50% of the organic matter content in agricultural land compared to forest soil.

Regarding EC and $CaCO_3$, the recorded values showed a decrease in the agricultural land compared with the control area, thus, the differences were not significant (Figure 2).

Soil physical properties. Statistical analysis of physical properties showed that the conversion of forest soil to agricultural land slightly affected these properties (Figure 3). Bulk and real densities increased in the surface horizon by 0.12 and 0.23 g cm^{-3} in soil converted to agricultural land compared to forest soil, respectively.

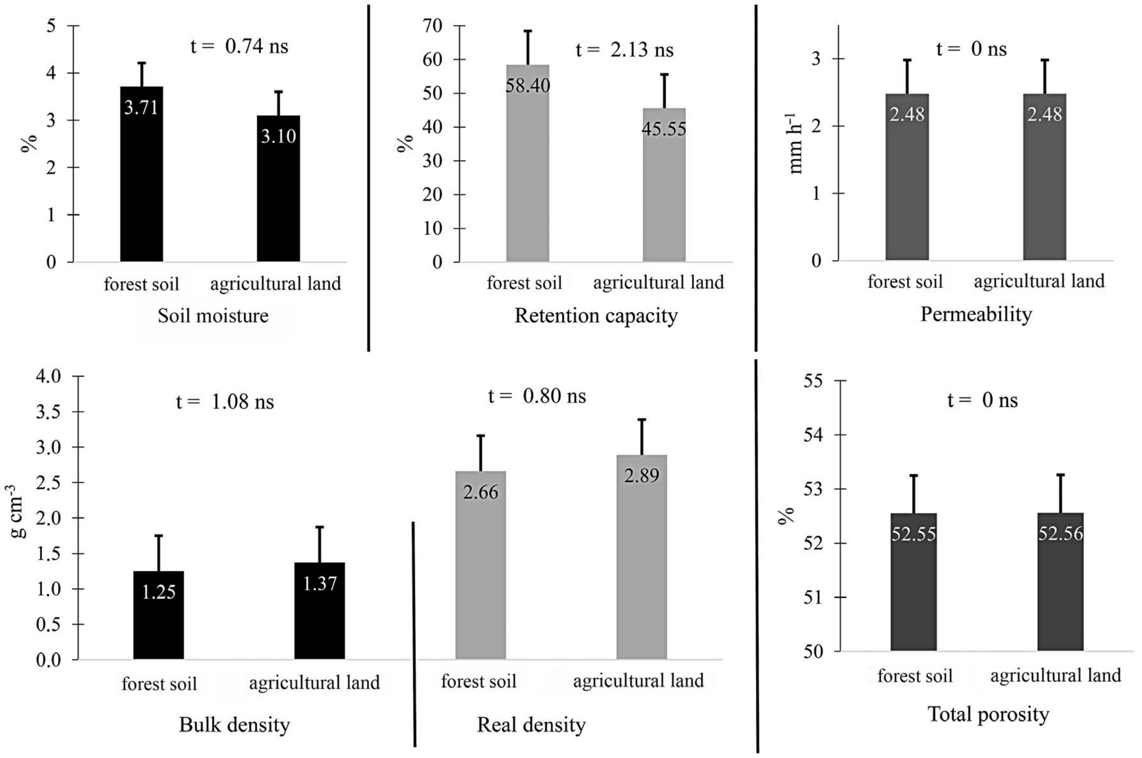


*, **, *** – significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$; ns – not significant; bars indicate standard error

Figure 2. Main chemical properties of agricultural land compared to forest soil

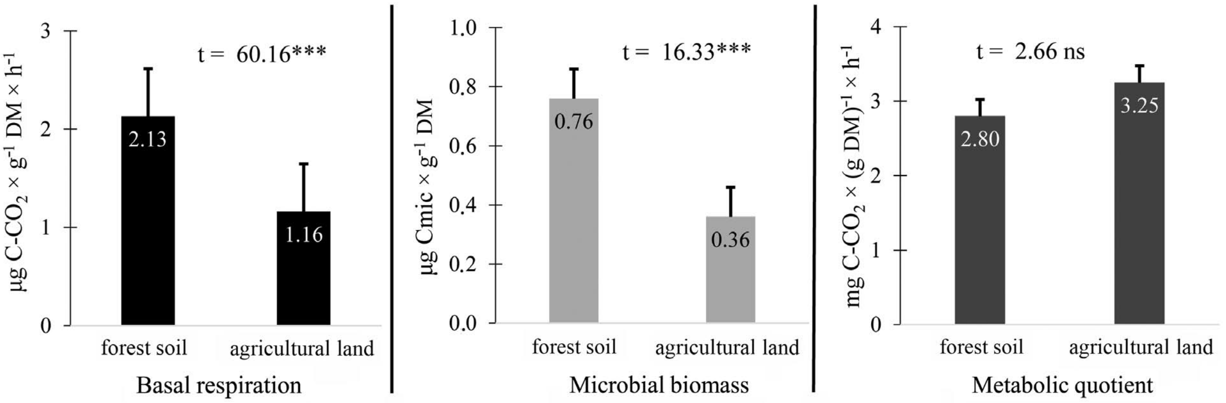
Almost similar values for the total porosity were recorded. Regarding soil moisture and retention capacity, the conversion of forest soil to agricultural land decreased the percentages of these two properties by 7% and 21%, respectively, while the permeability did not changed in the two areas.

Soil biological properties were negatively affected by the conversion of forest soil to agricultural land (Figure 4). Basal respiration decreased significantly in the agricultural land compared to the forest soil, approximately by 0.97 µg $C\text{-}CO_2 \times g^{-1}$ DM × h^{-1}. Furthermore, for microbial biomass, the decrease was by 0.4 µg Cmic × g^{-1} DM. Regarding the metabolic quotient, an increase of 0.45 mg $C\text{-}CO_2 \times (g\ Cmic)^{-1} \times h^{-1}$ in the agricultural land compared to the forest soil was recorded, but this increase was not significant.



ns – not significant; bars indicate standard error

Figure 3. Main physical properties of agricultural land and forest soil



DM – dry mass of soil; C-CO_2 – quantity of mineralised carbon; Cmic – microbial biomass carbon; *** – significant at $p < 0.001$; ns – not significant; bars indicate standard error

Figure 4. Main biological properties of agricultural land and forest soil

Discussion

The results of this study showed that pH_{H2O} was negatively affected by the conversion of forest soil to agricultural land. The increase recorded in the agricultural land compared to the forest soil is consistent with that obtained by Beheshti et al. (2012), who recorded soil pH_{H2O} values higher (from 3% to 33%) in agricultural land compared to forest soil. Besides, Seifu et al. (2020) found higher pH_{H2O} values in the converted soil (regardless of use type) compared to the forested soil. Regarding the long-term effects of forest soil conversion to agricultural land, Zajícová and Chuman (2019) recorded high pH_{H2O} values after a conversion period of 190 years. We suggest that the increase of pH in agricultural land is because of repeated soil turning by ploughing, which removes parts of shallow bedrock and deposits it on the surface of the agricultural land every time.

The calculation of ΔpH (pH_{H2O} and pH_{KCl}) for the same area shows a decrease of 0.1 for the forest soil and 0.5 for the converted soil. However, a significant decrease in pH_{KCl} between the control and converted soil was 0.24 indicating that the latter has a high acidification capacity compared to the forest soil. These results are consistent with Hamamoto et al. (2018) study, in which they recorded lower pH_{KCl} values in cleared and cultivated land under different use patterns compared to forest soil.

The conversion of forest soil to agricultural land slightly decreased the electrical conductivity in this soil compared to forest soil (Figure 2). This difference was not significant, and these values confirmed that the soil is not salty (0.6 (S m^{-1}). Due to the total amount of $CaCO_3$, the indicators recorded in two areas showed a slight decrease in the agricultural land compared to the forest soil, which was 6.15% and 10.38%, respectively. According to Wang et al. (2015), several interactive processes such as carbon sequestration modify the carbonate content and cause the stability of the global carbon cycle in arid and semi-arid regions.

Land use changing can change land cover and associated carbon stocks (Deng et al., 2014). The results of present study are in agreement with those of Bogunovic et al. (2020), in which the organic matter stocks were higher in the forest soil compared to the plots with intensively tilled cropland, vineyard, and traditional grass-covered orchard. Similarly, losses of organic matter stocks after forest to cropland conversion have mostly been reported in previous studies (Beheshti et al., 2012; Wang et al., 2015). According to Koga et al. (2020), the conversion of forest soils to agricultural lands is characterised by an initial rapid loss of organic matter stocks followed by its decline with time after deforestation.

The decrease of organic matter content in the agricultural land is the result of a combination of several factors. At first, a reduction in the inputs to the soil after the harvest (Zhu et al., 2012) followed by a reduction of organic carbon stocks due to accelerated erosion processes and biological oxidation of this organic matter (Olson et al., 2016).

Compared to forest soil, recorded values of bulk and real density are higher in agricultural land subjected to various types of agricultural use (Bogunovic et al., 2020). In the study of Bini et al. (2013), lower densities were observed in soils that were subject to less anthropogenic intervention such as natural forests. Meanwhile, changes in uses such as ploughing will increase soil densities, and these results are in agreement with Koga et al. (2020) study, where a higher bulk density was recorded in cultivated soils compared to forest soils.

For total porosity and permeability, the recorded values in the two areas were almost identical, and these two parameters had a direct correlation relationship. According to Wang et al. (2018), porosity and permeability are positively correlated – the higher porosity of soil, the higher its permeability. Therefore, a slight difference in bulk and real density between the two areas gave them similar porosity and equal infiltration rate.

A slight decrease in moisture and retention capacity in the converted soil was reported by numerous studies. It was reported that changes in land use alter their moisture (Bahilu et al., 2016) and decrease its water retention capacity (Bogunovic et al., 2020). The decrease in the properties of water may be caused by organic matter deficit recorded in agricultural land. According to Cardoso et al. (2013), humic substances in organic matter increase the water-holding capacity of soil due to the charges of their carboxylic and phenolic groups that attract molecules of water. Consequently, the amount of organic matter in the soil determines its water status.

The conversion of forest soils to agricultural lands associated with repeated tillage modifies the physicochemical properties of the soil, which affects the microbial biomass (Pabst et al., 2013). In other study (Mganga et al., 2016), microbial biomass was higher in natural forests. Similarly, an overall reduction in microbial activities was recorded after this conversion, especially its basal respiration (Zarafshar et al., 2020). A positive correlation was found between biological properties (microbial biomass and basal respiration) and soil organic matter content (Pabst et al., 2013), which are often lower in agricultural lands with low carbon inputs (Bini et al., 2013).

The conversion of natural ecosystem to arable land causes a loss of organic matter in these fields and a decrease in their moisture content through desiccation (Chen et al., 2019), which generates small amounts of microorganisms (Błońska et al., 2017). Another study has reported on the relationship between the state of rhizosphere development and microbial biomass. According to Sun et al. (2021), the greater the root exudation, the more the microbial growth is stimulated. In the case of agricultural lands, the passage of machinery after ploughing forms a strong sealing layer on the surface, where plants with poor rooting systems will grow, which decreases the microbial biomass (Mganga et al., 2016).

The values recorded in agricultural land are higher than in forest soil, although this difference is not significant. According to Abdalla et al. (2016), cultivation practices such as ploughing result in the release of large amounts of CO_2, which increases the metabolic quotient values. Higher metabolic quotient values indicate that the microbial population is under the stress due to environmental disturbance. This result is confirmed by previous studies that concluded that as land-use intensity increases, so does the metabolic quotient (Pabst et al., 2016). Furthermore, this parameter may reflect the physiological state of soil microorganisms and their efficiency in using microbial carbon to build-up (Cotrufo et al., 2013).

Conclusions

The sustainability of the forest system under the constraint of a changing environment is due to the increased human pressure by intensive agricultural practices. This problem is associated with forest ecosystem cultivation. In this context, a detailed study was conducted to assess the current state of forest soils by comparing the physico-chemical and biological analyses of agricultural lands with protected forest soils.

1. Analysis of the properties of cleared soils shows that the conversion of forest soil to agricultural land significantly increased pH_{H2O} by 0.16 units in forest soils compared to agricultural lands. Contrariwise, in

the converted soil, there was a drop by 0.24 units in pH_{KCl} and by 50% in the organic matter content of the soil. Regarding electrical conductivity (EC) and the total amount of limestone ($CaCO_3$), their decline was not significant.

2. Physical properties were also negatively affected by this conversion. A slight increase of 0.12 g cm^{-3} for bulk density and 0.23 g cm^{-3} for real density was recorded in the converted soil compared to the forest soil. Soil moisture and retention capacity decreased due to the organic matter decline in agricultural land by 7% and 21%, respectively. Meanwhile, for total porosity and permeability, similar values were recorded.

3. The conversion of forest soil to agricultural land significantly reduced basal respiration and microbial biomass by 54.46% and 47.36%, respectively. Besides, high metabolic quotient (qCO_2) values in agricultural land confirm that this practice disrupted the forest soil microbial population.

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