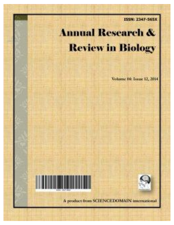

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Soil Quality Dynamics during Different Growth Stages of Corn (*Zea mays,* L.) Cultivation in Sri Lanka

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Authors' contributions

This work was carried out in collaboration between both authors. Author TKW designed the study, wrote the protocol and interpreted the data. Author KTGKP anchored the field study, gathered the initial data and performed preliminary data analysis. Authors managed the literature searches and produced the initial draft. Both authors read and approved the final manuscript.

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ABSTRACT

Maize known as Corn is popular among farmers as a cost effective crop with limited fertilizers. Cutting down natural forests for the planting of monocultures has had drastic impact on the soil quality leading to changes in soil properties. In Sri Lanka, no studies have been carried out to assess the effect on the properties of soil due to Maize although it is one of the extensive monoculture crops at present. The objective of the present study is to find out the effects on soil properties due to Maize cultivation during the different growth stages of the crop. This information is expected to assist in making decisions for sustainable soil management. Standard methods were used in measuring soil properties. % moisture, permeability, conductivity, Cation Exchange Capacity (CEC), the total organic carbon (C_{org}) and microbial biomass (C_{mic}) are significantly higher at seedling stage than the harvesting stage indicating possible impacts on the quality of soil. There are very little differences between growing and blooming stage for all the tested parameters. The data on effects are positively correlating with each other displaying possible consequences due to maize monoculture. The Cmic/Corg ratios of soils were low during both seedling and harvesting stages

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suggesting reduced number of microorganisms in soil. However, comparatively higher microbial action has been observed during both growing and blooming stages due to fertilizers. The lowest microbial respiration data during harvesting stage in the present study clearly indicates the impacts of maize plant on the biological quality of soil. Pearson's Correlation Matrix for Soil Properties reveals that there are positive correlations for pH, Conductivity, CEC and % Organic Carbon between growth and blooming stage. Slightly negative correlation for the microbial biomass indicated that biological quality is very slowly decreasing from growth to blooming. Our results suggest that there is a very clear indication that soil is slowly deteriorating with the growth of Maize and this could lead to serious situation with continuous growth of the same plant as practiced by Sri Lankan farmers.

Keywords: Monoculture; blooming stage; microbial biomass; amendments; soil quality.

1. INTRODUCTION

In agriculture, improving and maintaining soil fertility is of paramount importance to meet the demands of food grain production for an ever-increasing population in a country [1]. Good quality soil will no doubt ensure the highest production in a sustainable manner. Therefore, it is very clear that attention must be focused on the quality of soil while continuing with crop production. The knowledge on the changes of soil properties during different growth stages of a crop would be very useful to decide on the trend of soil degradation as well as on the mitigatory measures.

Soil constitutes a medium for plant growth. According to Doran et al. [2], soil quality is "the capacity of a soil to function within an ecosystem and sustain biological productivity, maintain environmental quality and promote plant and animal health". Scientists have identified and quantified chemical and biological soil-quality indicators for agro ecosystems, which are useful in evaluating the soil quality status owing to their early reaction to soil condition change. Among these indicators, microbiological and biochemical properties have been widely reported. These are furthermore related to the accumulation and the cycling of soil organic matter (SOM), a key component of soil quality. In the absence of clay with high exchange-capacity, SOM becomes the main nutrient storage site for soils in the tropics. Therefore, the role of SOM in the retention of plant nutrients emphasizes the need for management strategies designed to maintain adequate levels of soil organic matter [3].

In simple terms, soil quality is the capacity of soil to function. This definition, based on function, reflects the living and dynamic nature of soil. The chemical and biological soil quality indicators for agro ecosystems are useful in evaluating the soil quality status owing to their early reaction to soil condition changes [3]. Among these indicators, microbial and biochemical properties have been widely reported for measuring the soil quality [4]. Soil quality can be divided in to three areas such as sustained biological productivity, environmental quality, and plant and animal health. The soil resource must be recognized as a dynamic living system that emerges through a unique balance and interaction of its biological, chemical, and physical components [5].

Successful soil quality assessment strategies are needed to improve our ability to manage soils sustainably. Soil chemical parameters were less variable than biological or physical measures. It also showed that those biological and physical aspects of soils influenced by organic matter were the properties most altered by agronomic practice [5]. Particulate organic matter (POM) was identified as a promising soil quality measure. A simple method of estimating changes in biologically active soil carbon (C) could help to evaluate soil quality impacts of alternative management practices. The active soil C measurements were more sensitive to management effects than total organic C, and more closely related to biologically mediated soil properties, such as respiration, microbial biomass and aggregation, than several other measures of soil organic C [6].

Jaap Bloem and Anna Benedetti [7] reported about microbiological methods for assessing soil quality. Soil quality is useful as an indicator of the sustainability of agricultural practices and land management. Indicators of soil quality should give some measure of the capacity of soil to function in terms of plant and biological productivity and environmental quality. Soil microorganisms are of great importance to agro ecosystem function and sustainability through their contributions to the decomposition and dynamics of SOM and biogeochemical cycling of soil nutrients. All of which are fairly related to soil management practices which alter soil environment and affect soil processes [8].

On the other hand, monoculture plantations are extremely prone for soil deterioration due to many reasons such as exposure of land, run off losses, leaching of nutrients, retardation of microbial growth etc. A study conducted in India shows a notable decline in organic carbon and the cation exchange capacity in a rubber plantation compared to a natural forest [9]. Many of the soils are vulnerable to the effects of erosion during intense cropping. Laboratory and field studies indicate that monoculture systems without grass-legume forages lower organic C and N equilibrium levels [4]. Wheat rotation crops under irrigated and dry land conditions and in a range of climates where cotton is grown can improve soil quality indicators such as subsoil structure, salinity, and sodicity under irrigated and dry land conditions, while leguminous crops can increase available nitrogen by fixing atmospheric nitrogen, and by reducing N volatilisation and leaching losses [10]. Both broad leaf monoculture and mixtures of broad leaf and conifer exerted a favorable effect on soil fertility. Improvement in soil quality, enhanced biological activity and forest productivity demonstrated that mixed stands are an effective measure to maintain sustainable forest productivity, as well as to control soil degradation under successive stands of Chinese fir [11]. In addition, microbiological and biochemical parameters measured were sensitive to the forest management, they may be potential indicators for assessing the sustainability of different management systems. Chima et al. [12] also showed that total organic carbon, cation exchange capacity and microbial biomass carbon are effective indicators of the improvement or deterioration of soil quality under forest .

Although a number of studies on soils under different land use and land cover types had been conducted, no study has been conducted to evaluate and compare top soil properties under monoculture plantations of indigenous and exotic tree species in dry zone forests in Sri Lanka. The main objective of this study is to examine some selected soil physico-chemical and biological properties in an exotic monoculture (Corn) plantation in the Anuradhapura district of Sri Lanka. Apart from providing baseline data upon which future comparative studies will be based, the study in the interim tries to provide relevant information that will aid management decisions on sustainable soil management.

2. METHODOLOGY

A Corn grown site was selected in Eppawala in Anuradhapura. Samples were collected in March, April, July and August 2013representing different growth stages (beginning stage with small plants, growth stage: blooming stage & after harvesting stage). Soil samples (30X30X30 cm^3) were collected randomly in polythene bags and tied with sufficient air. Ten soil samples of study site were tested for all physical (% moisture content, sand content and permeability), chemical (pH, conductivity, Cation Exchange Capacity, Organic Carbon) Nitrate and phosphate content and biological (soil microbial biomass and total bacterial count) parameters using standard methods. In addition, air content was measured in the field and fresh soil core samples were collected for bulk density measurements using the same plots. Six soil samples were obtained from dry mixed evergreen forest in Anuradhapura (adjoining to the study site) randomly as a control. Finally, the results were analyzed using a one way ANOVA with Minitab statistical software Package.

3. RESULTS AND DISCUSSION

B- Beginning (Seedling) Stage, BL- Blooming Stage, G - Growing Stage, AH- After Harvest Stage.

Beginning stage of maize plants showed a significantly high moisture percentage (Fig. 1) than the after harvesting stage (2.30- 0.94%) ($P=0$; $P<0.05$). In the G and BL stages, soil moisture depletion may be related to the increased uptake by upper biomass through roots. Results further indicated remarkably high evaporation during no plant or after harvesting stages and this could have a drastic effect on soil biota. This decline is not favorable for both microorganisms and the roots as it creates moisture stress within soil plant system. Wang et al. [13] showed that maize is a good plant protector from evaporation of water. Since all these stages were falling during dry months, this water loss could also be due to the high absorption by the upper biomass from beginning to growing stage. Low value for after harvesting stage is due to the exposure of land for evaporation.

Fig. 2 shows the results for change of sand content during different growth stages

(74.82- 61.85%) (P=0; P<0.05). Increased percentage coarse and fine sand content by 13% with different growth stages indicated some sort of erosion with respect to both organic matter content and clay content. As reported by Gregorich et al. [4], the decomposition of limited biomass could lead to have less organic matter under monoculture plantations. Therefore, presence of high sand content over the growth period is justifiable. Other possible reasons could be increased surface runoff and depletion of OM during growth stages of single plant species.

The results show that permeability to water has been increasing over the growth stages (Fig. 3) and this significant increase of soil permeability (235.8-105.5 cm^3) (P=0; P<0.05) might due to structural/textural damage caused by water erosion under single plant cultivation leading to high amount of sand content due to monocultures. As reported by Van and Klingebiel [14], the addition of limestone and fertilizers has increased the permeability rate of the soil cultivated with maize and this response might be attributed to increased growth of maize plants. This maize plantation is also fertilized and observed high and increased permeability over the growth period could be due to the same reason.

The lowest soil pH was observed during the after harvesting stage (Fig. 4) and the highest pH was recorded at the beginning stage of maize cultivation (5.68-6.63) (P=0; P<0.05). This could be due to less OM decomposition and less activity of soil organisms. This trend could be as a result of decrease in the concentration of exchangeable bases - Mg, K, Na and Ca, with increased erosion due to lack of good plant cover. It is also reported that pH could also be decreased with increased fertilizer usage for maize plantations.

Conductivity decreased significantly (Fig. 5) from beginning to after harvesting stage (104.03-281.89 µs) (P=0; P<0.05). Soil electrical conductivity (EC) is a measure of the amount of salts in soil (salinity of soil). It is an important indicator of soil health. It affects crop yields, crop suitability, plant nutrient availability, and activity of soil microorganisms. Therefore, the reasons for this significant drop could be the removal of inorganic ions from the site due to higher absorption of minerals from the soil from growing stage to the harvesting stage of maize. As reported by Chima [15], soil conductivity was conspicuously high in natural forest compared to monoculture sites. EC can also serve as a measure of soluble nutrients – both cations and anions.

The CEC value of the beginning (seedling) stage was higher than the values of after harvesting stage (Fig. 6) of maize (608.5-374.5 NTU) (P=0.002; P<0.05). The cations and anions can be absorbed (taken up) by plant roots, leached from the soil via the soil water or can be adsorbed to the surfaces of negatively and positively charged soil particles. Lower levels of clay and silt are seen in that stage due to surface runoff as reported earlier in this study. These results further confirm that previously recorded low conductivity and high sand content over the growth scale. Further, this decrease might be due to decreased decomposition of biomass due to many reasons such as low pH, reduced moisture and reduced conductivity.

Percentage Soil Organic C (OC) has been reducing significantly (Fig. 7) from beginning to after harvesting stage (6.62 - 3.44%) (P=0; P<0.05) and this might be due to the heavy utilization of nutrients by the plant thus creating high decomposition rates in soil. As reported by Richard et al. [16], this might be due to increased surface runoff under monoculture plantations. These results are further confirmed by similar reduction of CEC in the present study indicating again the reduced microbial decomposition due to low pH, low EC and decreasing moisture contents over the time. Gregorich et al. [9] reported that OC was significantly reducing under maize monoculture systems and further indicated that fertilizer application too was unable to arrest the depletion.

The nitrate level (5.67- 1.94 µg ml^{-1}) was higher in the growing stage of maize plantation than in the after harvesting stage (P=0; P<0.05) and could be due to the fertilizer application in the growing stage [17]. However, significant decrease during blooming and after harvesting stages could be due to the absorption by the plant and also due to the leaching under monoculture plantation especially at after harvesting stage. The phosphate level (4.92-2.18 µs ml^{-1}) (P=0; P<0.05) was higher in the growing stage similar to Nitrate content. As discussed earlier, this increase could also be due to the fertilizer application in the growing stage.

The results clearly show that soil microbial biomass has been reducing over the growth period (Fig. 8). The lowest microbial biomass is obvious in soils of after harvesting stage (0.75 μg g^{-1}). Nsabimana et al. [18] reported that there was a reduction in organic matter and microbial biomass content and in measurements of microbial and enzyme activity under maize during both conventional tillage (CT) and zero tillage (ZT). The same study also indicated that

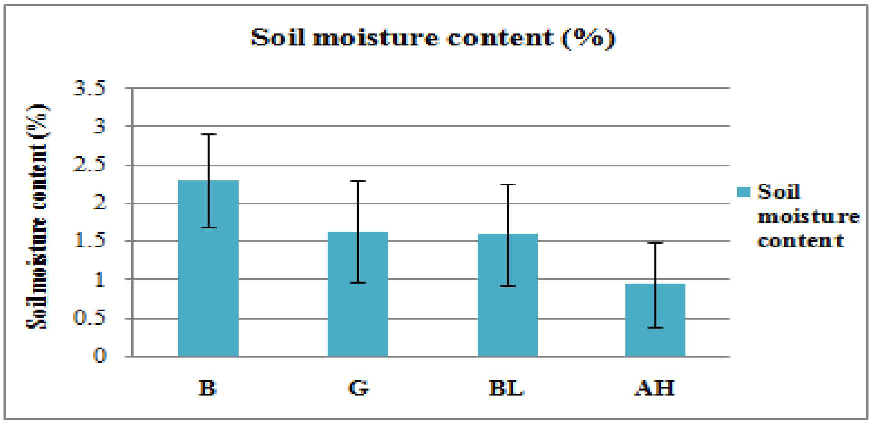

Fig. 1. Changes of % soil moisture with different growth stages

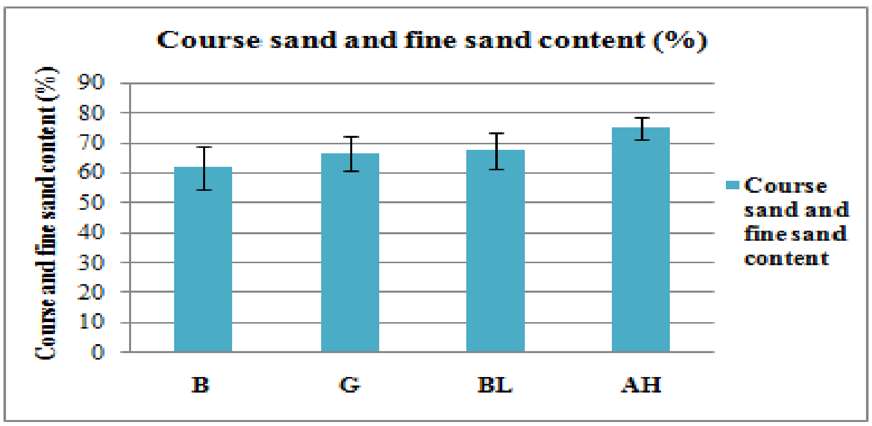

Fig. 2. Changes of % course and fine sand content at different growth stages

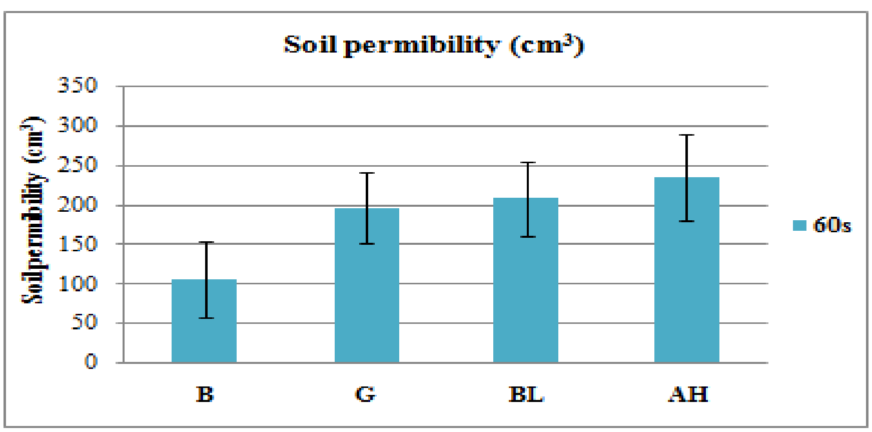

Fig. 3. Changes of soil permeability over the growth stages

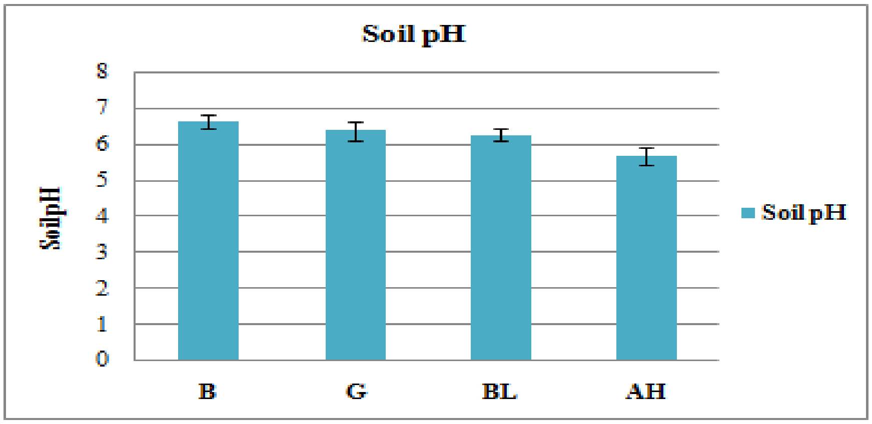

Fig. 4. Changes of soil pH over the growth stages

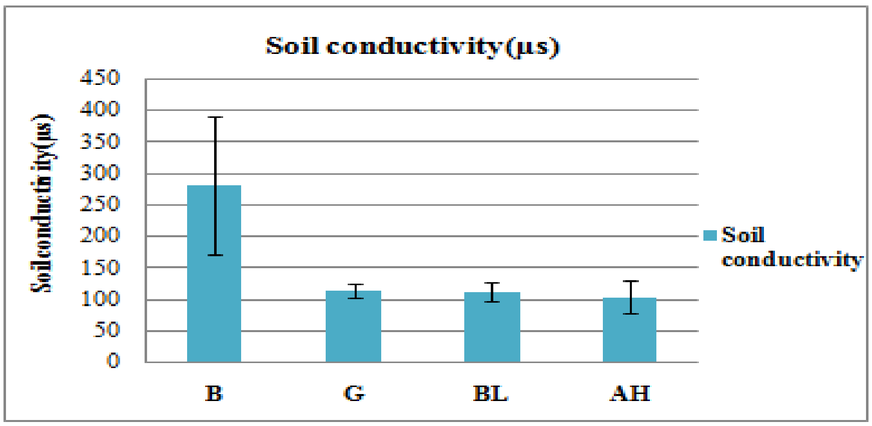

Fig. 5. Changes of soil conductivity at different growth stages

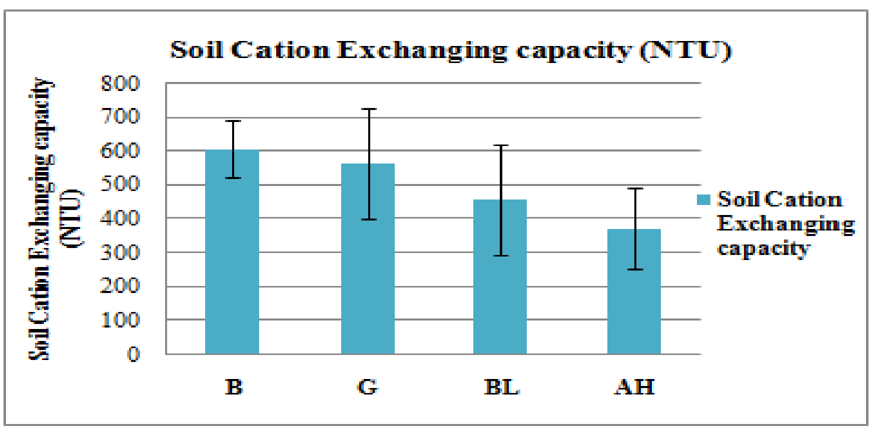

Fig. 6. Changes in Cation Exchange Capacity (CEC) with different growth stages

Principle component analysis of catabolic response profiles demonstrated that there were large differences in the catabolic capability of the soil microbial communities inhabiting the various land use types. Nsabimana et al. [18] also concluded that land use had substantial effects on the size, activity and diversity of the soil microbial community and that these changes

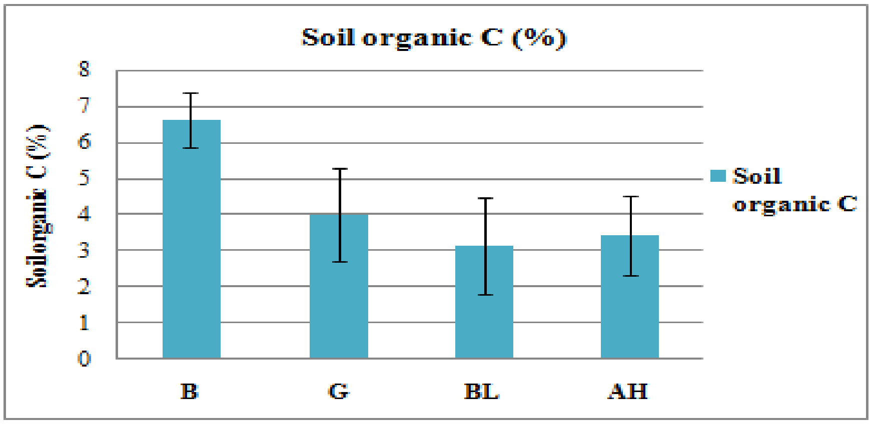

Fig. 7. % Organic carbon (C_{org}) of different growth stages

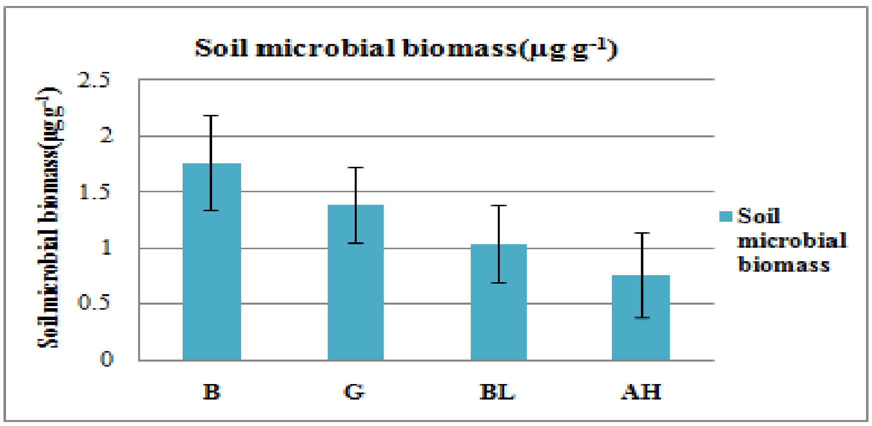

Fig. 8. Changes of soil microbial biomass (C_{mic}) over the growth stages

could be broadly related to changes in soil organic matter content. Yu et al. [11] also reported that soil microbial biomass is deteriorating with monoculture plantation due to not having suitable organic matter content in soil.

3.1 Pearson's Correlation Matrix of Soil Properties

Strong positive correlation($r \geq 0.86$) was shown by the pH, Conductivity, CEC & % Organic Carbon of this soil between growth and blooming stages indicating the changes of these properties during growth stage are similar to blooming stage. However, a strong negative correlation ($r = -0.43$) was observed for % moisture content and slightly positive correlation($r = 0.21$) was observed for microbial biomass between growth and blooming stages. This implies that moisture content is decreasing and microbial biomass is slowly increasing from growth stage to blooming stage. This analysis clearly shows that similar changes are obvious with both growth stages highlighting possible soil quality deteriorations and similar influences by Maize plants.

4. CONCLUSIONS

- It is obvious that the properties of soil have been changed by the maize cultivation displaying soil quality deterioration.
- Soil organic carbon content, cation exchanging capacity, soil conductivity, bulk density and microbial biomass of the soil seem to be the best physical and chemical indicators to determine the soil quality reduction and soil deterioration with maize monoculture cultivation.
- Large amount of inorganic salts, minerals and organic carbon may be removed due to the exposure of land for leaching as a result of maize monocultures.

- Extremely high nitrate and phosphate contents in the field over the growth period are due to the application of chemical fertilizers and long term effects of these treatments have to be studied.
- Reduced organic carbon of soil and low microbial biomass could be due to high leaching rates under monocultures and less decomposition rates caused by changed land use.
- The preliminary observations made with biological properties clearly establish the fact that soils under maize are under some sort of stress which could lead to land degradation with less soil quality if the same crop continues over the years.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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