Influence of crops on soil properties in agricultural lands of northern Iran

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Abstract

This study evaluates the effects of land use and soil management on a combination of physico-chemical, biological and hydrological properties of soil, in order to assess its quality. Three land uses were selected at the Fuman area, near Masouleh (Iran), grouping soils covered by tea, garden crops and rice. A total of 24 soil samples (3 land uses × 4 replications × 2 soil layers, topsoil and sub-surface soil) was collected; microbial respiration, available water, stability of soil aggregates, pH, organic matter, cation exchange capacity and nutrient content (P, K, N, Mg and Ca) were determined in each land use/soil layer.

In comparison with other land uses, garden showed the highest available water, aggregate stability, microbial respiration, nutrient contents and cation exchange capacity, whereas the latter three soil properties had the lowest values in soils covered by tea and rice crops. Based on these results, under the experimental conditions garden had~~presents~~ the highest soil quality among the investigated land uses. Conversely, much caution must be paid to some soil properties of tea and rice crops, such as cation exchange capacity, microbial respiration and nutrient contents, which are the lowest among the investigated land uses. Moreover, the differences in the analysed soil properties between the two soil sampling depths were statistically significant ($p < 0.05$). Finally, a Principal Component Analysis clearly clustered soils covered by garden, tea and rice crops in three differentiated groups according to the sampled soil properties. This study provides a contribution in understanding the variability of soil properties under different land uses, indicating that some of these properties must be considered with caution, in order to avoid a decay of soil health.

Keywords: tea crop; rice crop; garden; soil quality; soil management practices; Principal Component Analysis.

1. Introduction

Soil, a key resource for human well-being (Fao, 2010), plays an important role in natural and anthropogenic ecosystems (Hannam et al., 2006), provided that its quality is protected and improved. Soil quality is defined as its ability and capacity to perform functions as one of the components of the environment (Bunemann et al., 2018), and consists of the physico-chemical and biological properties. The evaluation of the effects of land management on soil quality by a quantitative approach is a challenging task, due to the number of soil processes and characteristics impacted by land use (Carter, 2002; Tiwari et al., 2006).

For this quantitative evaluation a set of soil quality indicators can be selected. These indicators measure the physico-chemical and biological properties of soil, according to the soil functions of interest (Zornoza et al., 2015) (for instance, agricultural production and mitigation of erosion risk). When land use and the linked management practices are thought to modify soil quality of agricultural lands (Cherubin et al., 2017), the selection and application of these indicators is essential to protect and possibly improve its properties. This evaluation is important to preserve fertility, which must support growth and replication of plants and crops as well as soil microorganism communities (Hannam et al., 2006), and control the hydrological response of a soil, in order to avoid the flooding and erosion risk (Bombino et al., 2019; Lucas-Borja et al. 2018a; 2019).

Various studies have used a combination of several physical, chemical, biological and biochemical properties as indicators of soil quality (Kalu et al., 2015; Lucas-Borja et al., 2012; Lucas-Borja et al., 2019; Burgess et al., 1990). For instance, pH (Lucas-Borja et al., 2012), nutrient content and form (Burgess and Wetzel, 2000; Santa-Regina and Tarazona, 2001), texture (Fterich et al., 2014), organic carbon (Parras-Alcántara and Lozano-García, 2014), microbial respiration (Bastida et al., 2007; Lucas-Borja et al. 2018b) have been considered as useful indicators of soil quality and thus have been used to advance in the understanding of changes in soil properties. The hydrological properties of soil and the related indicators (e.g., water storage capacity, aggregate stability, hydraulic conductivity) are also important, since they quantify the hydrological response of a soil (namely the capacity of generating water runoff and triggering soil erosion), which is strongly influenced by land use (Lucas-Borja et al., 2019).

Changes in land uses and deviations of actual from natural land uses (the so-called "environmental land use conflicts", Pacheco et al., 2014; Valle Junior et al., 2014) strongly impact on soil fertility (Valera et al., 2016). Therefore, these changes are reasons of soil quality reduction (Jamala and Oke, 2013), as shown by the deterioration of the soil properties that are critical for soil health (Khormali et al., 2009). On this regard, the efforts of some countries (e.g., Brazil) to regulate land uses and minimize the impacts of land use conflicts through enforcement of the "polluter-pays" principle are noticeable (Valera et al., 2017). An inappropriate land use may lead to unsustainable land degradation processes. In particular, the use of land for intensive agriculture may generally cause soil damage (Cherubin et al., 2017; Claessen, 1997). Therefore, it is necessary to study how a specific land use modifies the different properties related to the quality of a given soil, possibly by a quantitative approach using the suitable indicators. As well known, agriculture, particularly when it is intensive and subject to frequent tillage operations, may strongly affect and degrade the properties of soil, making it more prone to erosion and fertility decay (Lucas-Borja et al., 2019). The research about the effects of land exploitation for agricultural production on soil properties is not complete, due to the huge number of local situations (soil properties, crops, agricultural practices) and on-site processes. Therefore, the large variability of the soil characteristics and processes from a site to another requires further investigations, leading to a better understanding of impacts of agriculture on soil quality. Iran is one of the Asian countries most devoted to agriculture. During the past

50 years, the amount of Iran's cultivated land has grown by more than five times (DEI, 2003). Land-use changes in Northern Iran have been more rapid in recent year (e.g. Sadeghi, et al., 2007; Emadi, et al., 2008); therefore, in this important agricultural context, the evaluation of soil quality and fertility, as affected by intensive agriculture, is compulsory to give land managers insights about the most suitable crops and cultivation practices. In the agro-forest contexts of Iran, literature about the effects of land uses on soil ~~porperties~~ properties is not exhaustive and mainly focused on the forest areas. Khormali et al. (2009) investigated on loess soils in semi-arid region of northern Iran, reported reducing of soil quality indices upon cultivation of native soils, and highlighted the impact of deforestation on soil quality in loess-derived soils of Golestan province. In the same province, Ayoubi et al. (2011) evaluated the effects of land use changes on properties in a Loess soil. Pourbabaei et al. (2015) analysed the relationships between the plant ecological groups and soil properties of common hazel stand in the N~~n~~orthern~~ of~~ Iran. Especially in Guilan (the same area of this study), Gholoubi *et al.* (2019) showed that after land use change, soil physical and chemical characteristics were changed due to land use effects, resulting in significant decreases in organic carbon, available potassium, soil microbial respiration and pH. Rezaei et al. (2012) reported the impacts of land use changes on soil properties and mineralogy of clayey forest soils in the Caspian Sea Region; these authors found that after changing land use, pH, cation exchange capacity, clay content and the amount of organic carbon of the soils were decreased in Lahijan region located in northern Iran. More in general, Bahrami et al. (2010) found that intensive cultivation and mismanagement have caused environmental problems and soil degradation in Northern Iran, showing that soil properties in different duration of plantation have significantly changed under long-term inappropriate cultivation activities.

In spite of these significant outcomes of these literature studies~~Therefore~~, more research is needed, in order assess to how and to what extent soil quality is modified by the typical croplands in these important agricultural environments through the analysis of individual case studies.

The general objective of this study is the evaluation of the changes in soil quality induced by agricultural practices in important croplands of Northern Iran. More specifically, in an attempt to determine whether soil properties vary with different land uses and to compare effects of land use changes on soil characteristics, this study analyses the effects of three different land uses (agricultural lands with tea and rice crops and garden with production of fruits and vegetables) on a combination of physico-chemical, hydrological and biological properties of soil at two different depths (topsoil and sub-surface soil). We hypothesize that all the properties of a given soil can be affected by significant changes due to the different agricultural practices on crops. Awareness of soil quality is important for land use systems and the information obtained in this work would allow planning and adoption of suitable management practices targeted to the increase of soil health.

2. Materials and methods

2.1. Study area

The study was carried out in three croplands within the Fuman area, near Masouleh City (49°18′ 33.70″ E and 37°13′ 18.09″N, Guilan province, North of Iran) with an area of about 10 km^2 (Figure 1). The altitude ranges from 950 to 1150 m above medium sea level. The climate is typically Mediterranean, Csa according to the Köppen-Geiger classification (Kottek et al., 2006). The average annual rainfall and temperature are 1275 mm and 15.7 °C, respectively.

The main land uses are gardens (the main land use of the area, which can be considered as crop reference)e, rice and tea, covering more than 50% of the total study area. Beside the main crop, the area covered by tea consists of various trees, shrubs, and bushes. Rice is cultivated on a flattened and irrigated field, in which rice is dominant crop. In gardens, fruits (kiwi, apple and greengage), wheat and seasonal vegetables (soybean and black-eyed pea) are cultivated (Table 1).

Texture of soils, quite homogenous in all the studied land uses, is mainly silt loam, while parent materials include limestone and shill (Pourbabaei and Adel, 2015) (Table 1). Soil is fertile and the quality is variable among the studied land uses, because of different management practices.

2.2. Soil sampling and analyses

The soil of the three land uses was sampled using a completely randomized design with four replications at two depths. The soil sampling took place in the fall (October 2014), winter (January 2015), spring (April 2015), and summer (July 2015). Twenty-four samples, eight per land use, of which four in the surface soil (0-15 cm) and as many in the sub-surface layer (15-30 cm), were collected and analysed in laboratory, in order to measure the main characteristics (texture, hydrological, biological and physico-chemical properties), evaluated by as many indicators.

Soil texture was measured by sieving samples, followed by the hydrometer method (Gee and Bauder, 1986), and evaluated by clay, silt and sand contents.

The hydrological indicators (field capacity, FC; permanent wilting point, PWP; available water, AW; and mean weight diameter, MWD, the latter being an indicator of the soil aggregate stability) were measured according to the methods proposed by Cassel and Nielsen [1986, for FC and PWP], Klute [1986, for AW]; and Kemper and Rosenau [1986, for MWD].

The soil biological activity was determined measuring the microbial respiration (MR), in terms of accumulated C-CO_2, according to Anderson (Anderson, 1982).

Among the soil physico-chemical properties, the following indicators were measured: organic matter (OM, by Walkley-Black method (1934); pH, on 1:2.5 soil:water ratio (Hesse, 1971); total nitrogen, N, by Kjeldahl method, Bremner and Mulvaney (Chapman, 1965); total phosphorous (P); potassium (K); Calcium (Ca) and Magnesium (Mg) (using the methods reported by Claessen) (1997); cation exchange capacity (CEC), according to Chapman (2012); and $CaCO_3$, according to Sparks (1996).

2.3. Statistical analysis

A two-way Analysis Of VAriance (ANOVA) was used to evaluate the statistical significance of differences in soil indicators among the studied land uses and the soil depths, and their interaction. The three land uses (tea, rice and garden) and the two soil depths (topsoil, 0-15 cm, and sub-surface soil, 15-30 cm above ground) were considered as independent factors, while the soil indicators were the dependent variables. Due to the sampling procedure, all point samples were considered as spatially independent. An independent Fisher's minimum significant difference test (LSD) was used for the post-hoc analysis comparisons. A $p < 0.05$ level of significance was adopted. To satisfy the assumptions of ANOVA (equality of variance and normal distribution), variables were square root transformed when necessary. Finally, a Principal Component Analysis (PCA) was applied to the soil parameters, in order to find correlations (using Pearson's method, Rodgers and Nicewander) (Rodgers and Nicewander, 1988) and dependency among the indicators, according to the investigated land uses and soil depths. All statistical analyses were carried out using the statistical software Statgraphics® Plus 6.0 and JMP® 7.0.

3. Results

3.1. Textural, hydrological and biological indicators of soils

~~In spite of~~Despite the same class (silt loam) of the investigated soils, textural and hydrological properties of the soils were significantly different not only among the three studied land uses ($p < 0.05$), but also at both investigated depths, except for SaC and PWP. The interactions between land uses and soil depths were significantly different ($p < 0.05$) only for textural properties, but not for the hydrological parameters (Table 2). More specifically, SaC and CC were the highest in rice crop and the lowest in garden, while SiC was lower in tea crop and mainly in rice crop, compared to garden (Figure 2a). These differences in soil texture also reflect on the hydrological properties of soils, as highlighted by the values of FC, PWP (both higher in garden) as well as AW and MWD (showing a significant gradient between garden and rice/tea crops) (Figure 2e). As regards the biological activity of the soils, MR significantly varied among land uses and soil depths and the interaction between these variability factors was significant (p <

0.05, Table 2). This soil biological property was more pronounced in garden and smoother in rice crop (Figure 2f).

3.2. Physico-chemical indicators of soils

~~All of~~All the physico-chemical properties of soils were significantly different among the analysed land uses and soil depths ($p < 0.05$), except for the content of OM. The latter, although falling in a large range of variability, was not significantly different among the three land uses. The statistical significance of these differences also reflected on the interaction between the two variability factors (that is, land use and soil depths), with the exception of OM and nutrient (N and P) contents of soils (Table 2). A deeper analysis of these properties shows that: (i) pH was higher in rice crop (on average 5.0) and lower in tea crop (3.75); (ii) soil OM was very similar among all the analysed land uses (from 2.8% of tea crop up to 3.4% of garden); (iii) garden showed the highest soil content of nutrients (0.18% of N, 4.2 mg/kg of P and 215 mg/kg of K) and rice crop the lowest (0.1% of N, 2.1 mg/kg of P and 39.9 mg/kg of K); (iv) there was a gradient garden > rice crop > tea crop in Ca and Mg contents of the soil. Finally, the soil content of $CaCO_3$ was quite similar between garden and rice crop and lower in tea crop, while garden and rice crop showed the highest and the lowest CEC, respectively (Figures 2b, 2c and 2d).

3.3. Correlation analysis

Soil pH was significantly correlated with a large number of other indicators. In particular, a positive correlation ($r = 0.81$) was shown with $CaCO_3$ and negative relationships were found with nutrient contents ($|r| > 0.52$) and MR ($r = -0.53$). Moreover, the latter indicators (MR and N, P, K contents) were fairly and positively correlated among them ($r > 0.66$). Soil content of OM was positively correlated with N content ($r = 0.55$) and MWD ($r = 0.54$), but not with AW of the soil ($r < 0.18$). Strong and positive correlations were also found between CEC and nutrient contents ($r > 0.62$). As regards the hydrological properties of the soils, only FC was significantly correlated with the textural parameters ($|r| > 0.42$), PWP ($r = 0.47$) and AW ($r = 0.76$). Finally, the latter was strongly correlated with MWD and MR (Table 3).

3.4. Principal Component Analysis

Using PCA two principal components (PCs) were identified, explaining together about 70% of the total variance of the original variables. In more detail, PC1 explained 49% of this variability, whereas PC2 another 20%. The first PC was associated with significant loadings to the P content, CEC and MR of soil, while the other nutrients and AW had a strong association with PC2 (Table 4).

Plotting the sample scores on the first two PCs, differences in soil properties emerged not only among land uses, but also between soil sampling depths. Three well-differentiated groups, one for each land use, were clustered and, within each cluster, a gradient separating the indicators of samples collected at the different soil depths was evident (Figure 3).

4. Discussion

It is well known, at least by a qualitative approach, how land use of a given territorial unit affects soil properties in several ways and at various rates. Different authors working in Iran have demonstrated that a change in land use is the major factor affecting the soil physico-chemical and biological properties and altering the dynamics and availability of soil nutrients (Ayoubi et al., 2011; Rezaei et al. 2012). The results of this study are in close accordance with these findings. The silt loam texture of the investigated soils was the same in all studied land uses, indicating the homogeneity of soil forming processes and similarity of parent materials (Foth, 1990). Nevertheless, over a very long period of time, pedogenesis processes such as deposition, erosion, weathering, and eluviations have change the soil texture (Foth, 1990; Brady and Weil, 2002). The agricultural practices, different crop by crop in the studied land uses, may have played an important role in modifying the other soil quality properties. This is demonstrated by the recorded variability of hydrological, biological and physico-chemical properties of both the surface and the sub-surface layers of the soils, which are mainly due the individual land uses. More specifically, with regard to the physico-chemical properties, the analysed land uses determined a significant variability of almost all the investigated parameters; moreover, the two studied layers (topsoil and sub-surface layer) are also influenced by a significant variability of soil properties.

The soil was acidic in all the land use and this may be due to the severe seasonal rainfalls in the period of the sampling activity, when precipitation may have leached cations. In general, the soils devoted to agricultural purposes show light acidity (Tran et al. 2014). Soil pH was lower in the sub-surface soil layer compared to the topsoil, presumably because of lower organic matter content. This acidity deserves much attention, since very low values of pH may be dangerous for crop and soil health. The low pH values of the soils of the sites covered by tea cultivation are due to a combination of agricultural practices: (i) the intensive application of nitrogen fertilizers; (ii) the addition of plant residuals and litter; (iii) an intensified decomposition of soil organic matter, which determined the oxidation of nitrogen and subsequent a reduction in the soil pH. Also Rezaei et al. (2012) showed that, in tea cultivation, pH and the amount of organic carbon of the soils can significantly decrease. The higher soil pH values measured in rice cropland compared to the other land uses may be due to repeated addition of inorganic fertilizers and manures to agricultural soils. This in accordance with other studies (Khormali et al., 2009; Celik, 2005), which stated that the rapid hydrolysis of urea in the soil can result in higher soil pH values. When urea is completely hydrolyzed, NH_4 ion is produced and, if this is not converted to NO_3 by nitrification or not taken up by plant, soil pH increases.

Soils cultivated with rice are exposed to continued drying and wetting cycles. The mechanisms mainly caused by the flooding water and surface puddling create differe~~re~~nces in properties from other land uses owing to different physical, chemical and biochemical processes (Zhang and He, 2004). Furthermore, nitrogen concentration decreases with wetter conditions of rice crop and this could be due to the anaerobic soil conditions.

The highest organic matter content detected in garden may be the result of its accumulation due to root biomass (Reicosky and Forcella, 1998). Zhang et al. (2016) stated that, when the rate of crop residues left on soil surface increases, as happened in garden in comparison to rice and tea crops, its organic matter content raises up. The lowest soil organic matter detected in tea crop could be due to decomposing microorganisms, high oxidation and water erosion (Girmay et al., 2008). On the other hand, management practices can increase soil organic matter such as fertilizer applications (Angelova et al., 2013; Yang et al., 2016). However, the literature results about organic matter content in soils are generally contrasting in the different land uses of Asia. For example, Kalu et al. (2015) stated that soil organic matter content was higher in forest of Nepal, whereas Shi et al. (2010) found that rice crops practiced on Chinese soils show the highest soil organic matter content.

The high amount of soil organic matter detected in garden can explain its higher microbial respiration compared to the other land uses. In other words, the higher production of biomass and subsequent accumulation of more organic matter in the garden played a significant effect on the microbial population of the soil. However, microbial respiration in agricultural soils must be monitored with care, since Bonanomi et al. (2011), who studied the soil quality indicators in different land uses, reported that microbial respiration can be reduced by the annual tillage operations. Carter (2002) stated that soil microbial activity is significantly reduced due to reduced organic matter after severe tillage operations.

Significant differences in nutrient contents of soils under the three land uses were detected in this study. More specifically, the higher nitrogen, phosphorous and potassium content in the garden could be associated with the higher organic matter, which in its turn resulted from crop residues left on soil, and to higher fertilizer (manure and compost) application. Rasmussen and Douglas (1992) stated that continuous application of phosphorus fertilizer leads to increased concentration of available phosphorous in soils. Yousefifard (2004) showed that the majority of soil phosphorous is in organic form, therefore, with increase in organic matter losses, phosphorus losses also increase. Other studies (e.g., Moges and Holden, 2008) stated that nitrogen is not significantly variable with land uses. Vice versa, the lower potassium in the rice crop could be probably due to potassium leaching and soil degradation (Landon and Booker, 1991). This study showed that the nitrogen concentration was significantly higher in the garden and tea croplands, which are frequently fertilized, compared to the rice site, less fertilised. According to (Raison et al., 1990), slow and steady inputs of nitrogen or repeated nitrogen additions could be favoured by nitrifying bacteria to accelerate the nitrification process. The high soil nitrogen concentration in the garden and tea land uses also may stimulate the nitrifier activity, which would result in a greater nitrate-N leaching potential. Bengtsson and Bergwall (Bengtsson and Bergwall, 2000) showed that the nitrogen concentration increased by 40% in a plot receiving the largest amount of fertilizer compared with a control plot that was not fertilized.

One of the most important indicators of soil fertility and quality is its cation exchange capacity (Doran and Parkin, 1994), since plants absorb nutrient elements in form of cations (Sharma et al., 2015). It can be inferred that, among the investigated land uses, garden has the highest quality and fertility, since it shows the higher cation exchange capacity, mainly due to the highest content of calcium and magnesium. On the contrary, the lowest cation exchange capacity measured in rice crop indicates the low level of fertility and quality of this land use.

Lower concentration of $CaCO_3$ in tea land use was found at Fuman area. The decreased calcium carbonate contents in tea cropland could be due to the peculiar management practices, including some additions of lime. There are numerous interactive processes responsible for the changes in carbonate contents, and an alteration in carbonate contents has been considered as an indicator of soil loss and landscape stability (Khormali et al., 2009).

Soil nutrient contents act as a major factor controlling the variability in soil microbial respiration under different land uses (Tardy et al., 2014; Mganga et al., 2016). The high soil respiration detected in garden can be explained by an increase in the contents of soil nutrients (i.e. N, P, K, Ca and Mg), which stimulate microbial activity, thereby leading to an increase in respiration from soil (Giesler et al., 2012). However, other studies (Wang et al., 2013; Gorobtsova et al., 2016) stated that influence of land uses on soil respiration is complex. Kooch et al. (2017) revealed the influence of the soil pH agrees with the established concept that soil pH strongly determines microbial respiration; soil pH close to seven is most suitable for microbial respiration.

In this study, the evaluation of soil hydrological indicators showed that land use significantly affects the related properties and particularly the available water and aggregate stability. The higher capacity of water storage in the soil available in garden could be due to the higher aggregate stability, which, determining a higher porosity of soil and thus increasing infiltration, may be linked to the higher organic matter content of soil. Organic matter acts as a cementation agent and it is important to flocculate soil particles and form soil aggregate (Kavdir et al., 2004). Gol (2009) stated that the stability of aggregates is affected by land use and long-term human activities can bring to a severe degradation of soil aggregate stability, shown by a significant decrease in the mean weight diameter. Therefore, since soil management operations may determine a reduction of aggregate stability and thus of available water in the soil, in soils subjected to tillage operations this parameter must be analysed with care. Repeated plowing of soil lets aggregates be poorly formed and makes soil more sensitive to degradation (Gholami et al., 2016).

The increased available water of soils with higher organic matter (such as garden) detected in this study is in accordance with Wolfe and Schneider (2003), who reported an increase of the available water capacity by about 1.5% with an increase by 1% of organic matter content, and with a similar study of Rawls et al. (2003), who also noticed high available water capacity in soils with high amount of organic matter. However, our study does not report a significant correlation between available water and organic matter contents of soil. Conversely, Hudson (1994), studying the effects of organic matter on available water capacity of three soil texture (sandy, silty loam and silty clay loam), noticed a positive and significant correlation between these two parameters. The author explains this correlation by the fact that the increase of organic matter induces a higher increase of field capacity compared to the permanent wilting point.

Finally, the results of PCA reveal that the different land uses clearly discriminate soil properties, grouping in separate clusters soils covered by tea crop, garden and rice and according to the soil properties, which mostly influence the two first principal components (namely nutrient contents, cation exchange capacity, available water and microbial respiration of soil). Moreover, these properties show a clear stratification between topsoil and sub-surface soil, as results of different physico-chemical processes specialising vertically the soil.

5. Conclusions

This study, where it has been hypothesized that all the soil properties of croplands can be affected by significant changes due to the different agricultural practices, has demonstrated how and to what extent soil quality is modified by agricultural land uses (garden, in which wheat, fruits and vegetables are cultivated, tea and rice crops) in lands of Northern Iran. Although the textural characteristics of the investigated soils were very similar, the hydrological, biological and physico-chemical properties were significantly different not only among the three studied land uses, but also in both topsoil and sub-surface soils, as we hypothesized. Garden showed the highest available water, aggregate stability, soil respiration, nutrient contents and cation exchange capacity, which all are indices of a higher soil quality and a better hydrological behaviour. Instead, pH and organic matter content were quite similar among the three studied land uses. Conversely, much caution must be paid to some soil properties of tea and rice crops, such as cation exchange capacity, microbial respiration and nutrient contents, which are the lowest among the investigated land uses. As shown by the results of PCA, the individual land use induces variations in the soil properties (in particular nutrient contents, cation exchange capacity, available water and microbial respiration, which mostly influence the first two principal components) and these changes are different between the topsoil and the sub-surface soil. These differences can be the results of the physico-chemical, biological and hydrological changes, induced by the different soil management practices used in cultivated lands. Therefore, we can conclude that, in spite of the homogeneous soil types, a specific land use may have noticeable influences on soil quality.

Overall, this study provides a contribution in understanding the soil quality under different land uses and suggests ~~related~~ that some sustainable soil management operations, minimizing soil disturbance, such as crop rotation, organic fertilisation, and cover crops~~, which~~ may be of help for soil quality preservation ~~in planning and adopting the most suitable cultivation practices targeted to the increase of soil health~~under intensive agriculture.

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TABLES

Table 1 - Main characteristics of soils and crops for the three land uses in the experimental site (Fuman area, Guilan province, Northern Iran).

<table>
<tr><th rowspan="2">Land use</th><th rowspan="2">Observation period (years)</th><th rowspan="2">Parent material</th><th rowspan="2">Soil texture</th><th rowspan="2">Main crop</th><th colspan="2">Shrub and herbal vegetation</th></tr>
<tr><th>Cover (%)</th><th>Type</th></tr>
<tr><td>Tea</td><td rowspan="3">1</td><td rowspan="3">limestone and shill</td><td rowspan="3">loam silty</td><td>tea</td><td rowspan="3">30-35</td><td>Crataegus microphylla and Ilex spinigera</td></tr>
<tr><td>Garden</td><td>fruits, wheat and vegetables</td><td>Corylus avellana and Epimedium pinnatum</td></tr>
<tr><td>Rice</td><td>rice</td><td>Fagus orientalis and Asperula odorata</td></tr>
</table>

Table 2 - Results of ANOVA applied to the textural, hydrological, biological and physico-chemical properties for the three land uses (garden, rice and tea) and two soil depths (0-15 and 15-30 cm) in the experimental site (Fuman area, Guilan province, Northern Iran).

Soil physico-chemical properties	**Factors**	**F-ratio**	**P-value**
pH	LU	202.33	<0.05
	SD	266.78	<0.05
	LU x SD	24.11	<0.05
OM	LU	1.32	0.29
	SD	13.38	<0.05
	LU x SD	1.9	0.18
N	LU	19.25	<0.05
	SD	102.57	<0.05
	LU x SD	0.03	0.97
P	LU	72.17	<0.05
	SD	23.3	<0.05
	LU x SD	0.73	0.49
K	LU	9776.8	<0.05
	SD	498	<0.05
	LU x SD	600.08	<0.05
Ca	LU	637.81	<0.05
	SD	11.52	<0.05
	LU x SD	4.99	<0.05
Mg	LU	111.78	<0.05
	SD	7.79	<0.05
	LU x SD	28.14	<0.05
CEC	LU	98.54	<0.05
	SD	99.06	<0.05
	LU x SD	6.54	<0.05
$CaCO_3$	LU	61.2	<0.05

	SD	40.66	<0.05
	LU x SD	6.87	<0.05
SaC	LU	11.18	<0.05
	SD	0.66	0.43
	LU x SD	12.76	<0.05
SiC	LU	33.68	<0.05
	SD	26.79	<0.05
	LU x SD	8.93	<0.05
CC	LU	7.22	<0.05
	SD	25.1	<0.05
	LU x SD	25	<0.05
FC	LU	28.03	<0.05
	SD	29.07	<0.05
	LU x SD	0.04	0.96
PWP	LU	5.34	<0.05
	SD	0.98	0.34
	LU x SD	2.68	0.10
AW	LU	16.9	<0.05
	SD	12.1	<0.05
	LU x SD	0.4	0.68
MWD	LU	37.31	<0.05
	SD	315.05	<0.05
	LU x SD	2.02	0.16
MR	LU	402.97	<0.05
	SD	216.03	<0.05
	LU x SD	9.89	<0.05

Notes: LU = land use; SD = soil depth; LU x SD = interaction between LU and SD; OM = organic matter; CEC = Cation Exchange Capacity; FC = field capacity; PWP = permanent wilting point; AW = available water; SaC = Sand content; SiC = Silt content; CC = clay content; MWD = medium weight diameter of soil aggregates; MR = microbial respiration.

Table 3 - Correlation matrix among the textural, hydrological, biological and physico-chemical properties for the three land uses (garden, rice and tea) and two soil depths (0-15 and 15-30 cm) in the experimental site (Fuman area, Guilan province, Northern Iran).

	pH	**OM**	**N**	**P**	**K**	**Ca**	**Mg**	**CEC**	**$CaCO_3$**	**SaC**	**SiC**	**CC**	**FC**	**PWP**	**AW**	**MWD**	**MR**
pH		-0,16	**-0,65**	**-0,67**	**-0,52**	**0,40**	**0,45**	**-0,71**	**0,81**	0,02	**-0,75**	**0,69**	**-0,48**	0,01	**-0,59**	**-0,67**	**-0,53**
OM			**0,55**	0,21	-0,17	**0,36**	0,08	0,32	0,01	-0,06	0,22	0,06	**0,35**	0,06	0,18	**0,54**	0,33
N				**0,72**	0,31	0,26	0,07	**0,80**	**-0,34**	-0,22	**0,73**	**-0,48**	**0,83**	**0,34**	**0,67**	**0,93**	**0,79**
P					**0,79**	0,17	0,10	**0,87**	-0,28	**-0,50**	**0,80**	**-0,43**	**0,73**	**0,33**	**0,77**	**0,64**	**0,88**
K						-0,01	0,05	**0,62**	-0,25	**-0,46**	**0,69**	**-0,37**	**0,49**	0,19	**0,61**	0,23	**0,66**
Ca							**0,83**	0,09	**0,71**	-0,29	0,12	0,08	**0,47**	**0,48**	0,26	0,25	**0,42**
Mg								-0,03	**0,78**	-0,12	0,10	0,04	0,31	**0,42**	0,22	0,06	0,30
CEC									**-0,41**	**-0,42**	**0,71**	**-0,40**	**0,77**	**0,38**	**0,74**	**0,81**	**0,91**
$CaCO_3$										-0,04	**-0,36**	**0,50**	-0,11	0,26	-0,27	**-0,36**	-0,12
SaC											-0,11	-0,26	**-0,42**	**-0,35**	**-0,39**	-0,13	**-0,49**
SiC												**-0,69**	**0,69**	0,25	**0,74**	**0,69**	**0,76**
CC													**-0,42**	-0,16	**-0,55**	**-0,53**	**-0,40**
FC														**0,47**	**0,76**	**0,79**	**0,87**
PWP															**0,34**	0,36	**0,55**
AW																**0,70**	**0,79**
MWD																	**0,77**
MR																	

Notes: OM = organic matter; CEC = Cation Exchange Capacity; FC = field capacity; PWP = permanent wilting point; AW = available water; SaC = Sand content; SiC = Silt content; CC = clay content; MWD = medium weight diameter of soil aggregates; MR = microbial respiration. Significant parameters at $P > 0.05$ are reported in bold.

Table 4 - Loadings of the original variables - textural, hydrological, biological and physico-chemical properties for the three land uses (garden, rice and tea) and two soil depths (0-15 and 15-30 cm) in the experimental site (Fuman area, Guilan province, Northern Iran) - of Principal Component Analysis on the first two Principal Components (PC1 and PC2) (significant parameters at P > 0.05 are reported in bold).

Original variables	**PC_1**	**PC_2**
pH	-0,258	-0,341
OM	0,119	-0,112
N	0,305	-0,007
P	**0,314**	-0,002
K	0,229	0,051
Ca	0,082	**-0,487**
Mg	0,040	**-0,464**
CEC	**0,319**	0,037
$CaCO_3$	-0,127	**-0,470**
SaC	-0,133	0,181
SiC	0,302	0,073
CC	-0,205	-0,196
FC	0,305	-0,142
PWP	0,148	-0,280
AW	0,299	-0,031
MWD	0,299	0,008
MR	**0,325**	-0,132

Notes: LU = land use; SD = soil depth; LU x SD = interaction between LU and SD; OM = organic matter; CEC = Cation Exchange Capacity; FC = field capacity; PWP = permanent wilting point; AW = available water; SaC = Sand content; SiC = Silt content; CC = clay content; MWD = medium weight diameter of soil aggregates; MR = microbial respiration. The significant values for each principal component are reported in bold.

FIGURES

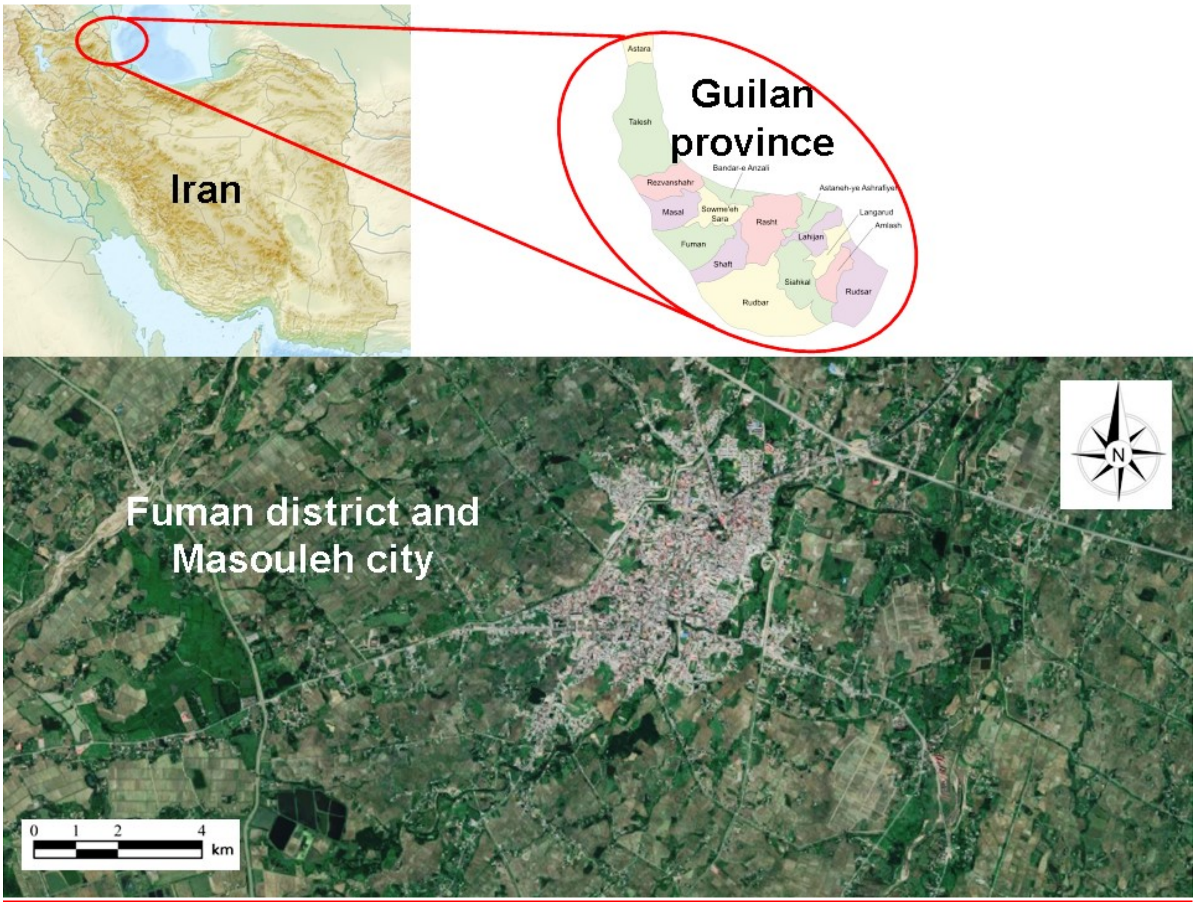
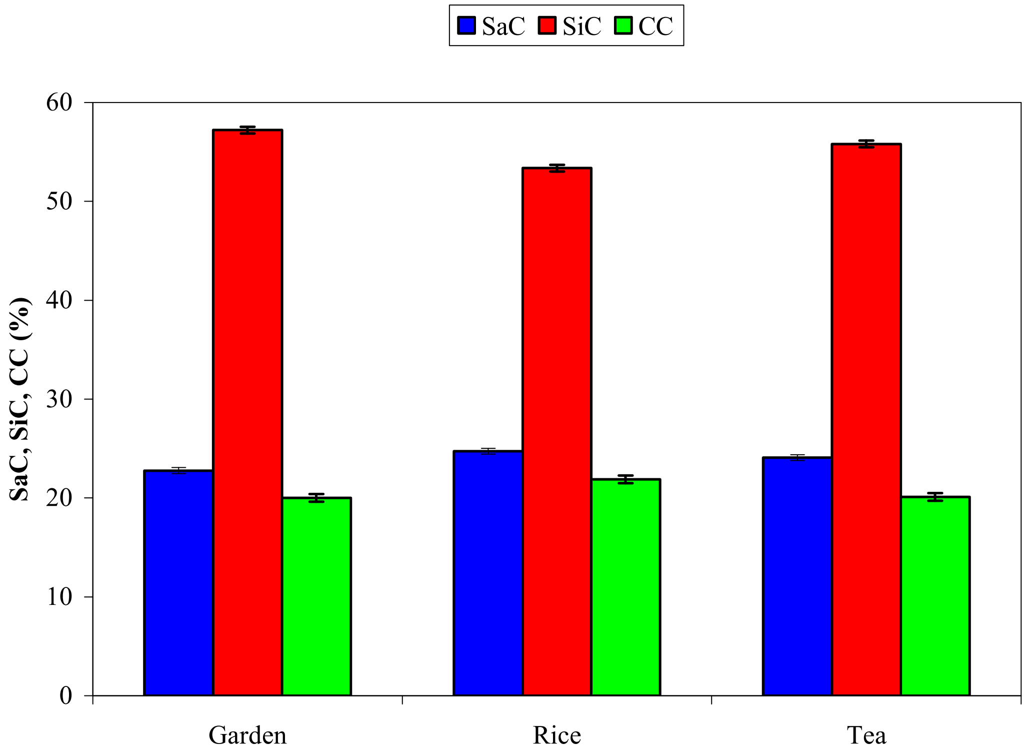
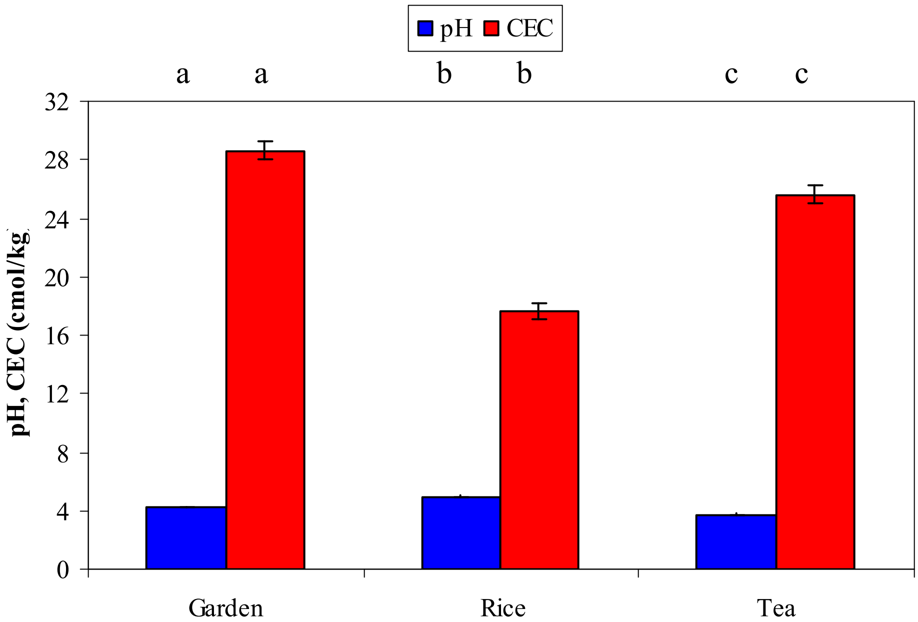


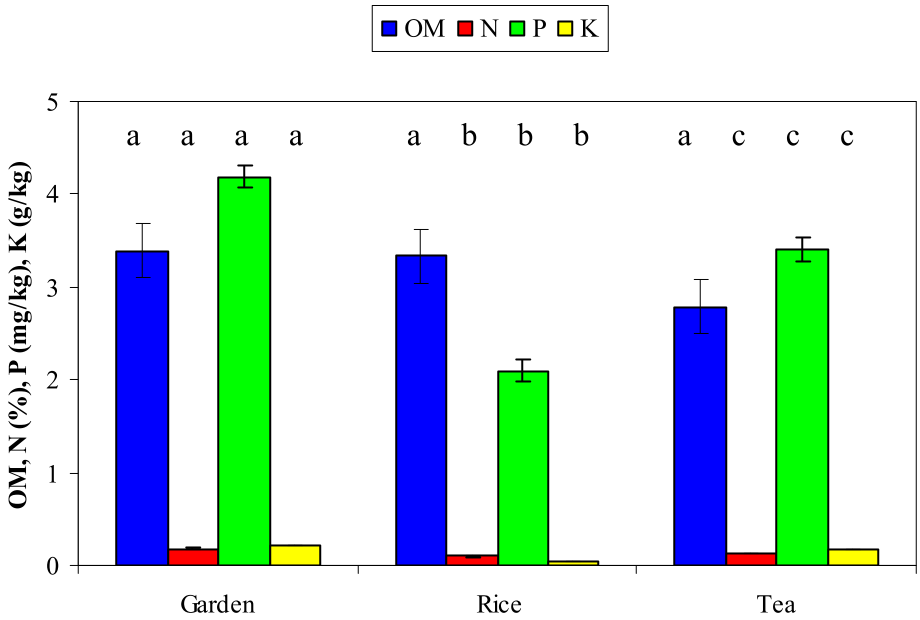
Figure 1 - Geographical location and aerial map (source: Google® Map®) of the study area.


SaC
SiC
CC
SaC, SiC, CC (%)
60
50
40
30
20
10
0
Garden
Rice
Tea

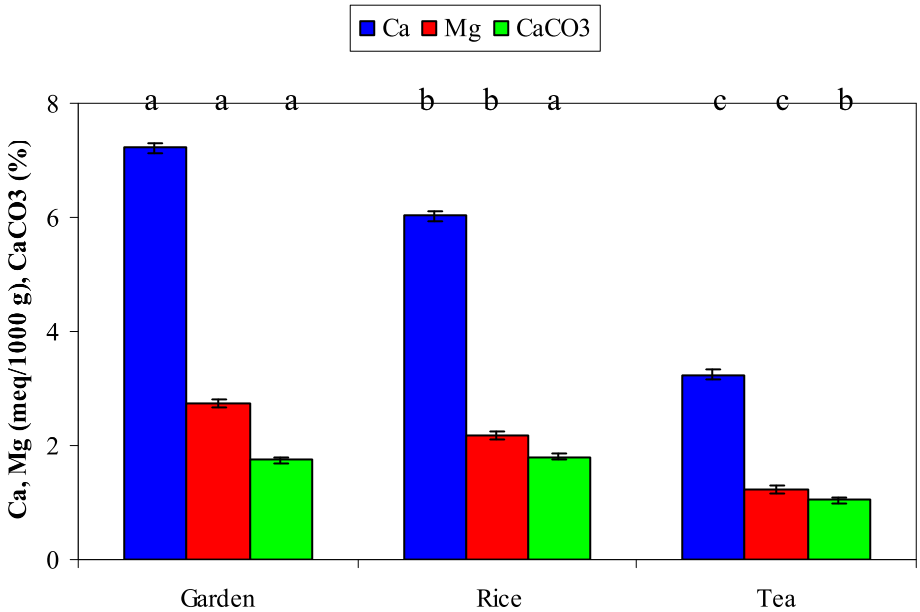
(a)


pH
CEC
a
a
b
b
c
c
pH, CEC (cmol/kg
32
28
24
20
16
12
8
4
0
Garden
Rice
Tea

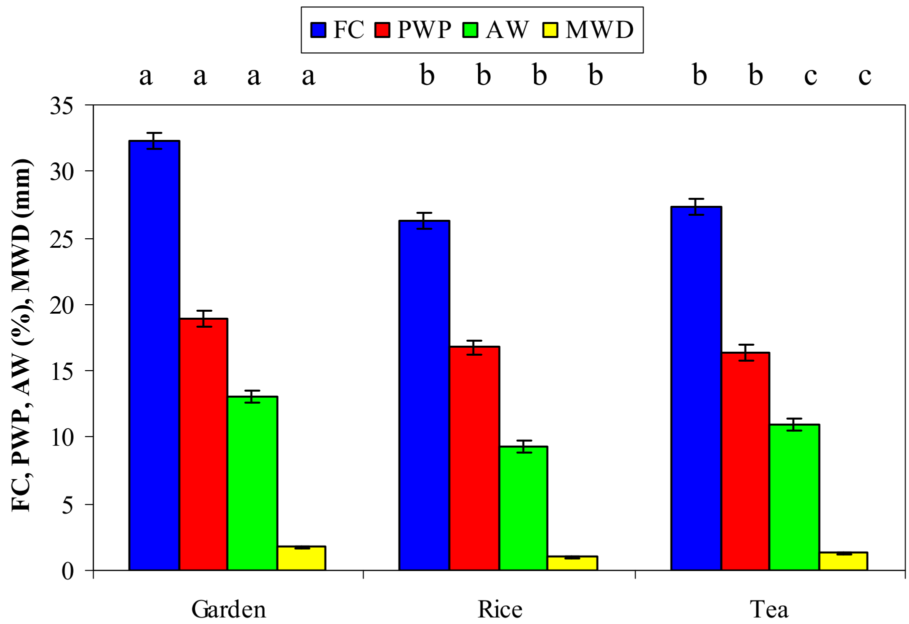
(b)

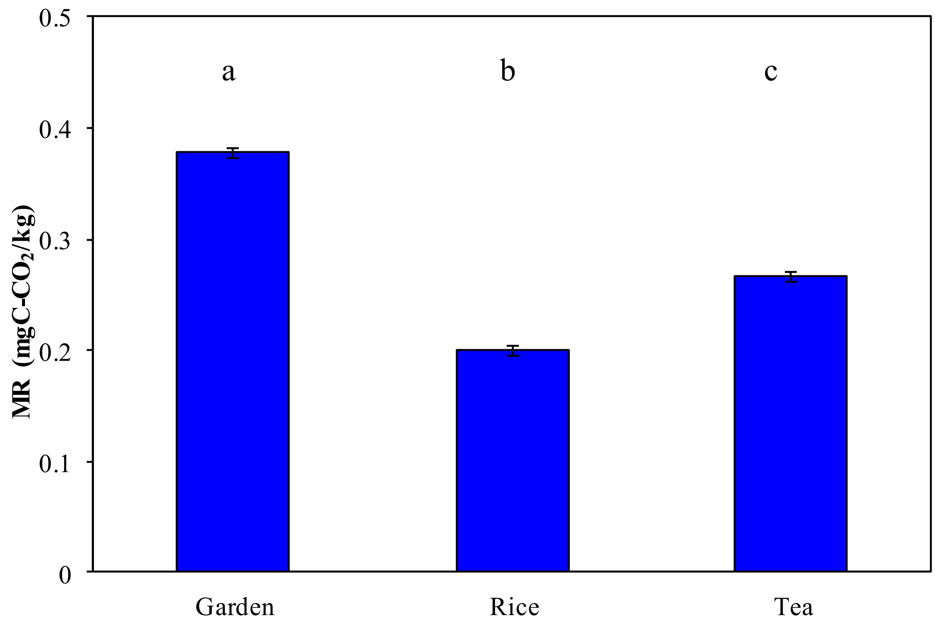

OM N P K
OM, N (%), P (mg/kg), K (g/kg)
0
1
2
3
4
5
a a a a
a b b b
a c c c
Garden
Rice
Tea

(c)


Ca Mg CaCO3
Ca, Mg (meq/1000 g), CaCO3 (%)
0
2
4
6
8
a a a
b b a
c c b
Garden
Rice
Tea

(d)





(e)

(f)

Notes: OM = organic matter; CEC = Cation Exchange Capacity; FC = field capacity; PWP = permanent wilting point; AW = available water; SaC = Sand content; SiC = Silt content; CC = clay content; MWD = medium weight diameter of soil aggregates; MR = microbial respiration.

Figure 2 - Main textural (a), physico-chemical (b, c and d), hydrological (e) and biological indicators for the three land uses (garden, rice and tea) - averaged at two soil depths (0-15 and 15-30 cm) - in the experimental site (Fuman area, Guilan province, Northern Iran)

(mean values ± standard error). Different lowercase letters indicate significant differences ($p < 0.05$).

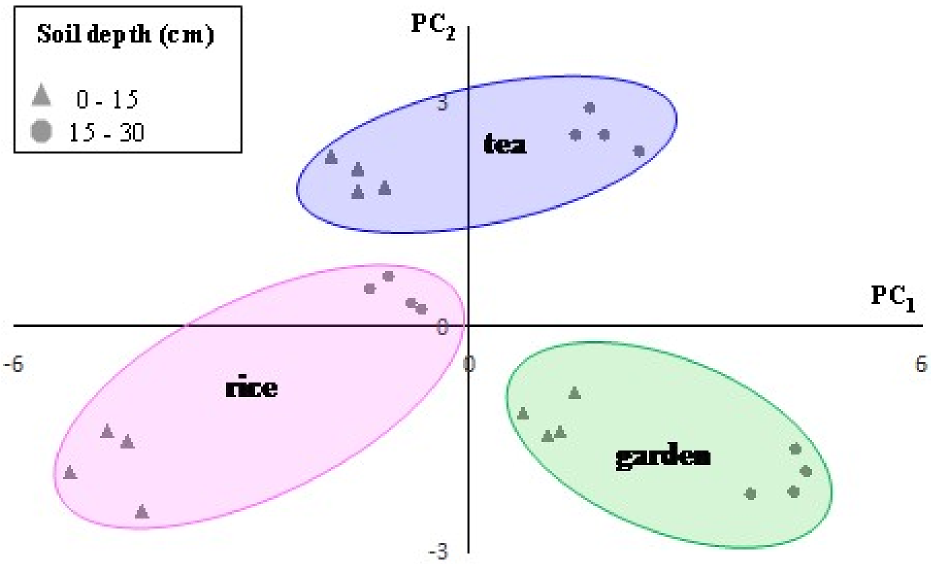


Figure 3 - Scores of the original variables - textural, hydrological, biological and physico-chemical indicators for the three land uses (garden, rice and tea) and two soil depths (0-15 and 15-30 cm) in the experimental site (Fuman area, Guilan province, Northern Iran) - on the first two Principal Components (PC1 and PC2) provided by Principal Component Analysis.