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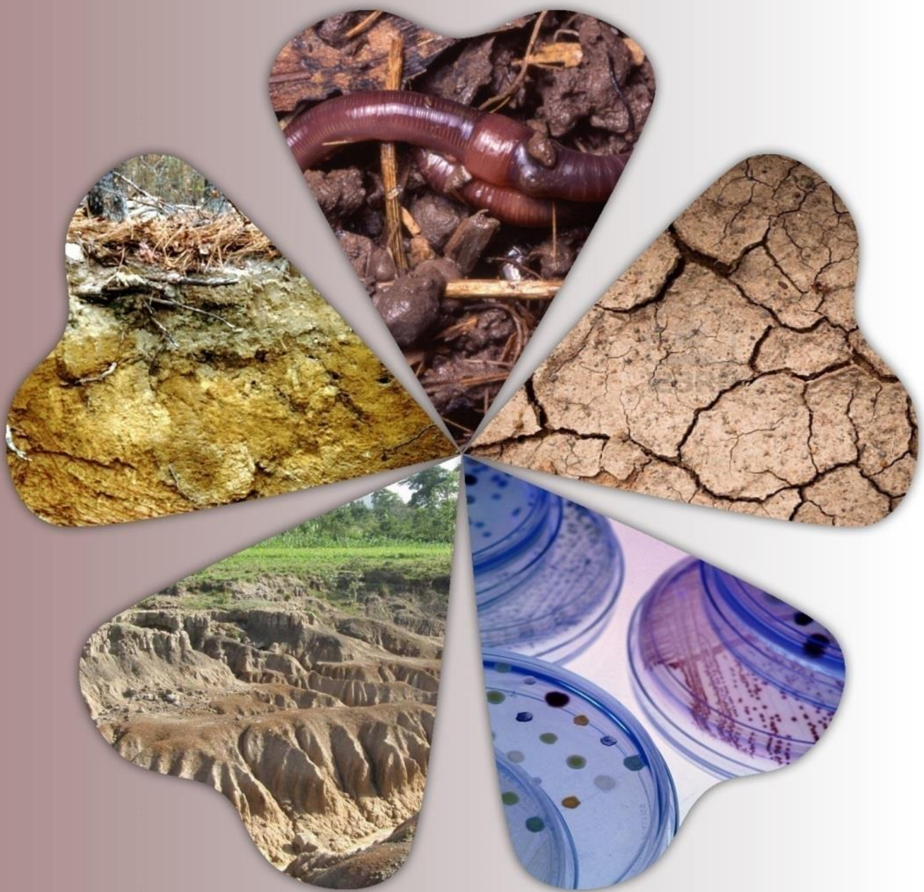

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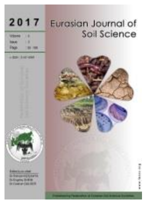

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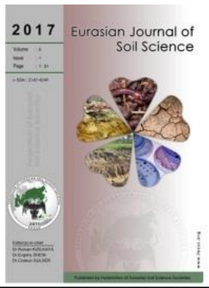

Modelling soil erosion risk in a mountainous watershed of Mid-Himalaya by integrating RUSLE model with GIS

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Abstract

Soil erosion is one of the major cause of land degradation and is a serious threat to food security and agricultural sustainability. Revised Universal Soil Loss equation (RUSLE) model using remote sensing (RS) and Geographical Information Systems (GIS) inputs was employed to estimate soil erosion risk in a watershed of mid-Himalaya in Uttarakhand state, India. Spatial distribution of soil erosion risk area in the watershed was estimated by integrating various RUSLE factors (R, K, LS, C, P) in raster based GIS environment. RUSLE model factor maps were generated using remote sensing satellite data (IRS LISS III and LANDSAT-8) and Digital elevation model. Agriculture (59%) was found to be the dominant land use system followed by scrub land (20%) in the watershed. Rainfall erosivity (R) factor was estimated using past 23 years rainfall data. SRTM DEM was used to generate slope length –steepness (LS) factor in this highly rugged terrain. Nearly 70% of the watershed is having steep to moderately steep slope (>40%). Satellite data was interpreted to prepare physiographic map at 1:50,000 scale. Surface soil samples collected in each physiographic unit was analyzed to generate soil erodibility (K) map. Soil erodibility factor ranged from 0.033 to 0.077 in the watershed. Soil erosion risk analysis showed that 36.25%, 9.31%, 15.80%, 15.27%, 11.46% and 11.89% area of watershed falls under very low, low, moderate, moderate high, high and very high erosion risk classes respectively. The average annual erosion rate was predicted to be 65.84 t/ha/yr. The soil erosion rates were predicted to vary from 3.24 t/ha/yr in dense mixed forest cover to 87.98 t/ha/yr in open scrub land. The soil erosion map thus generated employing remote sensing and GIS techniques, can serve as a tool for deriving strategies for effective planning and implementation of various management and conservation practices for soil and water conservation in the watershed.

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Keywords: Himalaya, watershed, soil erosion, revised universal soil loss equation (RUSLE) model, remote sensing, GIS.

Introduction

According to the United Nations Convention to Combat Desertification (UNCCD) land degradation has been defined as any reduction or loss in the biological or economic productivity of the land brought about by anthropogenic activities, accelerated by natural processes and thereafter magnified by the impact of climate change and biodiversity losses (UNCCD, 1994). So much so is the intensity and problem of land degradation that it has been identified as one of the major global challenges in the path of sustainable development by the world leaders at the Rio+20 conference (Rio+20, 2012). Global assessments about land degradation shows an increase in the highly degraded area from 15% in 1991 to 25% by 2011 and it is predicted that if

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land degradation continue to occur at the current rate over the next 25 years, it would reduce the global food production by 12% (IFPRI, 2012). The entire land degradation process has accelerated during the last century with an estimated loss of 24 million tons of fertile top soil from the agricultural lands across the globe (FAO, 2011). Thus, soil erosion is one of the major causes of land degradation which involves a gradual process of removal of soil particles from land surfaces by runoff, thus, causing deterioration of soil and adversely affecting the productivity of all natural ecosystems including agriculture, forest and rangeland ecosystems (Lal and Stewart, 1990, Pimentel et al., 1995).

In a developing country like India both on and off site damages of soil erosion has far reaching social, political, economic and environmental implications (Pandey et al., 2007) thus posing a serious threat to long term sustainability of agricultural production and environmental quality. In Indian context, the north western Himalayan belt are highly prone to soil erosion, because of the instability due to ongoing tectonic activities (Sati et al., 2011) and in recent times the developmental activities synonymous to the anthropogenic interventions have contributed highly to the instability in the Himalayan region, thereby increasing incidents of erosion and landslides. Soil resource is necessary to maintain the productivity in hilly terrain of Himalaya, where livelihood of people is mainly dependent on farming system and especially on subsistence agriculture. Sustainable use of mountains depends upon conservation and potential use of soil and water resources (Ives and Messerli, 1989). It has been observed that loss of fertile top soil, because of surface and gully erosion, is a common phenomenon and agricultural land has expanded to areas having marginal soil cover (Hofer, 1998). Thus, natural resources in mountainous terrain are profoundly afflicting from land degradation as a result of intensive deforestation, overgrazing and subsistence agriculture due to population pressure, large-scale road construction and mining etc. Garde and Kothyari (1987) reported that the soil erosion rate in the northern Himalayan region is high and in the order of 20 to 25 t/ha/yr. Therefore in Northern Himalayan region advance management procedure to balance soil erosion and soil conservation is extremely necessary. Over the past 40 years, significant concerns have been raised over the degradation of the soil resources in the Himalayan mountainous regions as a result of the expansion of agricultural land and the increase in cropping intensity.

The Himalayan mountains are young and fragile characterized by steep slopes (evolved out of exogenic and endogenic processes and are precariously balanced), low soil depth, poor water holding capacity of the soil due to coarse texture and are highly prone to soil erosion (Sati et al., 2011). In addition high seismicity, depleted forest covers, occasions of climatic extremities like focused rainfall (cloud burst) and pressure of utilizing natural resources beyond the capacity has all led to accelerated erosion problems raising a question on the long term sustainability of mountain ecosystems (Jain et al., 2001). The mid-Himalayan region is the main agricultural zone of Himalayas, which caters to the food production requirements of vast rural population, through the various low input subsistence farming activities and practices. Thus assessment of erosion risk in the mountainous Himalayan region for sustainable growth and development and ecosystem balance is the need of the hour. However, delineation of areas on steep slopes as management units is difficult, thus planning, conservation and management of natural resources on watershed basis becomes more convenient and easier. The concept of using watershed as a development unit in India dates back to 1970s and since then several watershed programs have been launched in the country (Wani and Garg, 2009). The watershed not only serves as hydrological unit but it also acts as a socio-political-ecological unit which plays a very crucial role in determining food, social and economic security and providing life support services to the rural people.

Soil conservation strategies in a watershed are generally planned according to the severity of the problem in that watershed and this severity is determined by considering a number of important factors including annual soil loss, quantitative measure of topsoil etc. Although physical verification of soil loss in thousands of watersheds and micro-watersheds in a river basin was near to impossible task until the recent development in remote sensing and Geographical information system techniques. Soil erosion management strategies in Himalayan mountainous region are also constrained by dearth of such data, because actual measurements of soil loss from crop fields and mountainous regions are uncommon in the country. Reliable and updated information on watershed soil erosion is an essential prerequisite for prioritization of watershed as well as formulation of appropriate management programs, which are key components for sustainable development (Pandey et al., 2007). However, it becomes difficult to measure or predict the erosion in a precise manner due to the complexity of the variables involved in erosional process. The remote sensing data provide accurate, and near real time information on the various aspects of watershed such as land use/land cover, physiography, soil types, drainage characteristics, etc. It also assists in the identification of the existing or potential erosion prone areas and provides data inputs to many of the soil erosion and runoff models.

Rapid and detailed assessment of erosion hazards can be effectively done using Remote sensing data and GIS along with Digital elevation models (DEM) (Jain et al., 2001), by providing valuable inputs to various erosion models like USLE/RUSLE, MMF, WEPP, SWAT, ANSWERS, LISEM etc, which are having their own specific characteristics and application scopes (Boggs et al., 2001; Lim et al., 2005; Dabral et al., 2008; Lu et al., 2004; Tian et al., 2009). GIS compatibility and convenience in application at various scales makes USLE/RUSLE the widely used erosion model to predict soil loss across the globe. (Millward and Mersey, 1999; Jasrotia and Singh, 2006; Bonilla et al., 2010). It predicts spatial extent of soil erosion as well as erosion rates in ungauged watersheds using knowledge of the local hydroclimatic conditions and watershed characteristics (Angima et al., 2003). Jain et al. (2001) estimated soil erosion from a Himalayan watershed by using two different soil erosion models, i.e. the Morgan model and Universal Soil Loss Equation (USLE) model, using remote sensing and GIS generated input parameters. .

The present study envisages the use of RUSLE model for assessment and quantification of annual soil erosion rate and developing soil erosion risk map of a mountainous watershed of river Maniyar in the Himalayan region using RUSLE and GIS technique. This particular area was chosen as it represents various characteristics of a typical mid Himalayan watershed including steep slopes with high slope variation, various LULC patterns and a predominance of agricultural area where low input subsistence farming is practiced. This study may contribute to our knowledge about the various factors affecting soil erosion in these fragile mid-Himalayan ecosystem and help us in adoption of various management strategies efficiently.

Material and Methods

Study area

The study was carried out in Maniyar watershed, which is located near Tehri dam in TehriGarhwal district in Uttarakhand, India (Figure 1).

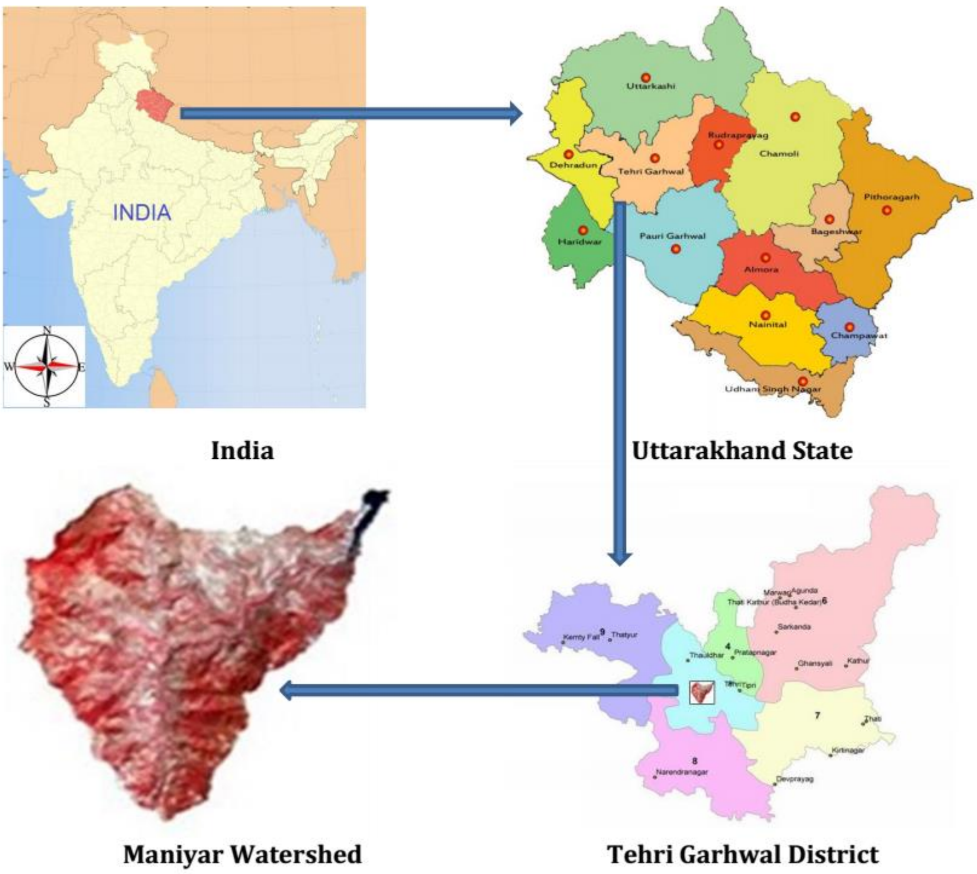

Figure 1. Location of the study area

It covers an area of 4428.5ha (44.29 sq.km) and lies between longitudes 78°28'0"E - 78°21'30"E and latitudes 30°20'0"N - 30°25'30"N. The region is highly undulating and exhibits the typical mountainous topography of North Western Himalayas, with an elevation between 667 to 2459 m above msl. The watershed is characterized by precipitous slopes, deep gorges, narrow valleys and rocky escarpments. The entire watershed consist of high hills and ridges which are deeply incised by the streams. The annual average rainfall is 1400 mm (1990-2013 period data) whereas the average number of rainy days (having daily rainfall >2.5 mm) is 61.5 days. Most parts of the watershed is highly inaccessible due to very steep sloping and rugged terrain. Geologically the area is represented by rocks of lesser as well Central Himalaya and contain mica gneiss, calcic gneiss, quartzite, marble, mica schist and amphibolite as major rock types. Agriculture land is the dominant land use system in the watershed followed by forest and scrub land. Rice, maize, vegetables and wheat are the major crops grown in the watershed.

Data used

Survey of India toposheet covering the study area was used as guide for carrying out field work as well as preparing road network. IRS P6 LISS III image of April and December months were used for accurate preparation of landuse/ land cover map by digitization based on field collected ground control points. SRTM DEM having 30m resolution was used for various hydro processing steps including generation of slope, aspect, flow direction, flow accumulation as well as drainage network maps. The products were used for estimation of LS factor values of the entire watershed. GPS receiver was used for recording the geographical coordinates of the various sampling points during field data collection. The values of various soil parameters, estimated by laboratory analysis of field collected soil samples were also used. The remote sensing as well as other spatial data were processed and analyzed using ERDAS imagine and Arc GIS10.1 softwares.

Methodology

The RUSLE model (Renard et al., 1997) was developed as an empirical model representing the main factors controlling soil erosion, namely climate, soil characteristics, topography, and land cover management. The equation is expressed as:

$$A = R \times K \times LS \times C \times P \quad (1)$$

where,

A = predicted average annual soil loss per unit area [$ton \cdot ha^{-1} \cdot year^{-1}$],

R = rainfall -runoff erosivity factor (rainfall and snowmelt) in [$MJ\ mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}$],

K = soil erodibility factor [$ton \cdot ha \cdot hr \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$],

LS = slope length-steepness factor (dimensionless),

C = cover-management factor (ratio of soil loss from a specified area with specified cover and management to that from the same area in tilled continuous fallow) (dimensionless)

P = conservation support practice factor (dimensionless).

The following section describes deriving of various factors of RUSLE from satellite data, DEM, rainfall data.

Data Processing and RUSLE factor generation

The above mentioned factors were generated using remote sensing as well as field derived information and further integrated in a GIS environment according to the following methodology to estimate soil erosion in the present study (Figure 2). The various RUSLE factor maps were generated in a digital GIS environment using Arc GIS 10.1 and ERDAS Imagine 2014, and the associated GIS packages. These factor maps were integrated employing RUSLE model to compute annual soil erosion rates and its severity.

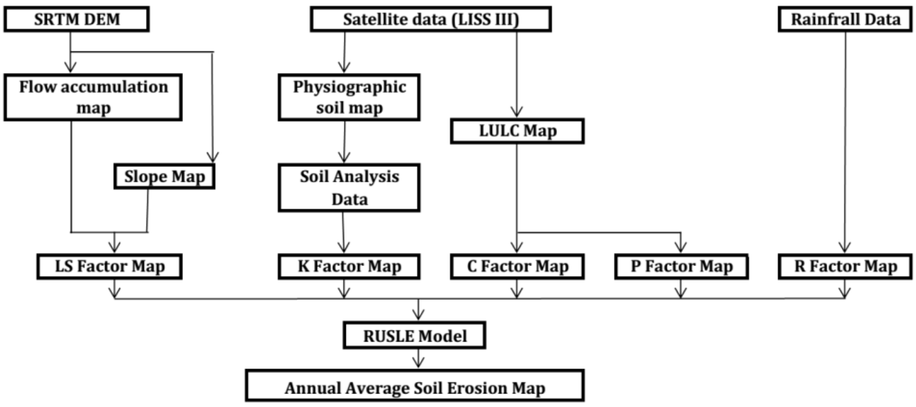

Figure 2. Methodology flow chart adopted in the study

R factor (rainfall erosivity factor)

The R factor is a measure of the erosive force of specific rainfall. It quantitatively expresses the erosivity of local average annual rainfall. R-factor computation requires long-term data of rainfall amounts and intensities. Since rainfall intensity of the study area could not be estimated in the absence of a recording type rain gauge, well established empirical equations using total rainfall (monthly, seasonal or annual) are widely employed. R factor was estimated using the rainfall data of past 23 years (1990-2013) obtained from Ranichauri University near the watershed, using empirical relationship (Babu et al., 2004).

$$R = 81.5+0.375*A \qquad (2)$$

($340 \le A \le 3500$mm), Where, A: Average Annual Rainfall (mm)

K factor (Soil Erodibility factor)

Soil erodibility factor (K) is a quantitative expression of the inherent susceptibility of soil to detachment and transport of soil particles (grains or crumbs), under an amount and rate of runoff for a specific rainfall, measured under standard plot. The erodibility factor depends on physico-chemical properties of texture, organic matter content, permeability of soil and soil structure. Physiographic soil map was generated by interpretation of std. FCC at 1:50000 scale by onscreen digitization. The various physiographic units were delineated based on the landform, slope characteristics and land use land cover types. Filed work was planned in such a way to collect soil samples from each of the physiographic units present in the watershed. The number of samples (3-4 nos) from each unit was determined by the area covered by each unit. The collected soil samples were analyzed in the laboratory for texture, organic matter content and structural characteristics, which are essential for the determination of K factor. The following equation was used to compute K factor (Wischmeier and Smith, 1965; Renard et al., 1997)

$$K = 27.66 * m^{1.14} * 10^{-8} * (12-a) + 0.0043 * (b-2) + 0.0033 * (c-3) \qquad (3)$$

Where:

K = soil erodibility factor (ton .ha. $h.ha^{-1}.MJ^{-1}.mm^{-1}$)
m = (Silt % + Sand %) x (100-clay %)
a = % organic matter
b = structure code: 1) very structured or particulate, 2) fairly structured, 3) slightly structured, 4) solid
c = profile permeability code: 1) rapid, 2) moderate to rapid 3) moderate, 4) moderate to slow, 5) slow 6) very slow

LS factor (Slope length and steepness factor)

The total erosion or sediment yield from a watershed depends not only on slope length but on steepness also. *LS* factor expresses the effect of local topography on soil erosion rate, combining effects of both slope length (L) and slope steepness (S). Various other factors such as compaction, consolidation and disturbance of the soil were also considered in addition to steepness and length while generating the LS-factor. Erosion increases with slope steepness but, in contrast to the L-factor representing the effects of slope length, the RUSLE makes no differentiation between rill and inter-rill erosion in the S-factor that computes the effect of slope steepness on soil loss (Renard et al., 1997; Krishna Bahadur, 2009). SRTM DEM with 30m resolution was used to compute LS factor using the spatial analyst and hydrology toolkits in ArcGIS software, following the method described by Moore and Burch (1986) and Mitasova et al. (1996).

$$LS = (\text{Flow Accumulation*Grid Size}/22.13)^{0.6}\,(\text{Sin[Slope]*}0.01745/0.0896)^{1.3} \qquad (4)$$

Where, flow accumulation denotes the accumulated upslope contributing area for a given cell, Cell size denotes the size of grid cell (30m), Sin of Slope values in degree

C factor (Crop cover factor)

C factor represents the effects of vegetation % and crop types on soil erosion (Renard et al., 1997). Its value ranges from 0 (waterbodies) to 1 (barren land), because of the lack of vegetation, root biomass or other surface covers to resist soil erosion. Thus, it expresses the relation between soil erosion on bare area and erosion observed under a particular cropping system and indicates the role played by cover-type as well as density on soil protection. The C factor thus incorporates the effects of plant cover, level of production as well as the various associated cropping techniques into one single value. In the study, C factor map was generated using the land use/land cover (LULC) map prepared by visual interpretation of satellite data. The boundaries of the various LULC classes was verified and corrected during the field survey. The major crops grown in the study area are rice, maize, wheat, fruit trees and various vegetables. Majority of the study area is dependent on rainfall as sole water source for agricultural activities. Only very less area, near the channels at low elevation have irrigation facilities. Low input subsistence farming using local varieties, traditional farming practices and inputs is practiced in the entire area. The land use/land cover map was reclassified based on C factor values using tools in ArcGIS, which assigned C factor values based on Wischmeir and Smith (1978) as well as previous studies undertaken in similar regions including Himalayas, by various researchers (USDA,1972; Rao, 1981; Suresh Kumar and Kushwaha, 2013).

P factor (Conservation Practice factor)

The P factor represents the effect of various conservation and support practices being taken up in the study area, on soil erosion. The various practices normally reduce the amount and rate of runoff water by influencing drainage patterns, runoff concentration, runoff velocity and hydraulic forces exerted by runoff on soil, eventually reducing soil erosion. It includes the effect of various practices such as contouring, terracing, strip cropping, bunds etc (Hyeon and Julien, 2011). In the study area various management practices like terracing, bunding, grass bunding etc are followed by farmers depending on the slope steepness and resource availability. In this study, P factor map was generated using the land use land cover map by assigning P values for each of the land use land cover types (Wischmeier and Smith, 1978).The map was reclassified based on P factor values using tools in ArcGIS, to yield P factor map in raster form.

All the inputs for RUSLE model execution were generated in GIS platform using remote sensing and field collected information. The various factor maps were generated and converted into raster format keeping uniform projection as well as cell size, to avoid erroneous execution and misinterpretation of results.

Results and Discussion

The various factor maps of RUSLE model (R, K, LS, C and P) generated using remote sensing and GIS inputs were integrated in a GIS environment using ArcGIS spatial analyst module in order to quantify and generate the soil erosion risk and severity maps of Maniyar watershed.

Land Use/Land Cover

Standard FCC of satellite data were visually interpreted for the information regarding land use/land cover type by making use of the interpretation keys. The map was digitized to prepare digital vector coverage and rasterized for spatial GIS analysis. The major types of land use/land cover interpreted were forest, agriculture, scrub land, river and settlement. Forest cover was further classified into dense mixed forest, dense pine forest, and open forest cover. Scrub land was further sub-divided into dense scrub and open scrub (Figure 3). Agriculture (58.9 %) formed the predominant land use/land cover type followed by scrub (23.52%). The major crops grown in the area were wheat, vegetables, mustard, fruit trees etc. Paddy was found to be cultivated in the valley, where irrigation facilities were available. Intensive agricultural practices on the steep sloping lands could be correlated with the enhanced soil erosion of Maniyar watershed. The LULC map was used to derive C and P factor maps (Table 1).

Table 1. Area under various land use/ land cover

Sl No	LULC	Area (sq. km) (%)	C factor	P factor
1	Cropland	26.29 (58.94%)	0.5	0.5
2	Dense mixed forest	1.85 (4.15 %)	0.008	1
3	Dense Pine forest	1.85 (4.15 %)	0.08	1
4	Open forest	2.64 (5.92 %)	0.4	1
5	Dense scrub	8.77 (19.66 %)	0.05	1
6	Open scrub	1.72 (3.86 %)	0.6	1
7	Settlement	0.16 (0.36 %)	1.0	0.0
8	River	1.32 (2.96 %)	0.0	1.0

Slope characteristics

The elevation of the watershed varied from 667 metres to 2459 metres above the mean sea level (Figure 4). The extracted DEM was used for generation of slope map (Figure 5). The entire watershed study area was classified into five different slope classes (Table 2), ranging from 0% to more than 60%. The slope analysis revealed that nearly 70% of land under study area is having slope more than 40% and nearly 90% of area is having slope more than 25%. Such degree of steepness in the slope is conducive to very high rates of soil erosion, even with slight or moderate amount of rainfall and soil disturbance. Also, higher slope accounts for very shallow soil depth, which limits crop cover establishment, which in turn is responsible for protecting the soil surface from erosive factors. Slope aspect map was also generated for the area (Figure 6). The entire study area was grouped into two aspects i.e., north and south aspects. This is important from plant growth point of view, as the aspect (direction) determines the amount of solar radiation received on soil surface and thus, the soil temperature and moisture available for plant growth and soil development.

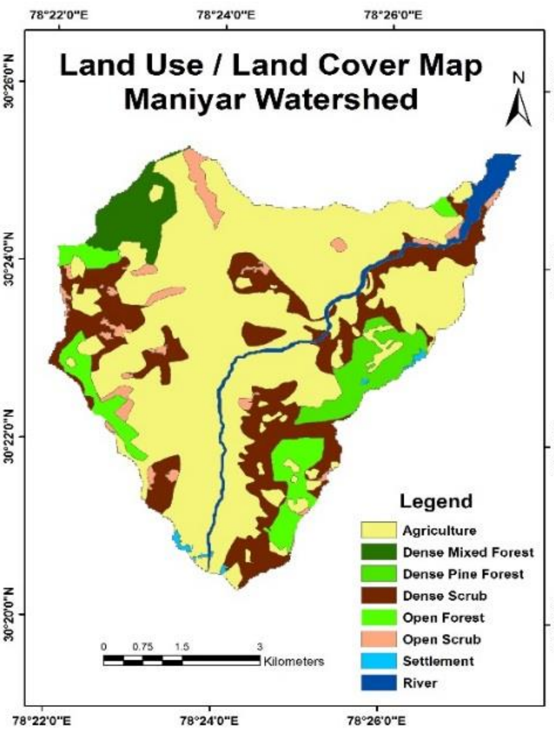

Figure 3. Land use Land cover map

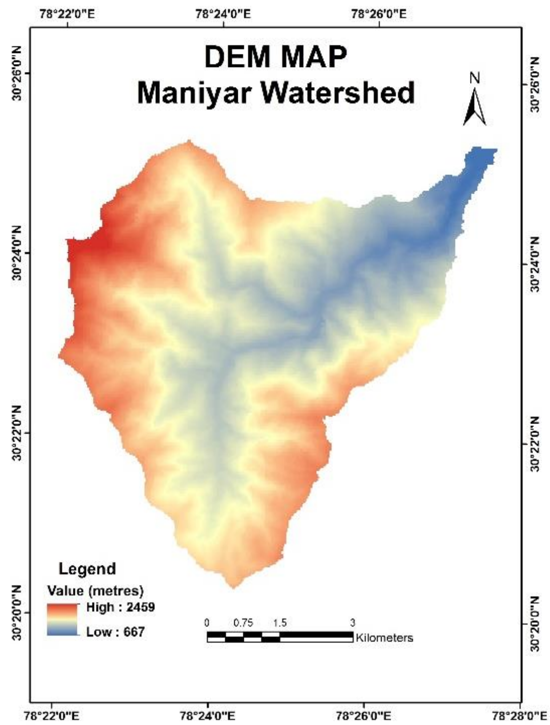

Figure 4. DEM of study area

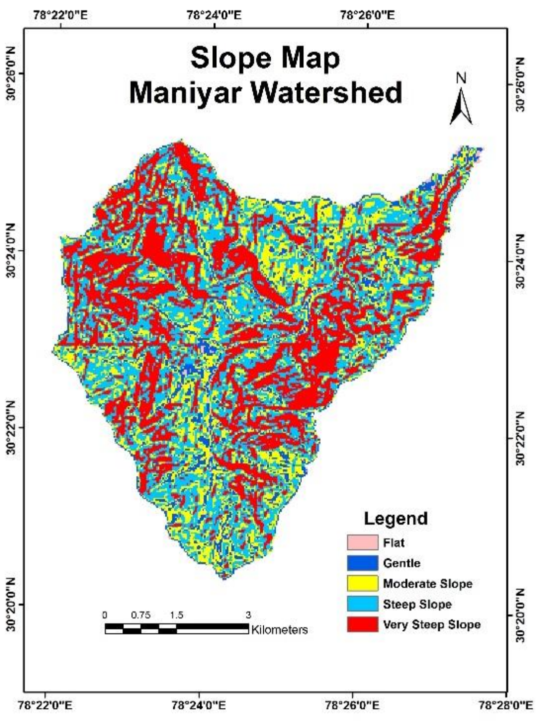

Figure 5. Slope map of study area

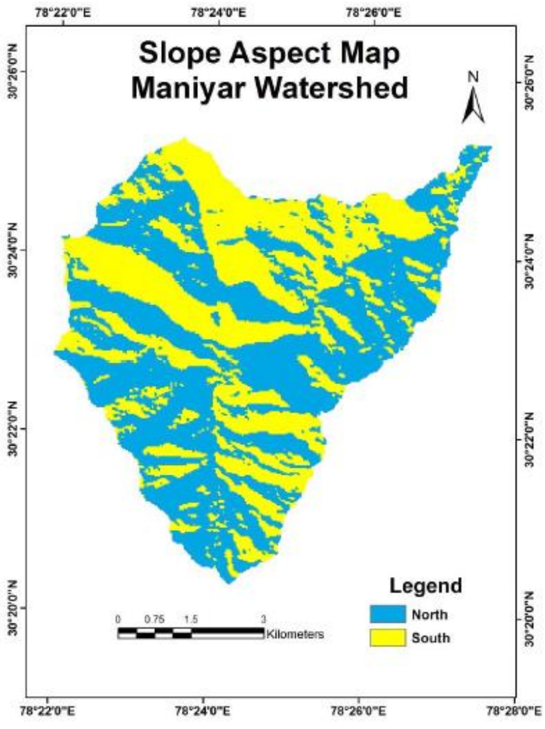

Figure 6. Slope Aspect map of study area

Table 2. Slope classes and distribution in the study area

Slope class	Slope values (%)	Area (sq.km)	% of Total area
Flat	0-10	0.48	1.01
Gentle	10-25	3.53	7.97
Moderate	25-40	9.36	21.13
Steep	40-60	16.15	36.47
Very steep	>60	14.77	33.34

Physiographic soil map

The physiographic soil map was prepared by visual interpretation of satellite imagery and with the help of slope map, aspect map and land cover land use map. Based on the landform, slope characteristics and land use / land cover pattern the study area was divided into 15 physiographic units excluding river (Figure 7). The major landform present in the study area is hills. The hilly landform was again divided based on variation in slope characteristics and aspect. The land use/land cover types present in various slope and aspect categories of hilly landform was considered for classification of area into 15 different physiographic units (Table 3). These physiographic units form the basis of soil sampling. It is the study of the factors and process of the landform evolution as the factors involved in physiographic processes are mostly the same as those influencing soil formations.

Table 3. Areal distribution of various physiographic units

Physiographic Unit	Area (sq.km)	Area (%)	K factor
Very steep hill-North-Forest (H111)	2.21	5.14	0.038
Very steep hill-South-Forest (H121)	7.03	16.36	0.045
Very steep hill-North-Agriculture (H112)	4.09	9.52	0.036
Very steep hill-South-Agriculture (H122)	1.08	2.513	0.065
Very steep hill-North-Scrub (H113)	2.09	4.86	0.044
Very steep hill-South-Scrub (H123)	4.01	9.33	0.077
Steep hill-North-Forest (H211)	2.11	4.91	0.058
Steep hill-South-Forest (H221)	0.69	1.61	0.055
Steep hill-North-Agriculture (H212)	5.97	13.89	0.076
Steep hill-South-Agriculture (H222)	6.20	14.43	0.051
Steep hill-North-Scrub (H213)	1.25	2.91	0.033
Steep hill-South-Scrub (H223)	0.35	0.81	0.050
Moderate hill-North-Agriculture (H312)	2.07	4.82	0.066
Moderate hill-South-Agriculture (H322)	1.79	4.17	0.061
Valley-Agriculture (V-Agri)	2.03	4.72	0.058

R factor

R factor was generated using 23 years rainfall data, employing the relationship given by Babu et al. 2004. The R factor value was estimated to be 606.5 MJ mm $ha^{-1}h^{-1}$ and as we had a single value no map was generated and was used as value along with other factors. As the study area doesn't have any record of daily rainfall intensity and since the area of watershed was only 44.29 sq km, a single R factor value was assumed for the whole area.. Similar R factor values have been estimated in various studies in India as well as abroad. The R factor value for Daltonganj watershed in Jharkhand was estimated to be 114.3 MJ mm $ha^{-1}h^{-1}$ (Tirkey et al., 2013). Similarly in a study carried out in Shivalik Himalayan region, Suresh Kumar and Kushwaha (2013) has reported a value of 383 MJ mm $ha^{-1}h^{-1}$, where the rainfall amount is less. Similar R factor values were also reported by Farhan et al. (2013) from a study undertaken in Jordan, Prasannakumar et al. (2012) from Western Ghats region, from Krishnagiri watershed region of Tamilnadu by Elangovan and Seetharaman (2011). Singh et al. (1981) has reported that the value of *R* factor ranges from about 250 – 1250 MJ mm $ha^{-1}h^{-1}$ in western Rajasthan and coasts of Maharashtra and Karnataka, respectively.

K factor

K factor values were estimated using the soil information generated from laboratory analysis of soil samples from various physiographic units.. Soil parameters used for K factor are soil texture (% of sand, silt and clay), soil organic matter, soil permeability class and soil structure class. K value of soils in the watershed varied from 0.033 to 0.077 (Table 3). The organic matter and soil texture were found to have high influence on K factor values. Waterbody as well as settlement were assigned K factor value equal to zero. The calculated K factor values were assigned to various physiographic units and reclassified to yield a K factor map depicting the spatial distribution of K factor values (Figure 8). Similar K factor values were reported earlier by Farhan et al. (2013) in an extensive study carried out in Kufranja watershed, Northern Jordan and by Ashiagbor et al. (2013) from a study in Ghana.

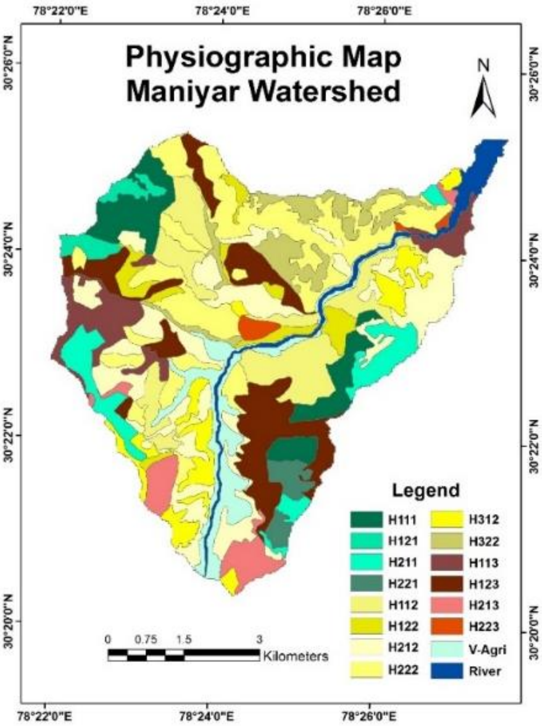

Figure 7. Physiographic map of study area

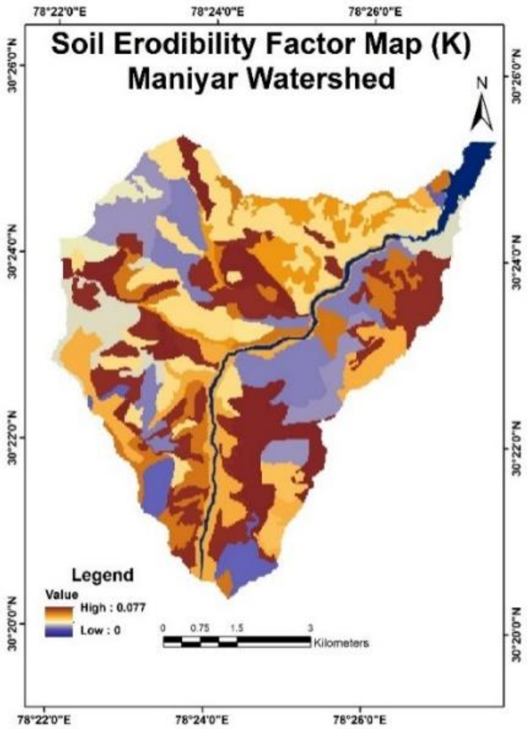

Figure 8. Spatial distribution of K factor

LS factor

LS factor map was created using the flow accumulation and slope maps generated by DEM analysis. LS factor values ranged from 0 (low) to 556.2 (high) in the watershed (Figure 9), with mean and standard deviation of 15.28 and 34.61 respectively. Majority of the study area had LS values less than 30 and only some areas near streams exhibited values more than 50. The high values may be due to the highly dissected terrain and abrupt slope changes near the drainage channels. Similar LS values have already been reported by various researchers in various regions and landscapes including mountainous sub watershed in western Ghats of Kerala (Prasannakumar et al., 2012), Densu river basin of Ghana (Ashiagbor et al., 2013), Kufranja watershed of Jordan (Farhan et al., 2013), Loess Plateau in north China (Sun et al., 2014) and Pathri Rao sub watershed in Shivalik region of Uttarakhand, India (Suresh Kumar and Kushwaha, 2013). All these studies unanimously agreed that higher LS factor values are observed in hilly and gully regions as well as mountainous areas with very steep topography and these areas are prone to sever erosion, due to topography. The unexpectedly high LS values observed in and near channels were excluded form RUSLE estimation, by using a stream network mask. Thus the impact of very high LS values on soil erosion estimation was reduced to the possible minimum to avoid abnormal results.

C factor

The C factor values of the watershed ranged from 0.008 to 0.6 (Table 1). Spatial distribution of crop cover factor is given in Figure 10. They were assigned based on land use land cover map and values obtained mainly from various studies. The values ranged from 0.008 in dense mixed forest to 0.6 in case of open scrub. Higher values of C factor indicate no cover effect and soil loss comparable to that from bare soil, while lower C means a very good vegetation cover effect and less soil loss comparable to bare soil and hence less or negligible erosion.. So in Maniyar watershed open scrub is highly prone to erosion whereas the various forest types are least prone to erosion. The scrub was also found to have low NDVI values, indicating very less crop cover on ground in comparison to other classes. Similar C factor values were used in various erosion studies by earlier researchers (USDA, 1972; Tirkey et al., 2013).

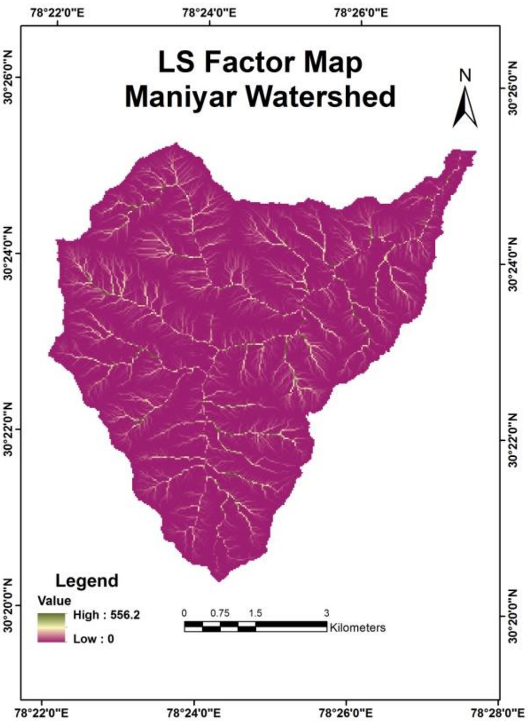

Figure 9. Spatial distribution of LS factor

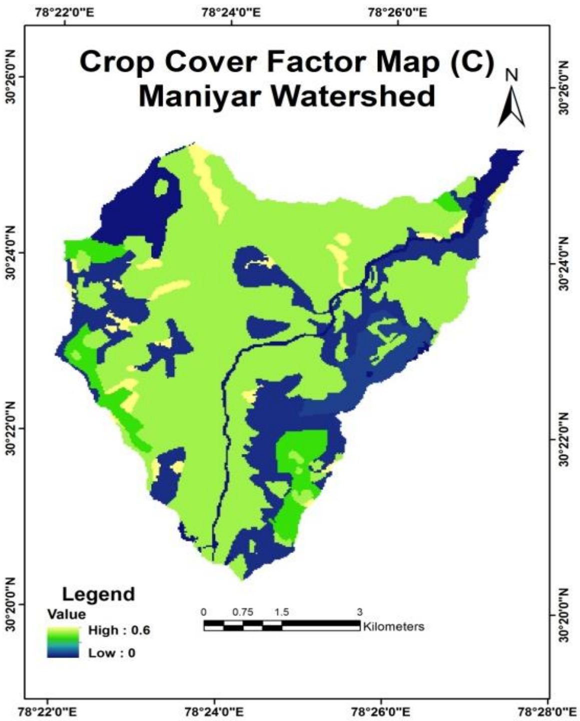

Figure 10. Spatial distribution of crop cover management (C) factor

P factor

Erosion control practice factor was derived based on the land use land cover map of the study area. The values were assigned from previous studies conducted in similar areas (Suresh Kumar and Kushwaha, 2013; Tirkey et al., 2013 and Sun et al., 2014). P factor values ranged from 0.5 to 1 in the study area (Table 1). Majority of the study area is under forest as well as scrub, and there is no control practices adopted in these land uses, giving them a P factor value of 1.0, whereas the agricultural lands having some conservation practices like bunding, terracing etc are having lower P factor value of 0.5 (Figure 11).

Soil erosion Risk Assessment

After preparation of all the RUSLE factor maps, they were overlaid using raster calculator in GIS environment to obtain the average annual soil erosion (A) map with values ranging from 0 to 1961 t/ha/yr, in the entire study area. The average annual soil loss in the watershed was found to be 65.84 t/ha/yr. The higher estimated A values indicate higher rate of sediment yield compared to the lower sediment yield rates associated with lower A values. Soil erosion was classified into six soil erosion risk classes (Figure 12) of very low (0-10 t/ha/yr), low (10-25 t/ha/yr), moderate (25-50 t/ha/yr), moderate high (50-100 t/ha/yr), high (100-200 t/ha/yr), very high (>200 t/ha/yr). The spatial distribution of soil erosion risk classes in the study revealed that 36.25% of the watershed has very low erosion, 9.31 % has low, 15.8 % has moderate, 15.27% has moderate high, 11.46% has high and 11.89% area is under very high erosion risk class (Table 4).

Table 4. Areal extent of soil erosion risk classes

Soil erosion classes	Soil loss (tons/ha/yr)	Area (sq.km)	Area (%)
Very low	0-10	15.75	36.25
Low	10-25	4.04	9.31
Moderate	25-50	6.86	15.80
Moderate High	50-100	6.63	15.27
High	100-200	4.98	11.46
Very High	>200	5.16	11.89

Results indicated that higher values of soil erosion are mainly observed on abrupt slopes neighboring the drainage lines, including streams and river. This may be due to the higher availability of weathered materials for the runoff to carry. The higher slope regions are also affected by rills, gullies as well as mass movement of sediments, which were clearly visible during field surveys and is a common phenomenon in the study area because of the fragile geomorphology. Average soil erosion rate per LULC class was also estimated (Figure 13) and it was found that dense mixed forest is having least erosion rates (3.24 t/ha/yr), whereas highest erosion rates are found in open scrub with a value of 87.98 t/ha/yr. The total amount of soil eroded will be highest from agricultural fields as they cover nearly 60% of study area and most of the cropped areas are rainfed.

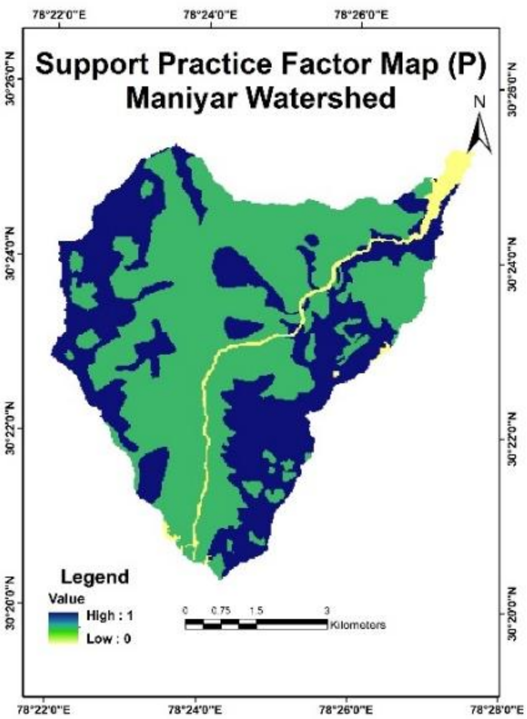

Figure 11. Spatial distribution of P factor

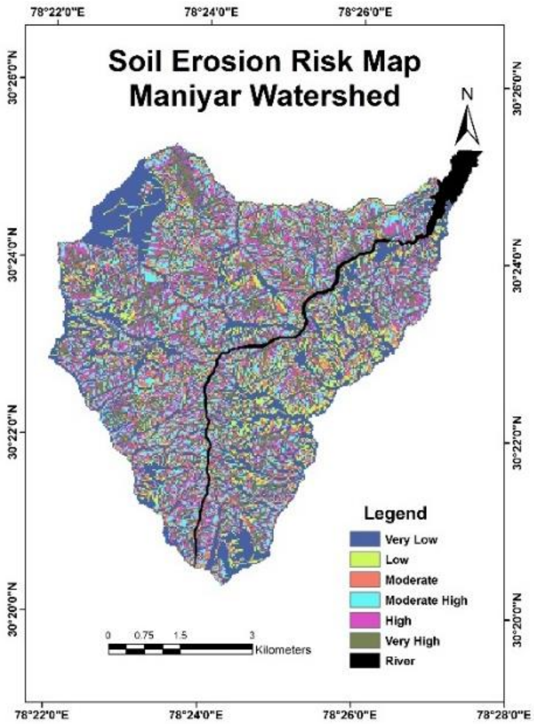

Figure 12. Soil erosion risk map of area

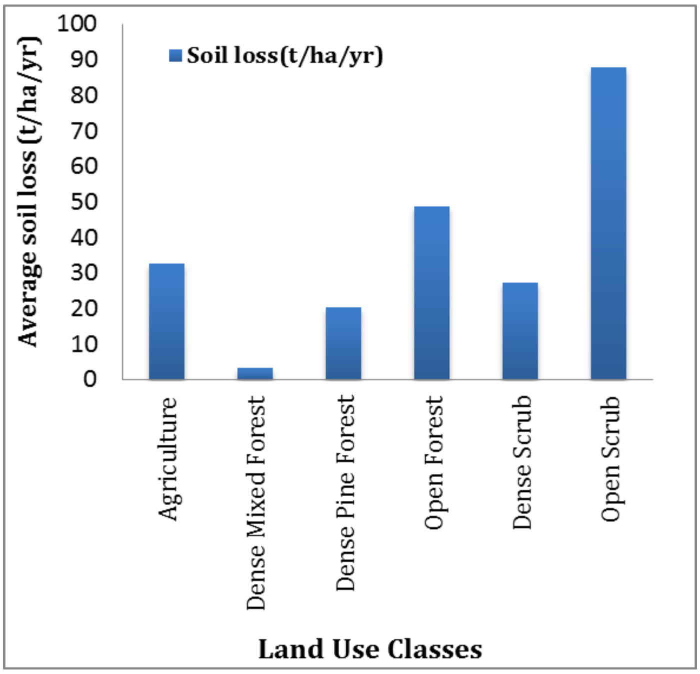

Figure 13. Average soil loss under various land use systems

The results are comparable with other studies undertaken in areas where similar terrain, soil, climatic characteristics as well as land use patterns prevail (Shiono et al., 2002; Lee and Lee, 2006; Adediji et al., 2010), where annual average erosion rates were found to be 0-45 t/ha/yr. Haile and Fetene (2011) reported maximum erosion rates of 50-60 t/ha/yr in upland regions of Kilie catchment in Ethiopia, where slope gradient is 8-13^0. A similar study conducted by Dabral et al. (2008) in Dikrong river basin of Arunachal Pradesh for 17 years using USLE model has indicated average annual soil losses upto 51 t/ha/yr.

They also reported that 25.61% of total area is under slight erosion, whereas 26.51, 17.87, 13.74, 2.39 and 13.88 percentages of area were under moderate, high, very high, severe and very severe erosion potential zones. In another significant study carried out in Pathri Rao sub-watershed in the Shivalik region of Himalayas, using RUSLE 3D and GIS techniques Suresh Kumar and Kushwaha (2013) has predicted average annual soil erosion rates to be 35.47 t/ha/yr. Their results also indicated that lowest erosion rates (8.50 t/ha/yr) are in areas of very dense forest cover, whereas the lowest rates (134.9 t/ha/yr) are associated with open forest area in the steep slopes of hilly terrain. Another study conducted by Poreba and Prokop (2011) in the hilly mountain terrain of Meghalaya, using Cs^{137} technique has given annual erosion values ranging from 29 to 79 t/ha/yr. Similarly, the average soil erosion rates of India have been estimated as 0.5 - 5 t/ha/yr for areas under natural vegetation, 0.3-40 t/ha/yr for cultivated lands and range of 10-185 t/ha/yr in case of bare soil regions (Singh et al., 1981; Morgan, 2005). Increase in agricultural activities on moderate and steep slopes has accelerated the erosion process. The expansion of agricultural activities in the fragile moderate and steep slopes of study area along with poor adoption of soil conservation measures accelerated the soil erosion rates and will ultimately result in decline of soil quality and fertility status

From the study it is quite evident that majority of the area (63%) have soil erosion rates above 10 t/ha/yr, which is a matter of grave concern from natural resource conservation and agricultural production point of view. Many reasons can be pointed out for these higher rates including increased agricultural activities, poor adoption of soil and water conservation measures, high intensity rainfall, less vegetative cover on surface, fragile slopes etc. These high rates of erosion if left unattended will result in soil degradation rendering the agricultural areas unsuitable for cultivation thus, ultimately leading to reduced productivity in the region. Also, the high sediment load emanating from the study area may pose a serious threat to the nearby dam reservoir, if continued without any check. The various RUSLE factors like LS, C and P, can be modified significantly by human beings for controlling erosion rates. The C and P factors can be modified through various measures like afforestation, adopting various cropping patterns and sequences suitable for the particular area, management practices like "terracing" bunding etc. LS factor, most sensitive for soil erosion can also be modified by reducing the slope length as well as slope steepness, by breaking the slope by means of construction of contour walls, bench terraces, check dams in gullies etc. Adoption of various soil and water conservation measures as well as strategies, which are very crucial for controlling runoff and erosion should be done in various land use systems in the area, after a thorough analysis of their respective topographical, soil as well as land characteristics.

Conclusion

The present study was aimed to quantitatively assess soil erosion rates in Maniyar watershed in the Himalayas using RUSLE model in a GIS environment considering various datasets like rainfall, vegetation cover, soil as well as topographic characteristics. The study revealed that nearly 70% of area is having slope more than 40%, which has a positive impact on erosion rates. The average annual soil erosion rate of Maniyar watershed was found to be quite high, with a value of 65.84 t/ha/yr. The entire area was divided into six erosion risk classes, ranging from 0 to 1961 t/ha/yr. Erosion rates greater than 10 t/ha/yr was observed in nearly 63% of watershed, which necessitates immediate intervention for conservation approaches. The maximum area contributing to soil erosion is under agriculture, which are mainly rainfed. High intensity rainfalls, high LS factor due to terrain characteristics, increased human interventions as well as low vegetative coverage on ground can be identified as the major causes of high erosion rates. The computed erosion rates were found to be comparable with reported works in other areas of Himalayan region, and elsewhere, thus validating RUSLE model. This study calls for immediate adoption of various soil and water conservation measures in the watershed, on a high risk priority basis. The use of remote sensing and GIS inputs has enabled us to study and understand the erosion scenario in this hilly mountainous watershed, where traditional soil erosion studies stands no chance due to rugged terrain and inaccessibility of many areas which makes ground data collection very difficult. While this study using remote sensing and GIS enabled us to identify high erosion risk zones, the prediction accuracy and capability of model can be improved further by providing more micro-scale rainfall data as well as C factor values using NDVI. This study reveals that RUSLE model along with remote sensing and GIS inputs can be a powerful tool for assessing soil erosion risk and thus for effective adoption of conservation and management strategies, in various hilly mountainous watersheds. This type of studies helps us to identify high erosion prone areas within a particular watershed or small study area, and to prioritize planning as well as implementation of soil and water conservation measures at those areas.

References

Adediji, A., Tukur, A.M., Adepoju, K.A., 2010. Assessment of Revised Universal Soil Loss Equation (RUSLE) in Katsina area, Katsina state of Nigeria using remote sensing (RS) and Geographic Information System (GIS). *Iranica Journal of Energy & Environment* 1(3): 255-264.

Angima, S.D., Stott, D.E., O'Neill, M.K., Ong, C.K., Weesies, G.A., 2003. Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment* 97(1-3): 295-308.

Ashiagbor, G., Forkuo, E.K., Laari, P., Aabeyir, R., 2013. Modeling soil erosion using RUSLE and GIS tools. *International Journal of Remote Sensing & Geoscience* 2(4): 1-17.

Babu, R., Dhyani, B.L., Kumar, N., 2004. Assessment of erodibility status and refined Iso- Erodent Map of India. *Indian Journal of Soil Conservation* 32(2): 171–177.

Boggs, G., Devonport, C., Evans, K., Puig, P., 2001. GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. *Land Degradation and Development* 12(5): 417-434.

Bonilla, C.A., Reyes, J.L., Magri, A., 2010. Water erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, central Chile. *Chilean Journal of Agricultural Research* 70(1): 159-169.

Dabral, P.P., Baithuri, N., Pandey, A., 2008. Soil erosion assessment in a hilly catchment of north eastern India using USLE, GIS and Remote Sensing. *Water Resources Management* 22(12): 1783–1798.

Elangovan, A.B., Seetharaman, R., 2011. Estimating Rainfall Erosivity of the Revised Universal Soil Loss Equation from daily rainfall depth in Krishanagiri Watershed region of Tamil Nadu, India. International Conference on Environmental and Computer Science IPCBEE, IACSIT Press, Vol. 19. Singapore.

FAO. 2011. The state of the world's land and water resources for food and agriculture (SOLAW) - Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome, Italy.

Farhan, Y., Zregat, D., Farhan, I., 2013. Spatial Estimation of Soil Erosion Risk Using RUSLE Approach, RS, and GIS Techniques: A Case Study of Kufranja Watershed, Northern Jordan. *Journal of Water Resource and Protection* 5(12): 1247-1261.

Garde, R. J., Kothyari, U.C., 1987. Sediment yield estimation. *Journal Irrigation and Power (India)* 44(3): 97-123.

Haile, G.W., Fetene, M., 2011. Assessment of soil erosion hazard in Kilie catchment, East Shoa, Ethiopia. *Land Degradation and Development* 23(3): 293-306.

Hofer, T., 1998. Do land use changes in the Himalayas affect downstream flooding? Traditional understanding and new evidences. *Memoir Geological society of India* 19: 119-141.

Hyeon, S.K., Julien, P.Y., 2006. Soil erosion modeling using RUSLE and GIS on the IMHA watershed. *Water Engineering Research* 7 (1): 29-41

IFPRI,. 2012. 2011 Global Food Policy Report. International Food Policy Research Institute, Washington, DC. USA. Available at: http://www.ifpri.org/cdmref/p15738coll2/id/126897/filename/127108.pdf [access date: 05.08.2016]

Ives, J.D., Messerli, B., 1989. The Himalayan Dilemma- reconciling development and conservation. United Nations University, Routledge, New York, USA.

Jain, S.K., Kumar, S., Varghese, J., 2001. Estimation of soil erosion for a Himalayan watershed using GIS technique. *Water Resources Management* 15(1): 41-54.

Jasrotia, A.S., Singh, R., 2006. Modeling runoff and soil erosion in a catchment area, using the GIS, in the Himalayan region, India. *Environmental Geology* 51(1): 29-37.

Krishna Bahadur, K.C., 2009. Mapping soil erosion susceptibility using remote sensing and GIS: a case of the Upper Nam Wa Watershed, Nan Province, Thailand. *Environmental Geology* 57(3): 695-705.

Kumar, S., Kushwaha, S.P.S., 2013. Modelling soil erosion risk based on RUSLE-3D using GIS in a Shivalik sub-watershed. *Journal of Earth System Science* 122 (2): 389–398.

Lal, R., Stewart, B.A., 1990. Advances in Soil Science. Vol. 11, Soil Degradation. Springer Verlag, New York, USA. 345p.

Lee, G.S., Lee, K.H., 2006. Scaling effect for estimating soil loss in the RUSLE model using remotely sensed geospatial data in Korea. *Hydrology and Earth System Sciences Discussions* 3: 135-157.

Lim, K.J., Sagong, M., Engel, B.A., Tang, Z., Choi, J., Kim, K.S., 2005. GIS based sediment assessment tool. *Catena* 64(1): 61–80.

Lu, D., Li, G., Valladares, G. S., Batistella, M., 2004. Mapping soil erosion risk in Rondônia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degradation & Development* 15 (5): 499-512.

Millward, A.A., Mersey, J.E., 1999. Adapting the RUSLE to model soil erosion potential in mountainous tropical watershed. *Catena* 38 (2): 109-129.

Mitasova, H., Hofierka, J., Zlocha, M., Iverson, L.R., 1996. Modeling topographic potential for erosion and deposition using GIS. *International Journal of Geographical Information Systems* 10(5): 629-641.

Moore, I.D., Burch, G.J., 1986. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal* 50(5): 1294–1298.

Morgan, R.P.C., 2005. Soil Erosion and Conservation, 3rd Edition. Blackwell Publishing, Malden, USA. 303p.

Pandey, A., Chowdary, V.M., Mai, B.C., 2007. Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. *Water Resources Management* 21(4): 729- 746.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., Mcnair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267 (5201): 1117-1123.

Poreba, G.J., Prokop, P., 2011. Estimation of soil erosion on cultivated fields on the hilly Meghalaya plateau, north-east India. *Geochronometria* 38 (1): 77-84.

Prasannakumar, V H. Vijith, S. Abinod, N. Geetha., 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers* 3(2): 209-215.

Rao, Y.P., 1981. Evaluation of cropping management factor in universal soil loss equation under natural rainfall condition of Kharagpur, India. In: Proceedings of Southeast Asian regional symposium on problems of soil erosion and sedimentation, Asian Institute of Technology, Bangkok, p. 241-254.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. .Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). U.S. Department of Agriculture, Agricultural Research Service, Agriculture Handbook No. 703, Washington DC, USA. 384p.

Rio+20, 2012. Report of the United Nations Conference on Sustainable Development. Rio de Janeiro, Brazil 20–22 June 2012

Sati, S.P., Sundriyal, Y.P., Naresh, R., Surekha, D., 2011. Recent landslides in Uttarakhand: nature's fury or human folly. *Current Science* 100 (11): 1617-1620.

Shiono, T., Kamimura, K., Okushima, S., Fukumoto, M., 2002. Soil loss estimation on a local scale for soil conservation planning. *Japan Agricultural Research Quarterly* 36(3): 157-161.

Singh, G., Chandra, S., Babu, R., 1981. Soil loss and prediction research in India. Central Soil and Water Conservation Research and Training Institute, Bulletin No.T-12/D9, Dehra Dun.

Sun, W., Shao, Q., Liu, J., Zhai, J., 2014. Assessing the effects of land use and topography on soil erosion on the Loess Plateau in China. *Catena* 121: 151-163.

Tian, Y.C., Zhou, Y.M., Wu, B.F., Zhou, W.F., 2009. Risk assessment of water soil erosion in upper basin of Miyun Reservoir, Beijing, China. *Environonment Geology* 57(4): 937–942.

Tirkey, A.S., Pandey, A.C., Nathawat, M.S., 2013. Use of satellite data, GIS and RUSLE for estimation of average annual soil loss in Daltonganj watershed of Jharkhand (India). *Journal of Remote Sensing Technology* 1(1): 20-30.

UNCCD. 1994. Elaboration of an International convention to combat desertification in countries experiencing serious drought and/or desertification, particularly in Africa. United Nations, General Assembly. A/AC.241/27 12 September 1994, Article 2. Available at: http:// www.unccd.int/Lists/SiteDocumentLibrary/conventionText/conv-eng.pdf [access date: 05.08.2016]

USDA-SCS , 1972. National Engineering Handbook, Section 4, Hydrology Chapter 21. Design Hydrographs. US Department of Agriculture, Washington DC, USA. Available at: http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18393.wba [access date: 05.08.2016]

Wani, S.P., Garg, K,K., 2009. Watershed management concept and principles. Available at: http://oar.icrisat.org/3914/1/1._Watershed_Management_Concept.pdf [access date: 05.08.2016]

Wischmeier, W.H., Smith, D.D., 1965. Predicting rainfall-erosion losses from cropland east of the rocky mountains: Guide for selection of practices for soil and water conservation. U.S. Department of Agriculture, Agricultural Research Service, Issue 282 of Agriculture Handbook. Washington DC, USA. p. 47.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses: A guide to conservation planning. U.S. Department of Agriculture, Agricultural Research Service, Issue 537 of Agriculture Handbook. Washington DC, USA. p. 58.

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Persistence of myclobutanil and its impact on soil microbial biomass C and dehydrogenase enzyme activity in tea orchard soils

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Abstract

Persistence of the fungicide myclobutanil in three tea orchard soils with different cultivating ages, neighboring wasteland and forest soils, and its influence on microbial activities in 2- and 50-year-oldtea orchard soils at three rates were studied in the laboratory. Dissipation data fitted well to first-order kinetic equation, except for sterilized treatments, in which neglected dissipation of myclobutanil was observed. At 25°C, the dissipation half-lives (DT_{50}) at level of 1mg kg^{-1} were in the range of 15.07-69.32 days under non-flooded condition, significantly lower than flooded condition ($p < 0.05$), indicating that dissipation of myclobutanil was mainly driven by soil microorganisms under aerobic condition. Dissipation rate was significantly increased at 40°C compared to those at 4°C and 25°C for all five soils ($p < 0.05$). Under all incubation conditions, DT_{50} were lowest in 50-year-old tea orchard soil ($p < 0.01$). Correlation analysis between DT_{50} in tea orchard soils and soil properties showed that soil microbial biomass carbon was negatively correlated with DT_{50} under 25°C and 60% water holding capacity ($p < 0.05$). In general, soil microbial biomass carbon and dehydrogenase activity decreased as the concentration of myclobutanil and incubation time increased except 0.1 mg kg^{-1} spiked soils, in which soil dehydrogenase activity was stimulated after 10 days incubation.

Keywords: Myclobutanil, tea orchard soil, dissipation kinetic, soil microbial biomass, microbial activity.

Introduction

Myclobutanil, an important triazole fungicide used against powdery mildew of cereal, vegetables, and fruits, is registered in more than 40 countries worldwide (Anon., 1993; Kemmitt et al., 2008). It is also widely applied to tea orchard to prevent brown spot disease. The amended European Union legislation has set the maximum residue limits (MRLs) for myclobutanil in different agricultural products and the MRL for tea is 0.05 mg kg^{-1} (Regulation EU, 567/2016). Residues of myclobutanil in some crops and the soils in which they were grown have been found (Athanasopoulos et al., 2003). It was also detected in agricultural head water streams (Smiley et al., 2014) and rain (Vogel et al., 2008) in the US.

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Persistence of myclobutanil in different soils has been studied in laboratory and field conditions. The reported dissipation half-life (DT_{50}) values were from 11.0-19.2 days (Liu et al., 2009; Han et al., 2009; Wang et al., 2012) up to 574 days in anaerobic soil (WHO/FAO, 2014).The reasons to the varying DT_{50} values in soils need to be addressed. Study on composting and digestion at full-scale plants revealed that myclobutanil was moderately persistent to persistent (DT_{50} > 70 days) in aerobic soils and persistent in anaerobic soils (Kupper et al., 2008). Organic residue amendments increased persistence and significant relationship was observed between the sorption of myclobutanil by the soils and DT_{50} values ($p < 0.05$) (Marín-Benito et al., 2014). Laboratory studies on the adsorption/desorption to soils indicated a low to moderate potential for vertical mobility (PPDB, 2011).

Tea (*Camellia sinensis*) is cultivated widely on acid red soils in the tropical and subtropical zones in China as an important economic crop (Wang et al., 2014) and also in more than 50 countries in the world with an annual production of approximately 4.7 million tons (Fang et al., 2014). Xue et al. (2006) reported that the pH value of tea orchard soil gradually decreases, and soil organic matter, soil N and P contents incease with the increase of cultivating ages. Therefore, tea orchard soils with different cultivating ages provide good samples to study the influence of soil physicochemical and biological properties on myclobutanil persistence.

Previous papers reported that triazole fungicides can have non-target effects on soil microbial communities (Yen et al., 2009; Muñoz-Leoz et al., 2011; Zhang et al., 2014). However, there are few studies on the impact of myclobuanil on soil microbial biomass and activity (Marín-Benito et al., 2014). To ascertain myclobutanil persistence and its impact soil microorganisms, 2-, 50-, and 100-year-old tea orchard soils, and neighboring wasteland and forest soils were collected. The two main objectives of this study were to: (1) evaluate the persistence of myclobutanil in tea orchard soils and the effect of soil properties and incubation conditions, i.e., water content and temperature, on its persistence, (2) investigate the influence of the fungicide spiked at three levels on soil microbial biomass carbon (C_{mic}) and dehydrogenase activity (DHA).

Material and Methods

Soil samples

The soil samples were collected from five sampling plots that were randomly chosen within a 2-year-oldtea orchard, a 50-year-old tea orchard and a 100-year-old tea orchard in Hangzhou, China. To evaluate soil biochemistry and microbial properties as a function of land-use change and management practice, neighboring wasteland and forest were also chosen as study sites. The wasteland in this red soil area was covered with sparse grasses. The 100-year-old forest, established on wasteland in 1914, was a mixed-conifer forest. From each sampling plot, 20 cores (5 cm in diameter × 20 cm in length) were taken and mixed. All soils investigated were classified as red soils by the China Classification System (Ultisols in USA soil taxonomy). Soil samples transported on ice to the laboratory and passed through a 2 mm sieve to remove rocks and plant debris. Each bulked sample was then separated into two parts. One part was air-dried for chemical analysis (except that mineral-N was immediately analyzed), and another was stored at 4°C until the incubation experiment.

Soil pH was determined in a 1:2.5 soil/water ratio. Soil organic matter was measured according to the method of dichromate oxidation (Nelson and Sommers, 1982). Total nitrogen was determined by Kjeldahl digestion (Keeney and Nelson, 1982), and ammonium and nitrate was extracted with 2 mol L^{-1} KCl and determined colorimetrically in a continuous flow analyzer (SA5000, Skalar Inc., the Netherlands).

Available phosphorus analysis was undertaken following the method by Olsen and Sommers (Olsen and Sommers, 1982). Heavy metal analysis: Soils were digested with nitric (HNO_3), hydrofluoric (HF), and hydrochloric (HCl) acid. Heavy metals (Cr, Ni, Cu, Zn, Cd, and Pb) were analyzed with Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (Agilent 7700X, USA).

The selected soil characteristics and heavy metal contents are summarized in Table 1. With the increase of tea-orchard age, the pH value decreases, and SOM, nitrogen and phosphorous contents increase, except that C_{mic} is highest in 50-year tea orchard soil. According to the Environmental Quality Standard for Soils of China (GB 15618-1995), the concentrations of Cr, Cu, and Ni were generally at low levels. While in 50-year tea orchard soil and wasteland soil, the concentrations of Cd were 0.29 and 0.24 mg kg^{-1}, respectively, and over Grade I. In 100-year tea orchard soil and forest soil, Pb levels were over Grade I. The concentrations of Zn in all soil samples were over Grade II.

Table 1.Physico-chemical and biological properties parameters and heavy metal contents in five studied soils

Soil samples	pH (1:2.5)	SOM ($g\ kg^{-1}$)	NO_3^--N	NH_4^+-N	TN	C_{mic}	A-P	Heavy metal contents（$mg\ kg^{-1}$ dry weight）					
			($mg\ kg^{-1}$)					Cr	Cu	Ni	Zn	Cd	Pb
2-year	4.57	11.26	11.72	5.49	1.31	244.66	3.71	40.74	10.24	11.00	316.11	ND	29.24
50-year	4.00	33.26	13.54	16.83	2.93	565.78	56.68	31.06	15.28	10.89	287.77	0.29	31.35
100-year	3.52	61.13	57.96	22.06	5.61	341.44	246.02	38.09	20.34	10.98	298.74	0.18	36.35
Forest	4.11	76.51	17.18	19.49	5.11	349.56	22.96	37.62	11.05	9.41	211.76	ND	42.08
Wasteland	5.34	8.09	5.76	3.08	0.86	121.66	5.10	41.01	12.50	11.55	254.19	0.24	33.14

Persistence of myclobutanil in soils

Chromatography grade acetone and n-hexane were supplied by Sigma-Aldrich (Steinheim, Germany). An analytical standard of myclobutanil (> 99%) was obtained from Dr. Ehrenstorfer GmbH (Augsburg, Germany). The incubation experiments are based on a modification of the reported procedures (Singh and Dureja, 2000; Dong et al., 2013). To test water content on persistence of myclobutanil, each soil sample (5 g) was adjusted to 60% and 125% water holding capacity (WHC), and pre-incubated for 48 h in the dark at 25°C. Soil samples (1 g) was artificially spiked by 1 mL of 5 μg mL^{-1} myclobutanil solution and set for 30 min under the hood until n-hexane was evaporated completely, and then added the rest soil to give a final concentration of 1 mg kg^{-1} soil. The sterilized controls (60% WHC), unflooded (60% WHC), and flooded (125% WHC) treatments were then incubated at 25°C in the dark.- To test the season effect on persistence of myclobutanil, unflooded treatments were also incubated at 4°C and 40°C, respectively. Each treatment contained triplicate replicates. Soil moisture was regulated daily with sterile deionized water. Sampling was carried out after 0, 2 h, 1, 3, 5, and 10 days of incubation, and then stored at -20°C for myclobutanil determination. For myclobutanil extraction, 25 mL of acetone and water (v:v/5:3) was added and shaked for 2 h at the speed of 200 r min^{-1} at 20 ± 2°C, and then centrifuged at 7000 r min^{-1} for 5 min. This step was repeated twice by extraction with 10 mL of acetone and water. The extracts were concentrated until acetone was evaporated in a rotary evaporator, and the aqueous phase was extracted three times by ethyl acetate. The extracts were combined and dried over anhydrous Na_2SO_4, and then concentrated to near dryness in a rotary evaporator. The residue was dissolved again in 15 mL of n-hexane and transferred into 50 mL K-D tube, adjusted the volume to 20 mL. Sample was passed through 0.22 μm filter before GC analysis.

The concentration of myclobutanil was determined by gas chromatography equipped with Ni^{63} electron capture detector (Agilent 7890N, USA) and a HP-5 column (30 m × 0.25 mm i.d. × 0.25 μm film thickness) with ultrapure nitrogen as carrier gas and make-up gas at the flow rate of 1.0 mL min^{-1}. The injector and detector temperature were 260°C and 300°C, respectively. The oven temperature was programmed from 160°C (held for 1 min) to 250°C (held for 3 min) at 23°C min^{-1}, and then increased to 280°C at 4°C min^{-1} (held for 10 min). The injection volume was 1 μL. Compounds were identified by retention time using external standard and quantified using peak area integration. For every set of 10 samples, a procedural blank consisting of all reagents was run to check for interference and cross contamination. The recovery study was carried out three replicates at two spiked levels (0.1 and 1.0 mg kg^{-1}). Table 2 listed the mean recovery and relative standard deviation (RSD) of the method. The data confirmed the practicability of the analytical protocols herein in the determination of myclobutanil residues in all soil samples.

Table 2. Recoveries of myclobutanil in five studied soils at two spiking levels (n=3)

Soil samples	Spiking levels ($mg\ kg^{-1}$)	Recovery /%				RSD/%
		1	2	3	average	
2-year	0.1	86.4	94.7	91.9	91	4.640
	1.0	99.3	90.1	98.6	96	5.335
50-year	0.1	115.7	101.8	118.5	112	7.985
	1.0	105.5	118.1	127.4	117	9.394
100-year	0.1	86.3	95.4	85.3	89	6.253
	1.0	87.2	91.3	97.5	92	5.636
Forest	0.1	87.8	95.2	81.0	88	8.071
	1.0	87.6	95.4	99.0	94	6.199
Wasteland	0.1	113.2	110.7	121.1	115	4.721
	1.0	109.4	117.6	127.0	118	7.463

Soil microbial activities

Myclobutanil was applied to 2- and 50-year-old tea orchard soils at three rates (0.1, 1, and 10 mg kg^{-1}, respectively). Soils unexposed to myclobutanil were used as controls. Each treatment contained triplicate replicates. The soil samples were prepared as described above. After 0, 5 and 10 days of incubation, soil samples were transferred at 4°C for microbial biomass C and dehydrogenase activity analysis.

Soil C_{mic} was determined by the chloroform fumigation-extraction method (Vance et al., 1987). Moist soil was fumigated with ethanol-free $CHCl_3$ for 24 h at 25°C in sealed desiccators and extracted by shaking for 30 min with 0.5 M K_2SO_4 (40 mL). The other soil of equal weight was not fumigated but extracted under the same condition. Soil C_{mic} was calculated by the equation: C_{mic} = 2.64 E_C, where E_C = (C extracted from fumigated soil) – (C extracted from non-fumigated soil), with 2.64 being a conversion factor.

Soil dehydrogenase activity was measured according to the method described by Tabatabai (Tabatabai, 1994). Five grams of soil sample was incubated in 5 mL of 0.1% 1, 3, 5-triphenyltetrazolium chloride (TTC) solution for 24 h at 37°C in the dark. Two drops of concentrated H_2SO_4 were added to stop the reaction. After incubation, triphenylformazan (TPF) was formed by the reduction of TTC. TPF was extracted with 5 mL of toluene and determined by spectrophotometry at 492 nm. Blanks without soil were processed in the same manner.

Statistical analysis was performed by SPSS 16.0 (SPSS Inc., USA) using a one-way analysis of variance (ANOVA). The values were considered to be significantly different at a 95% confidence level. The values in the figures and tables are the average of triplicate data (n = 3) ± standard deviations. All data are based on soil dry weight (DW).

Results and Discussion

Persistence of myclobutanil

Persistence of myclobutanil in three tea orchard soils with different cultivating ages, adjunct waste and forest soils under 4°C, 25°C, 40°C, flooded and non-flooded conditions are presented in Table 3 and Figure 1.

Table3. Kinetic parameters of myclobutanil in soils under two WHC (60% and 125%) and three incubation temperatures (4, 25, and 40°C, respectively).

Soil samples	WHC (%)	Temperature	k (d^{-1})	R^2	DT_{50} (d)	Degradation (%)*
2-year	60	4°C	0.029	0.9550	23.90$^{a, A}$	23.84
		25°C	0.031	0.9633	22.36$^{a, A}$	26.47
		40°C	0.044	0.9717	15.75$^{b, A}$	36.59
	125	25°C	0.014	0.9665	49.51$^{***, A}$	12.66
50-year	60	4°C	0.045	0.9520	15.40$^{a, AB}$	34.80
		25°C	0.046	0.9816	15.07$^{a, B}$	35.44
		40°C	0.069	0.9556	10.05$^{b, AB}$	49.08
	125	25°C	0.022	0.9543	31.23$^{***, A}$	19.21
100-year	60	4°C	0.034	0.9627	20.39$^{a, B}$	27.27
		25°C	0.035	0.9509	19.81$^{a, C}$	28.49
		40°C	0.052	0.9602	13.33$^{b, B}$	40.70
	125	25°C	0.018	0.9612	38.51$^{***, A}$	17.02
Forest	60	4°C	0.020	0.9539	34.66$^{a, C}$	17.16
		25°C	0.020	0.9758	34.66$^{a, D}$	17.25
		40°C	0.030	0.9515	23.11$^{b, C}$	26.90
	125	25°C	0.011	0.9647	63.02$^{***, A}$	10.55
Wasteland	60	4°C	0.010	0.9449	69.32$^{a, D}$	9.57
		25°C	0.010	0.9356	69.30$^{a, E}$	9.44
		40°C	0.016	0.9502	43.33$^{b, D}$	15.21
	125	25°C	0.005	9376	138.64$^{***, B}$	4.90

Lower case letters indicate significant difference among different incubation temperatures under 60% WHCin the same soil ($p < 0.001$). Upper case letters indicate significant difference among different soils under the same incubation conditions ($p < 0.001$). *** indicates significant difference between 60% WHC and 125% WHC under 25°C ($p < 0.001$).

Dissipation data under different incubation conditions fitted well to first-order kinetic equation, $C_t = C_0e^{-kt}$, with correlation coefficient (R^2) higher than 0.936, except for sterilized treatments, in which only 0.08-1.41% of myclobutanil were dissipated after 10 days incubation. The degradation (D) was calculated according to the following equation: $D = (C_0 - C_t)/C_0 \times 100\%$. In non-sterile soils, 4.90-49.08% of myclobutanil was degraded. Neglected dissipation was observed in sterilized treatments indicated microbial decomposition played a critical role in myclobutanil dissipation in studied soils. At 25°C, the DT_{50} of myclobutanil at level of 1 mg kg^{-1} were in the range of 15.07-69.32 days under non-flooded condition, while under flooded condition, DT_{50} were from 31.23 days in 50-year-old tea orchard soil to 138.64 days in wasteland soil. The degradation rates decreased about 2-fold as the WHC increased from 60% to 125% for all soils, which indicated that dissipation of myclobutanil was mainly driven by aerobic biotransformation. Our results are consistent with other triazole fungicides, hexaconazole (Singh and Dureja, 2000), penconazole and propiconazole (Singh and Dureja, 2009), which were found more persistent in soils under flooded than non-flooded conditions. However, a minor role of microorganisms in hexaconazole degradation was found (Singh and Dureja, 2000). Another study showed that the two soil water contents did not cause significant differences in dissipation rates between two triazole fungicides, triadimefon and propiconazole (Yen et al., 2009).

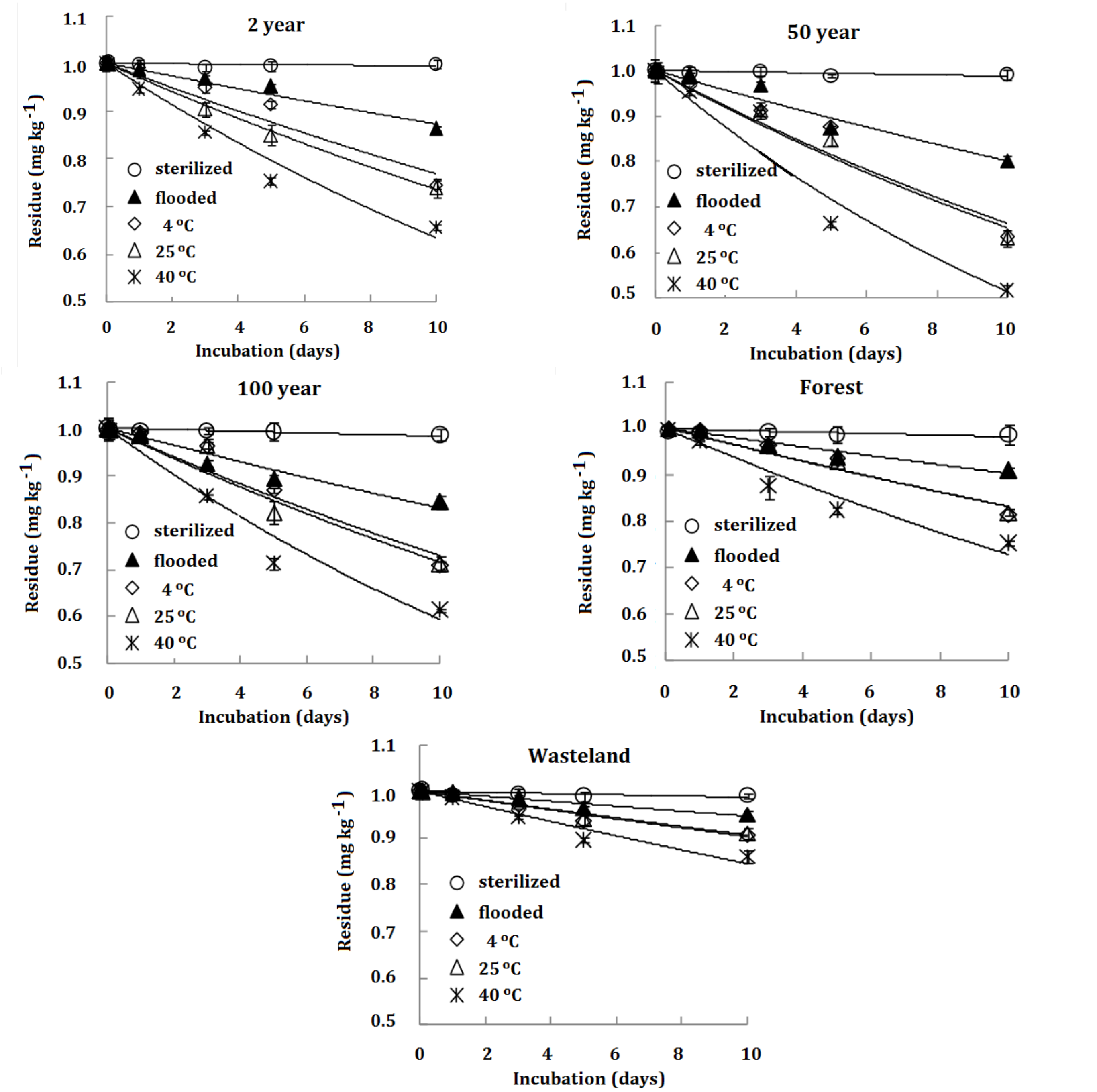

Figure 1. The dissipation of myclobutanil in five soils under sterilized (25°C, 60% WHC), unflooded (60% WHC)(4°C, 25°C, and 40°C, respectively) and flooded (25°C, 125% WHC) conditions.

Highest dissipation rate was observed in 50-year-old tea orchard soil, followed by 100- and 2-year tea orchard, and forest and wasteland soils, under all incubation conditions. Our result is in agreement with the findings on soil net nitrification study that the highest soil net nitrification was found in 50-year-old tea orchard, followed by 90- and 8-year-old tea orchard, and was significantly higher in the tea orchards compared to the wasteland and forest soils (Xue et al., 2006). Simple and multiple correlation analyses between DT_{50} and soil properties and heavy metal contents showed that C_{mic} was negatively correlated with DT_{50} ($p < 0.05$) in three tea orchard soils under 25°C and 60% WHC. Previous paper also showed that degradation of three fungicides (azoxystrobin, tebuconazole, and chlorothalonil) was fastest in the high microbial biomass soil (Bending et al., 2007).

Influences of temperature and water content–on myclobutanil degradation are similar in five soils. Dissipation rate was significantly increased at 40°C compared to those at 4°C and 25°C for all soils ($p < 0.05$). The effects of temperature on the persistence on myclobutanil are in agreement with other triazole fungicides. Degradation of hexaconazole (Singh and Dureja, 2000) and triadimefon (Singh, 2005) were faster at 35°C than at 27°C. Degradation rates of five triazole fungicides in two soils increased about 3-fold as the temperature was increased from 5 to 18°C (Bromilow et al., 1999). The faster degradation of myclobutanil at higher temperature could be mainly due to a higher microbial activity. Wang et al. (2014) found that high temperature significantly increased fungal abundance from 86 to 274% under 55% water holding capacity in a tea orchard soil. The volatilization in high temperature may have an insignificant effect on dissipation of myclobutanil, for myclobutanil is nonvolatile and has low mobility in soil. Myclobutanil exhibited negligible volatilization loss from golf course turfs (Wong et al., 2013).

Soil microbial activities

To assess the impact of application levels of myclobutanil on microorganisms in tea orchard soil, C_{mic} and DHA were analyzed in 2- and 50-year tea orchard soils at three incubation time (Figure 2).

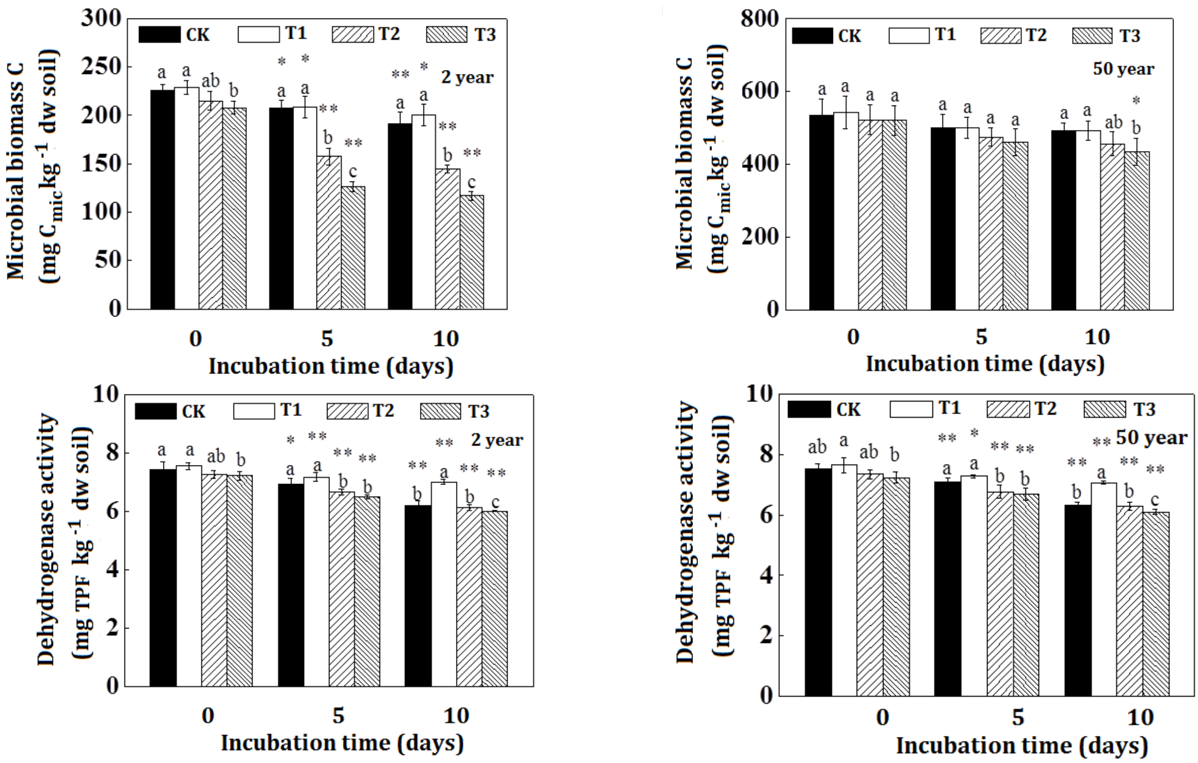

Figure 2. Effect of myclobutanil on soil microbial biomass C and dehydrogenase activity. Lower case letters indicate significantly difference among different spiking levels at the same incubation day ($p < 0.05$). ** ($p < 0.01$) and * ($p < 0.05$) indicate significant difference compared with day 0 at the same spiking levels of myclobutanil. CK, T1, T2, and T3 representing myclobutanil application levels at 0, 0.1, 1, and 10 mg kg^{-1}, respectively.

The C_{mic} values ranged from 116.90 to 228.83 mg kg^{-1} and from 461.27 to 542.59 mg kg^{-1} in 2- and 50-year-old tea orchard soils, respectively. Similar results have been found in forest soils that C_{mic} contents were higher in old-age forest soils compared to younger ones (Yan et al., 2009). No significant difference of C_{mic} was observed in 50-year old tea orchard soil among different spiking levels at all incubation times. The C_{mic} content only at 10 mg kg^{-1} spiked microcosms significantly decreased at day 10 compared with day 0 ($p < 0.05$). Inhibitory effect of myclobutanilon C_{mic} in 2-year old tea orchard soil was aggravated with the increase of myclobutanil concentration and incubation time. Myclobutanil at 0.1 mg kg^{-1} level showed no significant impact on C_{mic} during the entire incubation period, while the C_{mic} values in 1 and 10 mg kg^{-1} spiked soils were significantly lower than controls at day 5 and 10 ($p < 0.05$). Compared with day 0, both 1 and 10 mg kg^{-1} of myclobutanil addition significantly inhibited C_{mic} at day 5 and 10 ($p < 0.01$). At day 10, the C_{mic} value in10 mg kg^{-1} of myclobutanil spiked 2-year old tea orchard microcosms was 43.8% lower than that in control soils, whereas in 50-year old tea orchard the C_{mic} were only 16.52% lower. The results indicate that 50-year old tea orchard soil is more resistant to myclobutanil than 2-year old one. Previous papers on other triazole fungicides showed that tebuconazole application decreasedC_{mic} (Muñoz-Leoz et al., 2011; Zhang et al., 2014), but tended to recover at the end of the incubation when tetraconazole was applied at the recommended field rate (Zhang et al., 2014). In contrary, no significant impact on total microbial biomass was observed after tebuconazole addition in either the low or high OM/biomass soils (Bending et al., 2007).

The DHA values and inhibitory effect were similar in two soils. DHA values were both from 6.0 to 7.7 mg TPF kg^{-1} DW soil. DHA increased at 0.1 mg kg^{-1} application rate and inhibited at 1 and 10 mg kg^{-1} levels in both soils. In the 0.1 mg kg^{-1} amended soils, a significant increase of DHA was observed at day 10. The maximum inhibition of DHA was observed in 1 and 10 mg kg^{-1} spiked soils at day 5 and tended to recover at day 10 compared with controls. Compared with day 0, DHA values were significantly lower in day 5 and 10 microcosms. Stimulation effect of myclobutanil on soil DHA has been reported at the application rate of 2 mg kg^{-1} (Marín-Benito et al., 2014). For other triazole fungicides, DHA were significantly reduced by the addition of triadimefon at 1 mg kg^{-1} rate (Singh, 2005) and tebuconazole (Muñoz-Leoz et al., 2011). Therefore, as Hussain pointed out that a number of factors, such as, chemical nature and application levels of pesticides, soil microbial community structure, soil properties and conditions can contribute to divergent research findings (Hussain et al., 2009).

Our samples were incubated for only 10 days. The effect of myclobutanil on soil microbial biomass and activity could be long, as Yen's study found that after two fungicides were applied for 60 days and longer, the compositions of microbial communities were not recovered (Yen et al., 2009). Further work should be carried out with longer observation time to study the resistance and resilience of soil microbial communities to the fungicide application and especially the influence on narrow niche functions of fungal community.

Conclusion

Myclobutanil was readily aerobic degraded in studied soils with DT_{50} about 2-10 weeks. The dissipation rates of myclobutanil were clearly influenced by soil properties, temperature, and water content. Myclobutanil degradation was fastest in 50-year old tea orchard soil with the highest C_{mic} content. Low myclobutanil level (0.1 mg kg^{-1}) stimulated soil dehydrogenase activity, whereas high concentration (1 and 10 mg kg^{-1}) had negative effect on soil quality indicators which decreased significantly as myclobutanil concentration and incubation time increased. This study gains a better understanding of myclobutanil dissipation and its effect on microbial activities of this unique soil ecosystem, and helps management practices in tea orchard soils with different cultivating age.

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References

Anon. 1993. Agriculture Canada. Decision Document: Myclobutanil. E93-01. Available at: http://publications.gc.ca/collections/Collection/H93-013-4-93-01E.pdf

Athanasopoulos, P.E., Pappas, C.J., Kyriakidis, N.V., 2003. Decomposition of myclobutanil and triadimefon in grapes on the vines and during refrigerated storage. *Food Chemistry* 82(3): 367-371.

Bending, G.D., Rodríguez-Cruz, M.S., Lincoln, S.D., 2007. Fungicide impacts on microbial communities in soils with contrasting management histories. *Chemosphere* 69(1): 82-88.

Bromilow, R.H., Evans, A.A., Nicholls, P.H., 1999. Factors affecting degradation rates of five triazole fungicides in two soil types: 1. Laboratory incubations. *Pesticide Science* 55(12): 1129-1134.

Fang, W.P., Meinhardt, L.W., Tan, H.W., Zhou, L., Mischke, S., Zhang, D., 2014. Varietal identification of tea (*Camellia sinensis*) using nanofluidic array of single nucleotide polymorphism (SNP) markers. *Horticulture Research* 35: 1-8.

Dong, F., Li, J., Chankvetadze, B., Cheng, Y., Xu, J., Liu, X., Li, Y., Chen, X., Bertucci, C., Tedesco, D., Zanasi, R., Zheng, Y., 2013. Chiral triazole fungicide difenoconazole: absolute stereochemistry, stereoselective bioactivity, aquatic toxicity, and environmental behavior in vegetables and soil. *Environmental Science and Technology* 47(7): 3386-3394.

Han, B.J., Chen, L.X., Peng, L.X. 2009. Degradation of four fungicides in tropical soils from Hainan, China. *Journal of Food Agriculture and Environment* 7(1): 197-200.

Hussain, S., Siddique, T., Saleem, M., Arshad, M., Khalid, A., 2009. Impact of pesticides on soil microbial diversity, enzymes, and biochemical reactions. *Advances in Agronomy* 102: 159-200.

Keeney, D.R., Nelson, D.W. , 1982. Nitrogen-inorganic forms. In: Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2ndedition. Page A.L., Miller, R.H., Keeney, D.R., (Eds). American Society of Agronomy, Madison WI, USA. pp. 643-698.

Kemmitt, G.M., DeBoer, G., Ouimette, D., Iamauti, M., 2008. Systemic properties of myclobutanil in soybean plants, affecting control of Asian soybean rust (Phakopsora pachyrhizi). *Pest Management Science* 64(12): 1285-1293.

Kupper, T., Bucheli, T.D., Brändli, R.C., Ortelli, D., Edder, P. , 2008. Dissipation of pesticides during composting and anaerobic digestion of source-separated organic waste at full-scale plants. *Bioresource Technology* 99(17): 7988-7994.

Liu, X., Dong, F., Wang, X., Zheng, Y., 2009. The dissipation rates of myclobutanil and residue analysis in wheat and soil using gas chromatography-ion trap mass spectrometry. *International Journal of Environmental Analytical Chemistry* 89(13): 957-967.

Marín-Benito, J.M., Herrero-Hernández, E., Andrades, M.S., Sánchez-Martín, M.J., Rodríguez-Cruz, M.S., 2014. Effect of different organic amendments on the dissipation of linuron, diazinon and myclobutanil in an agricultural soil incubated for different time periods. *Science of the Total Environment* 476-477: 611-621.

Muñoz-Leoz, B., Ruiz-Romera, E., Antigüedad, I., Garbisu, C., 2011. Tebuconazole application decreases soil microbial biomass and activity. *Soil Biology & Biochemistry* 43(10): 2176-2183.

Nelson, D.W., Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: In: Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2ndedition. Page A.L., Miller, R.H., Keeney, D.R., (Eds). American Society of Agronomy, Madison WI, USA. pp. 539-580.

Olsen, S.R., Sommers, L.E., 1982. Phosphorus. In: Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2ndedition. Page A.L., Miller, R.H., Keeney, D.R., (Eds). American Society of Agronomy, Madison WI, USA. pp. 403-430.

Pesticide Properties Database (PPDB). UK: University of Hertfordshire, 2011. Available at: http://sitem.herts.ac.uk/aeru/ppdb/en/Reports/478.htm

Regulation EU 567/ 2016/. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0567.

Singh, N. 2005. Factors affecting triadimefon degradation in soils. *Journal of Agricultural and Food Chemistry* 53: 70-75.

Singh, N., Dureja, P. 2009. Effect of biocompost-amendment on degradation of triazoles fungicides in soil. *Bulletin of Environmental Contamination and Toxicology* 82(1): 120-123.

Singh, N., Dureja, P., 2000. Persistence of hexaconazole, a triazole fungicide in soils. *Journal of Environmental Science and Health, Part B* 35(5): 549-558.

Smiley Jr., P.C., King, K.W., Fausey, N.R. 2014. Annual and seasonal differences in pesticide mixtures within channelized agricultural head water streams in central Ohio. *Agriculture Ecosystems & Environment* 193: 83-95.

Tabatabai, M.A. 1994. Soil Enzymes. In: Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. 2ndedition. Weaver RW, (ed.). American Society of Agronomy, Madison WI, USA. pp. 903-947.

Vance, E.D., Brookes, P.C., Jenkinson, D.S. 1987. An extraction method for measuring soil microbial biomass C. *Soil Biology & Biochemistry* 19(6): 703-707.

Vogel, J.R., Majewski, M.S., Capel, P.D. 2008. Pesticides in rain in four agricultural watersheds in the United States. *Journal of Environmental Quality* 37(3): 1101-1115.

Wang, H., Yang, J.P., Yang, S.H., Yang, Z.C., Lv, Y.M., 2014. Effect of a 10°C-elevated temperature under different water contents on the microbial community in a tea orchard soil. *European Journal of Soil Biology* 62: 113-120.

Wang, X., Li, Y., Xu, G., Sun, H., Xu, J., Zheng, X., Wang, F., 2012. Dissipation and residues of myclobutanil in tobacco and soil under field conditions. *Bulletin of Environmental Contamination and Toxicology* 88(5): 759-763.

Wong, H., Haith, D.A., 2013. Volatilization of pesticides from golf courses in the United States: mass fluxes and inhalation health risks. *Journal of Environmental Quality* 42: 1615-1622.

WHO/FAO, 2014. Pesticide Residues in Food, Joint FAO/WHO meeting on pesticide residues. World Health Organization/Food and Agriculture Organization of the United Nations. Rome, Italy.

Xue, D., Yao, H.Y., Huang, C.Y. 2006. Microbial biomass, N mineralization and nitrification, enzyme activities, and microbial community diversity in tea orchard soils. *Plant and Soil* 288 (1): 319-331.

Yan, J., Zhang, D., Zhou, G., Liu, J. , 2009. Soil respiration associated with forest succession in subtropical forests in Dinghushan Biosphere Reserve. *Soil Biology & Biochemistry* 41(5): 991-999.

Yen, J., Chang, J., Huang, P., Wang, Y. 2009. Effects of fungicides triadimefon and propiconazole on soil bacterial communities. *Journal of Environmental Science and Health, Part B* 44(7): 681-689.

Zhang, W., Xu, J., Dong, F., Liu, X., Zhang, Y., Wu, X., Zheng, Y. 2014. Effect of tetraconazole application on the soil microbial community. *Environmental Science and Pollution Research* 21(13): 8323-8332.

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Combining selective sequential extractions, X-Ray Absorption Spectroscopy, and X-Ray Powder Diffraction for Cu (II) speciation in soil and mineral phases

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Abstract

Interaction of Cu (II) ions with the matrix of soil and mineral phases of layered silicates was assessed by the Miller method of selective sequential fractionation and a set of synchrotron X-ray methods, including X-ray powder diffraction (XRD) and X-ray absorption spectroscopy (XANES). It was shown that the input of Cu into Calcic Chernozem in the form of monoxide (CuO) and salt ($Cu(NO_3)_2$) affected the transformation of Cu compounds and their affinity for metal-bearing phases. It was found that the contamination of soil with a soluble Cu(II) salt increased the bioavailability of the metal and the role of organic matter and Fe oxides in the fixation and retention of Cu. During the incubation of soil with Cu monoxide, the content of the metal in the residual fractions increased, which was related to the possible entry of Cu in the form of isomorphic impurities into silicates, as well as to the incomplete dissolution of exogenic compounds at the high level of their input into the soil. A mechanism for the structural transformation of minerals was revealed, which showed that ion exchange processes result in the sorption of Cu (II) ions from the saturated solution by active sites on the internal surface of the lattice of dioctahedral aluminosilicates. Surface hydroxyls at the octahedral aluminum atom play the main role. X-ray diagnostics revealed that excess Cu(II) ions are removed from the system due to the formation and precipitation of coarsely crystalline $Cu(NO_3)(OH)_3$.

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Introduction

The bioavailability of metals is closely related to their forms of occurrence. Therefore, studies of soil contamination aimed at obtaining objective information about metal speciation become of special importance (Minkina et al., 2010). The complexity of the occurrence forms of metals and metalloids is most manifested in highly dynamic, physically and chemically heterogeneous ecological systems like soils, bottom

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sediments, and sewage sludge (Hesterberg et al., 2011). Analytical methods used to assess metal compounds are usually suitable for the study of limited combinations of metals and metalloids in environmental objects. The mechanical transference of extraction systems developed for background soils introduces additional uncertainties and errors in the study of contaminated soils. The proportions of phosphates, sulfides, and arsenates, for which there are no adequate extractants, increase in industrially contaminated soils (Orlov et al., 2005). Chemical reagents should provide the maximum completeness and selectivity of extraction for target metals. However, this is almost inaccessible for such a complex polydisperse heterogeneous system as the soil because of the internal spatial heterogeneity of soil samples. The determination of heavy metals (HMs) and metalloids in soils should evolve toward direct methods ensuring selectivity and sensitivity for the local structures of numerous elements; low detection limits; high spatial resolution; and a simple procedure of sample preparation, which makes these methods universal and accurate in studying the elemental composition of pollutants (Gräfe et al., 2014; Minkina et al., 2016).

The aim of this work was to study relationships between Cu(II) ions and components of soil organomineral matrix by X-ray absorption spectroscopy (XANES) and X-ray powder diffraction (XRD) using synchrotron radiation and, selective sequential fractionation.

Material and Methods

Objects of study included samples from the humus-accumulative A_1 horizon of Calcic Chernozem (FAO, 2006) collected in the Persianovskaya Step Specially Protected Natural Territory, Rostov oblast, Russia. The soil had the following properties: C_{org} 3.7%, $CaCO_3$ 0.4%, pH_{H2O} 7.6; exchangeable bases (mM(+)/100 g): Ca^{2+} 31.0, Mg^{2+} 6.0, Na^+, 0.06; physical clay 63.6%; clay 28.1%. The content of total Cu in the samples was determined by synchrotron radiation X-ray fluorescence analysis (SR XRF). Chemical compositions of the mineral component of Chernozem and the phases of layered silicates were determined using the procedure for measuring the mass fractions of element oxides in powdered samples by the X-ray fluorescence method on a MAKS-GV spectroscane.

The mineralogy of the clay and fine silt fractions from the humus-accumulative horizon of Calcic Chernozem is characterized by the following phase composition of layered silicates: the contents of illite, labile silicates, and kaolinite are 51–54 and 51–60, 23–27 and 12–27, and 22–23 and 22–28% in the clay and fine silt fractions, respectively. The fine silt fraction also contains micas, amorphous silica, and crystallized iron and aluminum oxides and hydroxides (Kryshchenko and Kuznetsov, 2003; Nevidomskaya et al., 2016).

To study the effect of organomineral matrix on the sorption of Cu^{2+} ions, a model laboratory experiment has been established under controlled conditions. The soil selected for the experiment was air-dried, triturated using a pestle with a rubber head, and sieved through a 1-mm sieve. Dry compounds of Cu ($Cu(NO_3)_2$ and CuO) were added to the soil at a rate of 2000 mg/kg. The soil was thoroughly mixed, wetted, and incubated for 3 years at 60% of the maximum water capacity. Experiments were performed in triplicates. Analogous procedures but without addition of metal were performed with the control sample.

After the end of incubation (3 years layer), an average sample was taken from each pot for analysis. The soil was brought to the dry state.

Samples of separate mineral phases (montmorillonite, kaolinite, hydromuscovite, and gibbsite) were saturated with Cu^{2+} ions. For this purpose, the studied samples were put into a saturated $Cu(NO_3)_2$ solution. The solution was changed twice a day for a week. The solution pH was maintained constant at 7.0 in the presence of CuO and 3.9 in the presence of $Cu(NO_3)_2$. After a week, the preparation was removed from the solution, dried, and ground.

Sequential extraction

The composition of Cu compounds in the soil was determined by the Miller method of sequential fractionation (Miller et al., 1986) modified by Berti and Jacobs (1996). The chemical fractionation extracted the following Cu compounds (Table 1): water-soluble, exchangeable, and acid-soluble; bound to Mn oxides, organic matter, and amorphous and crystalline Fe oxides; and insoluble (bound to aluminosilicates, or residual) ones. Analysis of Cu content in soil extracts was performed by atomic absorption spectrophotometry (AAS).

Table 1. Sequential fractionation of heavy metals by the Miller scheme (Miller et al., 1986) modified by Berti and Jacobs (1996) for 1 g sample

Fraction	Soil : solution ratio	Extraction conditions	Extractant
Water-soluble	1 : 10	Shaking at room temperature for 16 h	Distilled water
Exchangeable	1 : 10	Shaking at room temperature for 8 h	0.5 M $Ca(NO_3)_2$, pH 7.0
Acid-soluble	1 : 10	Shaking at room temperature for 8 h	0.44 M CH_3COOH, pH 2.5
Bound to Mn oxides	1 : 14	Shaking at room temperature for 30 min	0.1 M $NH_2OH \cdot HCl$ + 0.01 M HNO_3
Bound to organic matter	1 : 14	Shaking at room temperature for 24 h	0.1 M $Na_4P_2O_7$
Bound to amorphous Fe oxides	1 : 14	Shaking in the dark for 4 h	0.175 M $(NH_4)_2C_2O_4$ + 0.1 $MH_2C_2O_4$
Bound to crystalline Fe oxides	1 : 14	Placed in a boiling water bath under periodical shaking for 5 h	0.175 M $(NH_4)_2C_2O_4$ + 0.1 $MH_2C_2O_4$
Connected with silicates (residual)	1 : 25	Evaporation	Extract of HF + $HClO_4$ from the residual fraction

Soil samples were also analyzed by X-ray powder diffraction and X-ray absorption spectroscopy at the Structural Material Science station on the 1.3b channel of a synchrotron radiation source of the National Research Center "Kurchatov Institute" (Chernyshov et al., 2009). A 1.7 T bend magnet of the Siberia-2 storage ring is the source of synchrotron radiation. The electron beam energy is 2.5 GeV; the average current is 120 mA.

X-ray powder diffraction.

Diffraction studies of monochromatic synchrotron X-ray radiation (λ = 0.68886 Å, Si monochromator) were performed in transmission geometry using a Fujifilm Imaging Plate two-coordinate detector at 0.68886 Å. X-ray diffraction patterns were recorded in integrated mode at 20°C. The time of sample exposure was about 15 min. A silicon standard (NIST SRM 640C) was used for the angular calibration of the scale. The use of high-intensity monochromatic synchrotron radiation in combination with a two-coordinate detector and a Si monochromator significantly improves the intensity and resolution of diffraction patterns compared to the conventional X-ray diffractometry.

X-ray absorption spectroscopy.

Experimental Cu K-edge X-ray absorption near edge structure (XANES) spectra (~899–8995 eV) were measured at room temperature in fluorescence mode. A two-crystal Si(111) monochromator with the energy resolution $\Delta E/E \sim 2 \cdot 10^{-4}$ was used to monochromate the X-ray radiation. The obtained spectra were processed using standard procedures for noise discrimination and normalization by the K-edge jump. First-derivative XANES spectra were analyzed to specify information about the state of Cu(II) ions and reveal the differences in the analyzed samples that escaped detection during the analysis of XANES spectra. Along with the experimental XANES spectra, experimental spectra of the original copper-containing compound were also studied.

Results and Discussion

Fractionation of Cu compounds by the Miller method showed (Figure 1) that Cu compounds in the fraction bound to silicates dominate in the uncontaminated Chernozem (60 and 67% of the sum of total fractions). This is related to the regional biogeochemical features of the microelement composition of soils in Rostov oblast and the mineralogy of parent rocks (Akimtsev et al., 1962).

Copper compounds have low mobility in the uncontaminated soil. The relative content of Cu in the first three fractions does not exceed 1.5%, and the most mobile exchangeable forms compose only 0.4%. It is known that Cu is an organophilic element (Vodyanitskii, 2008; Ponizovskii et al., 1999); therefore, the organic matter fraction is characterized by a high Cu content. Perelomov (2001) and Kosheleva et al. (2002) confirmed that organic matter (especially high-molecular-weight humic acids) has higher effect on the fixation of Cu than carbonates and hydroxides. Copper compounds in the original soil are distributed as follows: silicate-bound (residual) fraction > organic matter-bound fraction > crystalline Fe-bound fraction > amorphous Fe-bound fraction >Mn oxide-bound fraction > acid-soluble fraction > exchangeable fraction ~ water-soluble fraction.

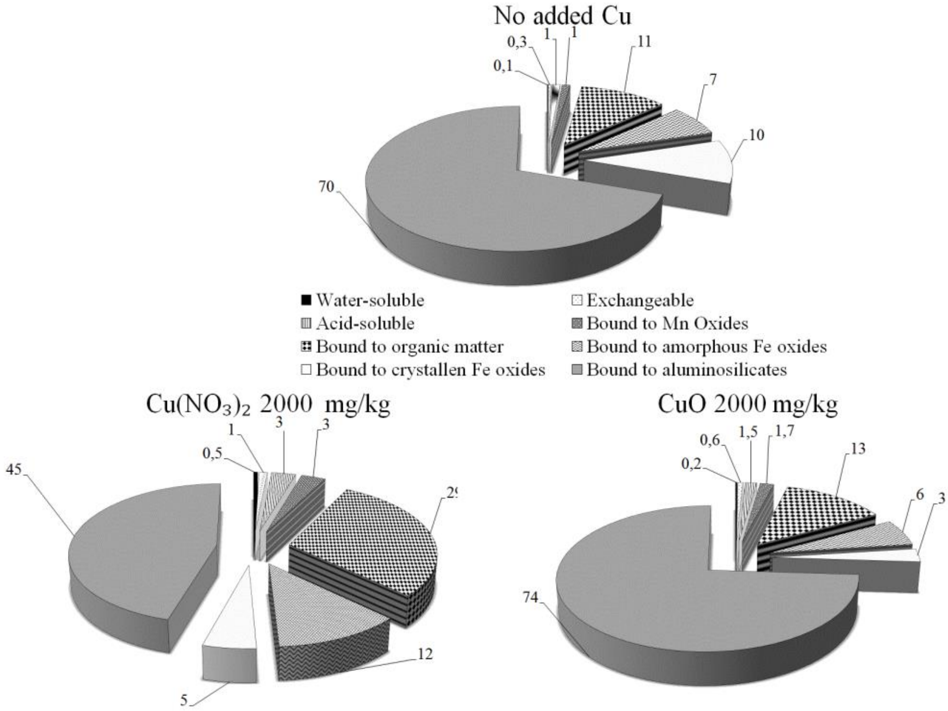

Figure 1. Distribution of Cu among fractions in the original Calcic Chernozem and that contaminated with $Cu(NO_3)_2$ and CuO from the Miller method, % of the sum of fractions

The artificial contamination of soil with Cu increases the absolute contents of all its compounds (Figure 1) and affects their distribution among the soil fractions. The proportion of the water-soluble fraction increases to 0.3–0.5% due to free Cu(II) ions and their soluble complexes with inorganic anions or organic ligands. The content of the exchangeable fraction, which includes exchangeablysorbed Cu compounds bound to different soil components (clay minerals; Fe, Al, and Mn hydroxides; and organic matter), increases to 1%. The content of Cu in the acid-soluble fraction, which characterizes its binding to carbonates, is three- to fivefold higher than that in the exchangeable fraction. A peculiar feature of Calcic Chernozem is the presence of micellar carbonates with a large specific surface area, which increases their activity in interaction with metals. Thus, an increase in the mobility of the metal is observed under contamination, which is manifested in increased relative contents of water-soluble, exchangeable, and acid-soluble fractions (Figure 1).

The content of organic matter-bound Cu increases under contamination from 11 to 29% as compared to the uncontaminated sample (Figure 1). Similar changes in the composition of metal compounds were noted earlier for soils of technogenic landscapes (Minkina et al., 2014).

Along with organic matter and clay minerals, Al, Fe, and Mn oxides and hydroxides play a significant role in the adsorption of HMs in soils. The addition of Cu to the soil insignificantly increases the content of the metal in the Mn oxide-bound fraction compared to the uncontaminated sample. This is related to the special importance of the separation of this fraction by the Miller method for soils with high Mn contents. The content of Mn in the studied soil is 860 mg/kg (Mn clarke for soils is 850 mg/kg, Vinogradov, 1957).

The addition of Cu nitrates and oxides increases the content of the metal in the fractions bound to amorphous Fe oxides to 12 and 6%, respectively, while the content of Cu in the fractions bound to crystalline Fe decreases to 5 and 3%, respectively (Figure 1). This changes the distribution of Cu among the separated fractions compared to the original soil: silicate-bound (residual) fraction > organic matter-bound fraction > amorphous Fe-bound fraction > crystalline Fe-bound fraction >Mn oxide-bound fraction > acid-soluble fraction > exchangeable fraction ~ water-soluble fraction.

The age of soil contamination can be estimated from the presence of the fraction bound to amorphous Fe oxides (Vodyanitskii, 2010). The crystallization of Fe oxides proceeds for a sufficiently long time, and an abrupt increase in the content of metals in the amorphous Fe oxide indicates a recent contamination. The relative content of the fraction bound to amorphous Fe almost doubles at the addition of soluble copper nitrate, while the difference from the contaminated soil is insignificant, if any, at the addition of copper oxide (Figure 1).

During the incubation of soil with CuO, the increase in the share of Cu in the residual fraction to 74% (Figure 1) is related to the potential entry of Cu in the form of isomorphic impurities into silicates, as well as to the incomplete dissolution of exogenic metal compounds at the high level of their input into the soil (Minkina et al., 2010).So, the content of metal in the residual fraction at the addition of Cu oxide at 2000 mg/kg is higher than at the addition of the equivalent rate of Cu nitrate (Figure 1).

Experimental X-ray powder diffraction patterns for the original soil sample and the mineral phases of layered silicates phase (for example montmorillonite)and after modification with a saturated $Cu(NO_3)_2$ solution are shown in Figure 2.

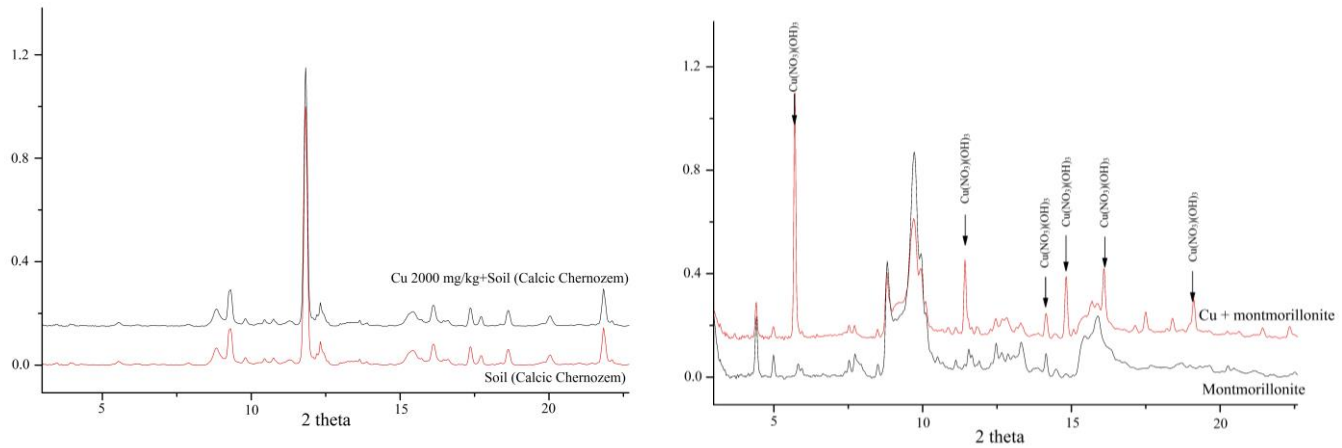

Figure 2. Comparative analysis of X-ray powder diffraction patterns for soil sample and layered silicate phase (for example montmorillonite) before and after modification with a saturated $Cu(NO_3)_2$ solution

The comparison of diffraction patterns for the soil sample and layered silicate phases (for example montmorillonite) before and after modification with a saturated $Cu(NO_3)_2$ solution (Figure 2) showed no appreciable changes in the diffraction pattern of the contaminated soil compared to the original samples. However, additional diffraction peaks corresponding to a new crystalline phase appeared in the diffraction patterns of layered phases saturated with Cu(II) ions.

A peculiar feature of layered silicate phases is the chemical and energetic heterogeneity of their surface characterized by the presence of structural defects and different functional groups, which can act as active centers during metal adsorption. These active centers on the surface of, e.g., montmorillonite can include exchangeable cations, surface hydroxyl groups, and oxygen atoms of the tetrahedral lattice. Some active centers occur on the lateral faces of minerals formed during the splitting of minerals.

The saturation of separate phases of layered silicates with a $Cu(NO_3)_2$ solution at a constant pH of 3.9 increases the share of acidic active centers, which affects the proportions of acid–base active centers on the surface of mineral phases (Ponizovskii and Mironenko, 2001). Hydrolysis processes, which shift the system equilibrium, also contribute. During the initial saturation period, Ca(II) cations are desorbed from the interlayer positions of layered silicates, especially smectites, into the contacting solution.

X-ray diffraction data showed that Cu^{2+} ions are sorbed from the saturated solution by active centers on the internal surface of the lattice of dioctahedralaluminosilicates, and surface hydroxyls at the octahedrally coordinated aluminum atom play the main role (Furnare et al., 2005; Strawn and Baker, 2009). X-ray diagnostics revealed that excess Cu(II) ions are removed from the system due to the formation and precipitation of coarsely crystalline $Cu(NO_3)(OH)_3$ (Figure 2). This fact agrees with the chemical fractionation data (Figure 1), which indicate an increase in the content of Cu in the silicate-bound residual fraction.

XANES data for the studied soil samples and mineral phases of layered minerals artificially contaminated with $Cu(NO_3)_2$ are shown in Figure 3.

Comparison of the first-derivative Cu K-edge XANES spectra for all samples with the spectrum of the $Cu(NO_3)_2$ standard showed sensitivity of the method for changes in the immediate surrounding of Cu(II) ions in these structures. The samples are characterized by the existence of peak A in the middle part of the spectrum (~899–8995 eV) due to the presence of Cu^{2+} ions. The absence of chemical shift of the main absorption edge in contrast to the initial spectrum of the compound indicates that the charge of Cu^{2+} ion in the soil does not change.

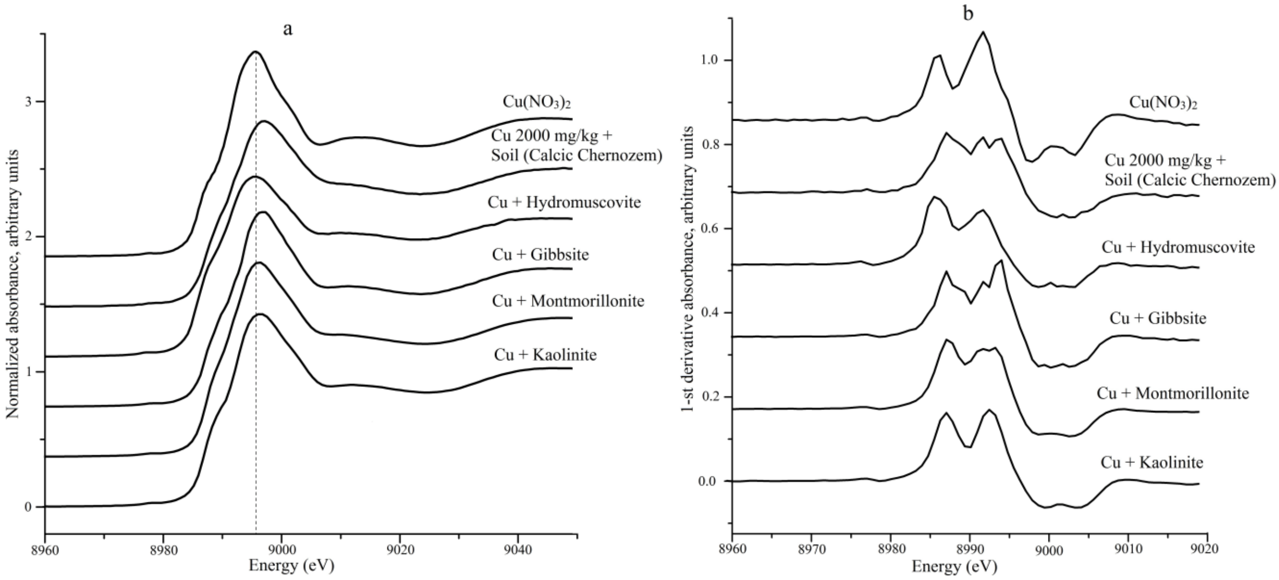

Figure 3. (a) Experimental Cu K-edge XANES spectra and (b) 1-st-derivative X-ray absorption spectra for soil, layered silicate phases, and $Cu(NO_3)_2$ standard

The spectral features of the central peak and low-amplitude lateral maximums of layered silicates, their shapes, and shifts against the original copper-containing compound indicate a shortening of interatomic distances between the adsorbed Cu^{2+} ions and the oxygen surrounding in accordance with the Natoly rule (Natoli, 1984). This agrees with data of X-ray diffraction analysis and earlier molecular dynamic simulation (Minkina et al., 2013).

Conclusion

Thus, contributions of different Cu forms to the distribution of the metal among soil components are shown. It is found that the contamination of soils with a soluble Cu(II) salt increases the bioavailability of the metal; the role of organic matter and Fe oxides in the fixation and retention of Cu also increases. During the incubation of soil with Cu monoxide, the content of the metal in the residual fraction increases, which is relatedto the potential entry of Cu in the form of isomorphic impurities into silicates, as well as to the incomplete dissolution of exogenic metal compounds at the high level of their input into the soil.

XANES data revealed the mechanism for the structural transformations of Cu(II) ions: they are sorbed from the saturated solution by active centers on the internal surface of the lattice of dioctahedralaluminosilicates, and surface hydroxyls at the octahedrally coordinated aluminum atom play the main role. X-ray diagnostics revealed a shortening of interatomic distances between the adsorbed Cu(II) ions and O atoms due to the displacement of some Al(III) ions in octahedral positions.

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References

Akimtsev, V.V., Boldyreva, A.V., Golubev, S.N., 1962. Content of microelements in soils of Rostov oblast. In: Microelements and Natural Radioactivity. RGU, Rostov-on-Don, Russia. pp. 37-42. [in Russian].

Berti, W.R., Jacobs, L.W., 1996. Chemistry and phytotoxicity of soil trace elements from repeated sewage sludge applications. *Journal of Environmental Quality* 25(5): 1025-1032.

Chernyshov, A.A., Veligzhanin, A.A., Zubavichus, Y.V., 2009. Structural Materials Science end-station at the Kurchatov synchrotron radiation source: recent instrumentation upgrades and experimental results. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 603(1-2): 95-98.

FAO, 2006. World reference base for soil resources 2006. World soil resources reports 103. Food and Agriculture Organization of the United Nations, Rome, Italy. 132 p.

Furnare, L.J., Strawn, D.G., Vailionis, A., 2005. Polarized XANES and EXAFS spectroscopic investigation into copper (II) complexes on vermiculite. *Geochimica et Cosmochimica Acta* 69(22): 5219-5231.

Gräfe, M., Donner, E., Collins, R.N., Lombi, E., 2014. Speciation of metal(loid)s in environmental samples by X-ray absorption spectroscopy: A critical review. *Analytica Chimica Acta* 822: 1-22.

Hesterberg, D., Duff, M.C., Dixon, J.B., Vepraskas, M.J. 2010. X-ray microspectroscopy and chemical reactions in soil microsites. *Journal of Environmental Quality* 40(3): 667-678.

Kosheleva, N.E., Kasimov, N.S., Samonova, O.A., 2002. Regression models for the behavior of heavy metals in soils of the Smolensk–Moscow Upland. *Eurasian Soil Science* 35(8): 954-966.

Kryshchenko, V.S., Kuznetsov, R.V., 2003. Clay minerals in soils of the Lower Don and Northern Caucasus regions. IzvestiyaVuzov. Severo-Kavkazskii Region. *Seriya Estestvennye Nauki* 3: 86-92. [in Russian].

Miller, P.W., Martens, D.C., Zelazny, L.W., 1986. Effect of sequence in extraction of trace metals from soils. *Soil Science Society of America Journal* 50(3): 598-601.

Minkina, T.M., Mandzhieva, S.S., Motusova, G.V., Burachevskaya, M.V., Nazarenko, O.G., Sushkova, S.N., Kızılkaya, R., 2014. Heavy metal compounds in a soil of technogenic zone as indicate of its ecological state. *Eurasian Journal of Soil Science* 3(2): 144-151.

Minkina, T.M., Motusova, G.V., Nazarenko, O.G., Mandzhieva, S.S., 2010. Heavy metal compounds in soil: Transformation upon soil pollution and ecological significance. Nova Science Publishers Inc. New York, USA. 184p.

Minkina, T.M., Soldatov, A.V., Motuzova, G.V., Podkovyrina, Yu.S.,Nevidomskaya, D.G., 2013. Molecular–structural analysis of the Cu(II) ion in ordinary chernozem: evidence from XANES spectroscopy and methods of molecular dynamics. *Doklady Earth Science* 449(2): 418-421.

Minkina, T.M., Soldatov, A.V., Nevidomskaya, D.G., Motuzova, G.V., Podkovyrina, Yu.S.,Mandzhieva, S.S., 2016. New approaches to studying heavy metals in soils by X-ray absorption spectroscopy (XANES) and extractive fractionation. *Geochemistry International* 54(2): 197-204.

Natoli, C.R., 1984. Distance dependence of continuum and bound state of excitonic resonances in X-ray absorption near edge structure (XANES), in: Hodgson, K.O., Penner-Hahn, J. (Eds.), EXAFS and Near Edge Structure III. Springer Proceedings in Physics 2. Springer, Berlin, pp. 38-42.

Nevidomskaya, D.G., Minkina, T.M., Soldatov, A.V., Shuvaeva, V.A., Zubavichus, Y.V., Podkovyrina, Yu.S., 2016. Comprehensive study of Pb(II) speciation in soil by X-ray absorption spectroscopy (XANES and EXAFS) and sequential fractionation. *Journal of Soils and Sediments* 16(4): 1183-1192.

Orlov, D.S., Sadovnikova, L.K., Sukhanova, N.I. 2005. Soil chemistry. VyshshayaSchkola, Moscow, Russia. [in Russian].

Perelomov, L.V., 2001. Immobilization factors of heavy metals in gray forest and alluvial soils of the Central Russian upland. Dissertation, Moscow, Russia. [in Russian].

Ponizovskii, A.A., Mironenko, E.V., 2001. Mechanisms of lead (II) sorption in soils. *Eurasian Soil Science* 34: 371-381.

Ponizovskii, A.A., Studenikina, T.A., Mironenko, E.V., 1999. Adsorption of copper (II) ions by soil as influenced by organic components of soil solutions. *Eurasian Soil Science* 32: 766-775.

Strawn, D.G., Baker, L.L., 2009. Molecular characterization of cupper in soils using X-ray absorption spectroscopy. Environmental Pollution 157(10): 2813-2821.

Vinogradov, A.P., 1957. Geochemistry of rare and dispersed chemical elements in soils. Moscow, Russia. [in Russian].

Vodyanitskii, Yu.N., 2008. Affinity of heavy metals and metalloids for carriers in contaminated soils. *Agrokhimiya* 9: 87-94.

Vodyanitskii, Yu.N., 2010. Study of Zn and Pb carrier phases in soils by chemical fractionation and synchrotron X-ray. *Agrokhimiya* 8: 77-86.

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Effect of mulch types on nutrient composition, maize (*Zea mays* L.) yield and soil properties of a tropical Alfisol in Southwestern Nigeria

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Abstract

Field investigations were carried out to evaluate the influence of shrub and herbaceous mulch types on soil properties and nutrient composition of maize (*Zea mays* L.) at the Teaching and Research Farm of the Federal University of Technology, Akure in the rainforest zone of southwestern Nigeria in 2013 and 2014 respectively. The shrub mulch; *Gliricidia sepium* and *Tithonia diversifolia*, herbaceous mulch; *Calopogonium mucunoides* and *Moringa oleifera* were applied at the rate of 5 t ha^{-1}. Application of NPK (20:10:10) fertilizer at the rate of 200 kg ha^{-1} was included as the standard treatment for the experiments. The treatments were laid out in randomized complete block design (RCBD) with three replication. The growth, agronomic parameters and nutritional quality of maize (*Zea mays* L.) were monitored and determined in both experiments. Results indicated that herbaceous mulch types and NPK fertilizer significantly ($P<0.05$) increased the number of leaves, plant height and leaf area when compared with the control in both years. Significant increases in yield parameters over the control were obtained for the NPK fertilizer treatment. In 2013 and 2014 cropping season NPK 20-10-10 treatment significantly produced the highest cob yield but was not significantly higher than the yield from *Gliricidia sepium* treatment in 2014. Soil organic carbon, total nitrogen (N), potassium (K), and exchangeable cations were positively stimulated by herbaceous mulches while residual phosphorus (P) was increased by NPK fertilizer treatment. Mulched treatments significantly increased crude protein, carbohydrate, nitrogen, phosphorus and ash content of maize grain in both years of cropping season thereby improving nutritional content of maize grain. Therefore, shrub and herbaceous mulch treatments applied at 5t/ha^{-1} could be applied alternatively in lieu of scarce and expensive inorganic fertilizer for improved maize yield, soil properties and nutrient composition.

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Introduction

Mulching is an effective method of manipulating crop growing environments in order to increase yield and improve product quality by controlling weed growth, reducing soil temperature, conserving soil moisture, reducing soil erosion, improving soil structure and enhancing organic matter content of the soil. Mulches are used for various reasons but water conservation and erosion control are the most important objective for its

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use in agriculture in dry regions. Other reasons for mulch use includes soil temperature modification, soil conservation, nutrient addition, improvement in soil structure, weed control and crop quality control. Mulching reduces deterioration of soil by way of preventing runoff and soil loss, minimizes weed infestation and checks water evaporation. Thus, it facilitates more retention of soil moisture and helps in control of temperature fluctuations, improves physical, chemical and biological properties of soil, as it adds nutrients to the soil and ultimately enhances the growth and yield of crops (Bhatt and Kheral, 2006; Anikwe et al., 2007; Sarkar and Singh, 2007; Glab and Kulig, 2008). Inyang (2005), revealed that mulch materials improved soil physicochemical properties, reduced soil temperature and evaporation, and increased the soil moisture content, thereby creating enabling soil microclimatic condition for crop growth.

Maize (*Zea mays* L.; family Poacea) ranks second to wheat in the world's cereal production. Wheat, rice and maize are the most important cereal crops in the world but maize is the most popular due to its high yields, ease of processing and digestion, and being cheaper than other cereals (Jaliya et al., 2008). Ayoola and Adeniyan (2006) reported that the use of inorganic fertilizers was not helpful under intensive agriculture because they were often associated with reduced yield, nutrient imbalance, leaching and pollution of groundwater (Sridhar and Adeoye, 2003). As the mineral fertilizer alone cannot meet the requirements of crops and cropping systems because of high cost and also environment related risks involved in its application and usage, integrated use of organics and inorganics is desired to attain the sustainability of a cropping system (Rao et al., 2002). Inorganic fertilizer use alone is inadequate to alleviate the physical and biological degradation of soil. The use of organic manure as fertilizer releases many important nutrients into the soil and also nourishes soil organisms, which in turn slowly and steadily make minerals available to plants (Erin, 2007). Soil amendment with manures, municipal biosolids, and other organic wastes has been found to improve the physical and chemical properties of soil (Barzegar et al., 2002; Mkhabelaa and Warmanb, 2005; Simon et al., 2013; Unagwu et al., 2013).

Moringa oleifera is one of the known promising exotic multipurpose tree species recommended for fuel wood, fodder, food, medicinal value and soil fertility improvement. *Moringa* is suggested as a viable supplement of dietary minerals. The pods and leaves of *Moringa* contain high amounts of Ca, Mg, K, Mn, P, Zn, Na, Cu and Fe (Aslam et al., 2005). The species has been reported to improve crop yield by improving soil fertility and providing semi-shade, useful in intercropping systems where intense direct sunlight can damage crops (Folkard and Sutherland, 1996). Early contact of *M. oleifera* leaf extracts with seeds of cereals enhanced germination of sorghum, length of maize radicals and hypocotyls of wheat. In the wake of skyrocketing global prices of inorganic fertilizers, land and water pollution associated with use of inorganic fertilizer and the contribution of inorganic fertilizer to climate change, there is a need to search for alternative sources of plant nutrients. *M. oleifera* is one such alternatives being investigated to ascertain their effects on growth and yields of crops. Sangakkara et al. (2005) reported that gliricidia leaves with a lower C:N ratio had a better impact on soil properties and crop growth. In the guinea savanna zone of Nigeria, Atayese and Liasu (2001) found that soil under *Tithonia* and siam weed had higher pH, porosity, moisture content, N, P, K, Na, Ca, mycorrhizal fungi spores and earthworm cast density and lower bulk density compared with bare soil. *Tithonia* has been found to produce high biomass and was reported as an effective biomass for mulching, increasing yield of rice and tomato (Liasu and Achakzai, 2007) and also an effective nutrient source for maize, beans and vegetables in Kenya, Malawi and Zimbabwe (Jama et al., 2000) and yam in Nigeria (Adeniyan et al., 2008). *Tithonia* is known to be rich in N, P and Ca (Taiwo and Makinde, 2005; Liasu and Achakzai, 2007), Olabode et al., (2007) reported that *Tithonia diversifolia* with its high nutrient status is a potential soil improver for enhanced productivity. The plant is recommended for use as a green manure or as a major component of compost manure. Dried *Tithonia* plants should also be preferably left to decompose on the field rather than burning them. Reducing fallow periods with sown leguminous plants such as *Calopogonium mucunoides* was also found to be a technically feasible, low-input method of improving soil nutrient levels for rice cropping in the Guinea and Sudan savannah regions of northern Ghana (Yiridoe et al., 2006).

Thus, the objectives of this study was to: (i) evaluate the effects of herbaceous mulch types, namely, *Moringa oleifera, Gliricidia sepium*, *Tithonia diversifolia*, *Callopogonium mucunoides*, and NPK 20:10:10 on soil health and fertility status, (ii) evaluate the effects of herbaceous mulch types and NPK 20:10:10 on growth and yield of maize; and (iii) assess potential increase in nutrient uptake and composition of maize as affected by mulching and chemical fertilization.

Material and Methods

Geology and vegetation of the study area

The study area (Akure), Ondo state Nigeria lies on latitude $7^{0}17^{1}$North of the Equator and on longitude 15^{0} 14^{1} east of the Greenwich meridian. It stands on an altitude of about 370 meters above the sea level. The study area also has hilly adjourning land which extends toward the bordering town of Ado-Ekiti (Ekiti state) and are studded with granite formations believed to be of volcanic origin spreading over an area of 99,287km^{2}. The study area falls into the pre-Cambrian exposed order granite belt, with formation dates back as far back as 600 to 3500 million years ago. Topographically, the site is generally flat and soil area generally falls into large quantity of red laterite and very little of mangrove swamp soil of humid tropical Equatorial area. Climatically, the study area has a tropical climate and belongs to the equatorial rain forest belts. The study area also has lots of adjourning creaks and lagoons, bordering the Atlantic Ocean, which are naturally separated one from another by mangrove swamps of raffia swamps. After this lies the well-drained rain forest region, which stretches to about two hundred kilometers inland.

Description of the experimental site

The experiment was conducted at the Crop Section of the Teaching and Research Farm of the Federal University of Technology Akure, Ondo State, Nigeria located at obanla within the University premises. The area lies within the tropical rainforest belt (7^{0} 17’N, 15^{0} 14’E). The rainfall pattern of Akure is bimodal with a wet season of about eight months occurring between April and October and with a brief dry spell which in most cases occur in the second half of August. The peak rainfall periods are June/July and September/October while the short dry season lasts from November to March. The mean daily temperature ranges from 27^{0}C to 37^{0}C throughout the duration of the study (Agro-climatological and Ecological Project, Ondo State Ministry of Agriculture).

Land preparation

The experimental field was mechanically cleared, ploughed and harrowed. The experimental layout was done and sectioned into blocks and plots.

Source of materials

Improved maize variety TZSR-Y-1 (streak resistant) was collected from the Ondo State Agricultural Development Project Seed Centre in Akure, Ondo state Nigeria.

Planting and cultural practices

The seeds of maize (*Zea mays* L.) were sown in an already prepared experimental field manually at 3 cm depth. Maize was sown at a spacing of 60 x 30 cm (55,555 plants/ha) with the total number of twenty-eight (28) maize plants per plot. Weed control was done manually by hand pulling and hoeing. Weeding was done three times throughout the cropping season. The first, second and third weeding were carried out at the 2nd, 6th and 9th weeks after planting. Weeds were not allowed to thrive before weeding was carried out in the experimental plots. Weeds uprooted were packed out of the experimental plots, so as not to interfere with the results of the experiment.

Field experiments

The experiments was laid out in a randomized complete block design (RCBD) and lasted for three months with each treatment replicated thrice. Each replicate consisted of six (6) treatments. Total land area measured 207 m^{2} (23 m by 9 m) with 24 plots in all and each plot size measured 2 m by 2 m (4 m^{2}) with 1 m alley ways between plots and replicates. The first experiment was carried out between 2nd of September to 30th November, 2013 and the second experiment was carried out between 1st of May to 30th of July, 2014 at the same experimental site. Fresh prunnings of leaf and stems of shrubs (*Tithonia diversifolia* and *Gliricidia sepium*) and herbaceous mulch prunnings of (*Moringa oleifera* and *Calopogonium mucunoides*) were collected from the Agroforestry and tree crop unit at the teaching and research farm of the Federal University of Technology Akure. These fresh leaf and stem prunnings were chopped, weighed and tilled into the soil using traditional hoe at the rate of 5 t/ha^{-1} across designated treatment blocks and plots while NPK 20:10:10 was applied at the recommended rate of 200 kg ha^{-1} using the side placement method.

Data collection and sampling techniques

Data collection commenced a week after the application of treatments at 3 weeks after planting (WAP). Data on agronomic characteristics like plant height and number of leaves were collected fortnightly at the 3rd, 5th, 7th, 9th and 11th WAP and leaf area was taken at 8 WAP. Yield and yield components were also analyzed after harvesting. Plant height were measured with a meter rule and number of leaves by direct counting of the leaves. Leaf area was measured with leaf area metre. To determine dry matter yield the two middle rows from each plot at maturity were harvested after removing cobs, stacked for uniform drying, weighed and then converted to kg ha^{-1} using the following formula:

$$\text{Dry matter yield (kg ha}^{-1}) = \text{kg stover yield m}^{-2} \times 10{,}000 \text{ m}^2 \qquad (1)$$

Shelling percentage was calculated using the following formula:

$$\text{Shelling percentage (\%)} = \frac{\text{Grain weight of four ears}}{\text{Total weight of four ears}} \times 100 \qquad (2)$$

Grain Yield: For determining the grain yield, the two middle rows from each plot at maturity were harvested, husked, dried and threshed. Grain yield was calculated and converted to kg ha^{-1} using the following formula:

$$\text{Grain yield (kg ha}^{-1}) = \text{kg grain yield m}^{-2} \times 10{,}000 \text{ m}^2 \qquad (3)$$

Biomass yield: At maturity, four central rows in each plot were harvested, dried to constant weight and weighed.

$$\text{Biomass yield (kg ha}^{-1}) = \frac{\text{Biomass yield per plot}}{\text{Plot area harvested}} \times 10{,}000 \text{ m} \qquad (4)$$

Harvest Index: Harvest index was calculated using the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Biomass yield (kg ha}^{-1})} \times 100 \qquad (5)$$

Soil sampling and physico-chemical analysis

The Soil at the experimental site is a clay loam alfisol classified as clayey skeletal oxic-paleustaif, five core samples were collected at random from each treatment plot with the aid of a soil auger at a depth of (0-15cm). The collected core samples were homogenized and a total of twenty four composite soil samples were collected from the trial sites for determination of chemical properties before planting and after harvest. The samples were air dried at room temperature, crushed and sieved through a 2mm mesh and subjected to particle size analysis using the Bouyoucos (1951) method. The soil pH was determined by using 1:2 of 10 g of soil to 20 ml distilled water ratio suspension. The suspension was stirred for 30 minutes and determined by glass electrodes pH meters which were standardized with a buffer of pH 7. Total nitrogen in the soil was analysed using Kjeldahl method, while available phosphorus was extracted using Olsen's extract and the P in the extract was determined via the use of spectrophotometer. The organic matter was determined using Walkley-Black (1934) wet Oxidation method. Potassium (K^+), Calcium (Ca^{2+}), Sodium (Na^+), and Magnesium (Mg^{2+}) were extracted by 1M Ammonium acetate (NH_4OAC), at pH 7 and the extracts were determined on a flame photometer while Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) were determined by ethylene di-amine tetra acetic acid (EDTA) titration (AOAC, 1997).

Determination of Proximate composition of maize grain

Moisture content

The moisture content was estimated by drying triplicates 10g weight of the maize grain sample at 105oC for 24hr and then reweighing after cooling in a desiccator. The moisture content is expressed as percentage of the dry weight.

$$\text{Moisture content} = \frac{\text{Weight loss of sample}}{\text{Weight of the original sample}} \times 100 \qquad (6)$$

(AOAC, 1997)

Ash Content

Two grams of grinded maize grain dried sample was weighed in to a dry porcelain dish and then heated in a muffle furnace at 6000C for 6 hours. It was cooled in desiccators and weighed. The percentage ash content was calculated thus:

$$\% \text{ Ash} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100 \quad (7)$$

(AOAC, 1997)

Fat content

The fat content was determined using Soxhlet extraction method. The amount of oil produced was calculated and expressed as percentage of original sample.

$$\% \text{ Fat} = \frac{\text{Weight loss of sample (extracted fat)}}{\text{Weight of sample}} \quad (8)$$

(AOAC, 1997)

Crude Protein

One gram of each grinded maize grain sample was weighed into a digestion flask. Ten grammes of potassium sulphate, 0.7g mercuric oxide and $20cm^3$ concentrated sulphuric acid were added to the sample in the digestion flask. The flask was heated gently at an inclined angle after cooling 90ml of distilled water was added and mixed. A small piece of pumice was added to prevent bumping. 80ml of 2M sodium hydroxide solution was added while tilting the flask so that two layers are formed. The condenser unit was rapidly connected, heated and the distilled ammonia collected in 50ml boric acid / methyl red indicator. Fifty millilitres of the distillate was collected and titrated against 0.1M hydrochloric acid solution. The percentage nitrogen content percent was calculated thus:

$$\% \text{ N} = \frac{\text{(Volume of acid x Molarity of standard acid)}}{\text{Weight of sample (g)}} \times 0.014 \times 100 \quad (9)$$

% Crude protein content = nitrogen content x 6.25 (AOAC, 1997) (10)

Total Carbohydrate

The total carbohydrate was determined by differential method. This was achieved by subtracting the total protein, fat, moisture and ash content from 100 thus:

% carbohydrate = (100 – (% moisture + % ash+ % fat + %protein + %fibre) (AOAC, 1997) (11)

Data analysis

The data obtained on the morphological characteristics, yield and yield components were analyzed statistically using the Analysis of Variance. Data were analyzed using SPSS 17th edition and the treatment means comparison done with the Tukey's HSD test.

Results and Discussion

Soil chemical properties as affected by mulch types

Table 1 shows the nutrient status and soil pH of the experimental site before the application of treatments. The pH of the soil was 5.77 and the values of OC, OM, N, P and K in the soil were 1.44 g kg^{-1}, 2.48 g kg^{-1}, 0.36 g kg^{-1}, 2.52 mg kg^{-1} and 0.67 cmol kg^{-1} respectively. The other exchangeable bases such as Na, Ca and Mg were 0.16 cmol kg^{-1}, 2.50 cmol kg^{-1} and 1.00 cmol kg^{-1} respectively. Soil particle fraction showed that the soil was a clay loam in texture indicating its low organic matter content and high percentage of clay. The soil was characterized by moderate acidity with pH value of 5.77. The fertility of the soil was low compared with established critical levels in a tropical alfisols. The organic matter content was low compared to the critical level of 20-30 g kg^{-1} reported by Enwezor et al. (1979). The soil was deficient in N compared with the critical values of 1.5 – 2.0 g kg^{-1} reported by Sobulo and Osiname (1981) while P was deficient based on the critical values of 10-16 mg kg^{-1} established by Adeoye and Agboola (1985). The K component of the soil was high compared to the critical levels of 0.16-0.25 cmol kg^{-1} indicated by Adeoye and Agboola (1985). The magnesium and calcium were sufficient compared with 0.2- 0.4 cmol kg^{-1} critical values of Adeoye and

Agboola, (1985) and 2.50 cmol kg-1 critical levels of Akinrinde and Obigbesan (2000) respectively. All the treatments utilized in this study were analyzed and found to contain N, P, K, Ca, Mg and a host of other mineral elements in appreciable amounts.

Table 1. Pre-Planting Physico-chemical properties of experimental site at a depth of (0-15cm)

Properties	**Values**
Physical properties (g kg^{-1})	
Sand	32.80
Silt	30.00
Clay	37.20
Textural class	Clay loam
Chemical properties	
pH in H_2O (1:1)	5.77
Organic carbon (g kg^{-1})	1.44
Organic matter (g kg^{-1})	2.48
Available P (mg kg^{-1})	2.52
Total N (g kg^{-1})	0.36
Exchangeable bases (cmol kg^{-1})	
Ca	2.50
Mg	1.00
K	0.67
Na	0.16

*Mean values of three replicates of soil sample are presented in the table

Table 2, shows that *Gliricidia sepium* has the highest content of N among the mulch materials, while *Calopogonium mucunoides* also had a relatively high N contents of 5.10%. However, *Tithonia diversifolia* had N content of 6.64% which was higher than that of *Calopogonium mucunoides,* the mechanism behind this high N content in *Tithonia diversifolia* when compared with *Calopogonium mucunoides* a known leguminous N fixer need to be studied. Other nutrient elements that were analyzed are P, K, Ca and Mg. NPK 20-10-10 fertilizer had the highest P content (9.65%) amongst the treatment, *Moringa oleifera* (7.30%) and *Gliricidia sepium* (2.29%) had the highest and lowest P content respectively amongst the mulch types. *Moringa oleifera* also contain higher Ca and Mg content (5.72 and 2.44 mg/kg) while *Tithonia diversifolia* (2.70mg/kg) contains the lowest Ca and *Calopogonium mucunoides* (1.28 mg/kg) the lowest Mg content. K content was highest in NPK fertilizer treatment (9.74%) and lowest in *Tithonia diversifolia* (2.41%) while *Moringa oleifera* had the highest K content (6.84%) amongst the mulch types. The effect of shrub and herbaceous mulch type's application on soil chemical properties after maize harvest are presented in Table 3. Significant increase with respect to soil pH after maize harvest was observed in all mulched treatments in comparison with the control and NPK standard rate. *Gliricidia sepium* and *Tithonia diversifolia* (5.69 and 5.67) mulched plots recorded higher soil pH levels over other mulched plots, control plot and NPK standard (Table 3).

Table 2. Chemical composition of shrub mulch and 20:10:10 NPK fertilizer

Elements	NPK	*Moringa oleifera*	*Gliricidia sepium*	*Tithonia diversifolia*	*Calopogonium mucunoides*
N (%)	18.25	4.55	7.18	6.64	5.10
P (%)	9.65	7.30	2.29	5.80	6.40
K (%)	9.74	6.84	3.65	2.41	4.52
Ca (mg/kg)	1.87	5.72	4.26	2.70	3.00
Mg (mg/kg)	1.21	2.44	1.50	1.58	1.28

The increase in soil pH might be due to the effect of the chopped herbaceous mulch and shrub which tend to improve on soil exchangeable bases while reducing exchangeable acidity thereby reducing soil acidity, similar results were also observed by Egbe et al. (2012). Soil organic carbon (SOC) of mulched plots was also increased significantly with *Calopogonium mucunoides* (1.99 g/kg) recording the highest SOC rate over all other treatments which includes the control and NPK treatment. The organic carbon accumulation in the herbaceous mulch treatment is a result of balance from subtraction by decomposition process and additions from synthesized humus from shrubs and herbaceous mulch. The incorporation of this mulch types improved the SOC better than the control and NPK standard rate. This can be attributed to the presence of more nutrients and organic carbon in the herbaceous mulch. The result of this study is similar to the findings of Tejeda et al. (2007) who reported that the application of leguminous residue had a positive effect on soil physical, chemical and biological properties and could be considered as a good alternative for improving low nutrient soils. With respect to soil nitrogen content, *Calopogonium mucunoides* and *Gliricidia sepium* mulched plot (0.76 g/kg) respectively recorded a significant increase over the control treatment (0.12 g/kg) and the NPK standard treatment (0.42 g/kg). A significant increase in soil available P was recorded in the *Moringa oleifera* mulch treatment (4.24 mg/kg) and the NPK standard treatment (5.06 mg/kg) when compared with other treatments. The benefit of using organic herbaceous mulch and shrubs is to release trapped atmospheric nitrogen and make it available as a biological source of nitrogen in a mulched plot for a following crop. These herbaceous mulch conserve soil moisture, increase soil organic matter and improves soil properties and microbial activity thereby supporting mineralization rate and release of nutrient such as N, P and K into the soil. This could be the rationale behind the increased nitrogen and potassium content in the shrubs and herbaceous mulch treated plots thereby contributing to better maize growth, biomass and yield in this mulch treatment over other mulch treatments. A significant increase in exchangeable bases was observed in the shrub and herbaceous mulched treatments. *Moringa oleifera* and *Calopogonium mucunoides* mulched plot reflected significant increase in soil Ca levels when compared with all other treatments (3.90 and 3.20 cmol/kg respectively), while *Gliricidia sepium* (0.80 cmol/kg) and *Calopogonium mucunoides* (1.40 cmol/kg) recorded significant increase in Mg levels. *C. mucunoides* and *Moringa oleifera* also significantly increased K levels (1.62 and 1.03 cmol/kg) respectively amongst the mulched treatments. All treatments significantly increased soil Na levels when compared to the un-mulched control treatment, however *Moringa oleifera* mulched plot recorded marginal higher Na values (0.16 cmol/kg) above other treatments. This probably had a stimulatory effect on the soil pH which influenced the reduction in exchangeable acidity of the soil and slightly raised the soil pH in all mulched treatments. The findings of this study revealed that exchangeable bases and soil fertility increased in herbaceous mulch and shrub treated plots corroborates earlier findings that leguminous shrubs are sources of utilizable N, P, K, Ca, Mg and organic matter (Awodun et al., 2007). This also confers liming characteristics to some herbaceous mulch and shrubs such as *Calopogonium mucunoides*, *Moringa oleifera*, *Gliricidia sepium* and *Tithonia diversifolia*. The soil is a very important medium for crop growth with significant bearing on physical, chemical and biological functions influencing plant productivity. Optimal application of organic mulch over a given field can influence soil properties such as, texture, organic matter, salinity, porosity, moisture content and subsoil characteristics which are critical factors that can influence crop yield.

Table 3. Soil chemical properties of treatments (0 – 15cm) after maize harvest in 2014

Treatments	pH (H_20)	OC (g/kg)	P (mg/kg)	N (g/kg)	Ca (cmol/kg)	Mg (cmol/kg)	K (cmol/kg)	Na (cmol/kg)
Control	5.32c	0.44d	1.28d	0.12d	1.10d	0.09d	0.24d	0.04b
NPK 20-10-10	5.15c	1.52c	5.06a	0.42c	1.90b	0.40c	0.59c	0.13a
M. oleifera	5.34abc	1.72b	4.24ab	0.60ab	3.90a	0.70b	1.03a	0.16a
G. sepium	5.69ab	1.53c	1.79c	0.76a	1.60b	0.80b	0.85b	0.12a
T. diversifolia	5.67ab	1.74b	3.71b	0.63ab	1.50c	0.70b	0.92b	0.13a
C. mucunoides	5.15c	1.99a	3.58b	0.76a	3.20a	1.40a	1.62a	0.13a

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD test

Effects of the applications of mulches and NPK fertilizer on growth parameters of maize during the 2013 and 2014 cropping season

Tables 4 and 5 show the effects of herbaceous mulches and NPK fertilizer on number of leaves per maize plant at two weeks intervals over a period of 9 weeks after treatment applications in 2013 and 2014 cropping seasons. In both years, there were no significant differences in the numbers of leaves of maize at 3WAP. In both years all herbaceous mulch treatments and NPK fertilizer significantly increased the number of leaves produced when compared with the control at 5, 7 and 9 weeks after treatment application. There were variations in the number of leaves in their response to treatments. Significant increases in plant height over the control were obtained for all the treatments throughout the period of growth of maize with the NPK fertilizer consistently producing plants with the tallest height (Tables 6 and 7). It was also observed in both years that the number of leaves reduced in 11WAP as a result of shedding of leaves. In both years, all the mulches and NPK fertilizer significantly increased maize leaf area throughout the evaluation period when compared with the control (Tables 8 and 9). NPK manifested the highest leaf area throughout the evaluation period. The significant increases in leaf number, plant height and leaf area of maize obtained with the application of mulches throughout the evaluation period over the control suggests that they constitute an excellent source of mineral nutrients needed for plant growth. It was observed that NPK 20:10:10 fertilizer release of nutrient was quick as observed in the rapid physiological growth rate of maize plant on the experimental field immediately after inorganic fertilizer application. However, 21 days after shrub and herbaceous mulch application, the transient effect of the mulches on maize physiological growth became more pronounced than that of the inorganic fertilizer due to increasing rate of mineralization through the action of soil microbes. This agrees with the finding of Erin (2007), on the use of organic amendment as fertilizers, which releases many important nutrients into the soil and also nourishes soil organisms, which in turn slowly and steadily make minerals available to plants. The superior growth parameters and early tasseling in maize crop observed in this study and corroborated by earlier researcher (Uwah et al., 2011) could be attributed to the relatively available and fast release of nutrients inherent in the herbaceous mulch which promoted vigorous foliage, increased meristematic and intense physiological activities in plants which aided synthesis of more photo-assimilates.

Table 4. The effects of mulches and NPK on the number of leaves at different stages of growth of maize in 2013

	Number of leaves				
Treatments	3weeks	5weeks	7weeks	9weeks	11weeks
Control	5.00a	6.67a	8.00d	10.33ab	9.67bc
NPK (20:10:10)	5.33a	8.00a	10.00a	11.00a	10.67ab
M. oleifera	5.00a	7.00a	8.33cd	10.33ab	10.33ab
G. sepium	5.33a	7.00a	9.67ab	10.33a	10.33ab
T. diversifolia	5.00a	7.00a	9.33abc	10.00ab	10.00ab
C. mucunoides	5.00a	6.67a	9.33abc	11.00a	10.67ab

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD test.

Table 5. The effects of mulches and NPK on the number of leaves at different stages of growth of maize in 2014

	Number of leaves				
Treatments	3weeks	5weeks	7weeks	9weeks	11weeks
Control	6.00ab	8.00b	9.33bc	11.33b	11.00c
NPK (20:10:10)	6.67a	9.00a	11.00a	13.67a	13.00a
M. oleifera	6.33a	8.00b	10.00b	11.67b	11.67bc
G. sepium	6.33a	8.00b	10.33ab	12.00b	11.67abc
T. diversifolia	6.67a	8.33ab	10.00b	11.67b	11.33bc
C. mucunoides	6.67a	8.67a	10.33ab	11.67b	2.67ab

*Means followed by the same letter within each column are not significantly different (P= 0.05) as indicated by Tukey's HSD Test

Table 6. The effects of mulches and NPK on plant height (cm) at different stages of growth of maize in 2013

	Plant height(cm)				
Treatments	3weeks	5weeks	7weeks	9weeks	11weeks
Control	33.56a	70.20b	84.71d	118.19d	121.04d
NPK (20:10:10)	31.59a	94.89a	145.22a	201.64a	205.99a
M. oleifera	30.19a	67.36b	87.92d	117.48d	121.99d
G. sepium	32.43a	74.07b	122.00b	163.75b	167.78b
T. diversifolia	30.58a	71.08b	112.02bc	147.85bc	153.58bc
C. mucunoides	30.74a	63.79b	104.52bcd	134.32cd	137.75cd

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD Test.

Table 7. The effects of mulches and NPK on plant height (cm) at different stages of growth of maize in 2014

	Plant height(cm)				
Treatments	3weeks	5weeks	7weeks	9weeks	11weeks
Control	40.71a	71.67c	108.45e	160.71d	165.75e
NPK (20:10:10)	43.64a	106.85a	168.35a	239.81a	237.73a
M. oleifera	33.83a	86.52bc	130.31cd	168.13cd	175.18de
G. sepium	34.10a	90.42abc	135.65bcd	179.11cd	185.25cd
T. diversifolia	33.98a	91.27ab	121.55de	175.29cd	183.43cde
C. mucunoides	33.85a	84.68bc	119.67de	170.18cd	178.89de

*Means followed by the same letter within each column are not significantly different (P= 0.05) as indicated by Tukey's HSD Test

Table 8. The effects of mulches and NPK on leaf area (cm^2) at 8 WAP of maize in 2013

	Leaf area (cm^2)

Treatments	
Control	197.88e
NPK (20:10:10)	399.79a
M. oleifera	199.87e
G. sepium	360.74ab
T. diversifolia	222.35de
C. mucunoides	297.66bc

*Means followed by the same letter within each column are not significantly different (P= 0.05) as indicated by Tukey's HSD Test

Table 9. The effects of mulches and NPK on leaf area (cm^2) at 8 WAP of maize in 2014

	Leaf area (cm^2)
Treatments	
Control	372.44cd
NPK (20:10:10)	488.22a
M. oleifera	388.22cd
G. sepium	401.55c
T. diversifolia	436.44bc
C. mucunoides	438.15bc

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD Test

Effects of mulches and NPK fertilizer on maize yield parameters at the end of the 2013 and 2014 cropping season

The trend in biomass yield as affected by treatments is similar in both years (Tables 10 and 11). The NPK fertilizer significantly increased biomass yield over the mulch treatments and control. The NPK and *Calopogonium mucunoides* gave the significantly highest biomass yield in the first year but NPK had the highest biomass yield in both years while control gave the lowest yield. Significant differences in grain yields were also observed among the treatments in both years (Tables 10 and 11).

Table 10. Effects of mulches and NPK fertilizer on maize yield parameters at the end of 2013 cropping season

Treatment	Dry matter ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Biomass Yield ($t\ ha^{-1}$)	Shelling percentage (%)	Harvest index (%)
Control	0.98d	0.63d	3.05c	70.31ab	20.66bc
NPK (20:10:10)	2.32a	2.19a	7.55a	72.10ab	29.01ab
M. oleifera	1.29cd	0.66d	3.11c	64.29b	21.22bc
G. sepium	1.90ab	1.41bc	4.22bc	70.36ab	34.41a
T. diversifolia	1.75ab	1.15c	4.91bc	68.95ab	23.42bc
C. mucunoides	2.15ab	1.72b	5.64ab	76.11a	30.50ab

*Means followed by the same letter within each column are not significantly different (P= 0.05) as indicated by Tukey's HSD Test.

Table 11. Effects of mulches and NPK fertilizer on maize yield parameters at the end of 2014 cropping season

Treatment	Dry matter ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Biomass Yield ($t\ ha^{-1}$)	Shelling percentage (%)	Harvest index (%)
Control	1.94d	1.23cd	4.98d	63.97c	24.65c
NPK (20:10:10)	3.18a	2.76a	9.12a	74.66a	30.26a
M. oleifera	2.16cd	1.60c	6.28c	67.00bc	25.64bc
G. sepium	2.79ab	2.22ab	7.89b	69.70b	28.14abc
T. diversifolia	2.66b	2.15b	7.52b	65.62c	28.59abc
C. mucunoides	2.35c	2.02bc	6.91c	71.89ab	29.18ab

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD Test

NPK fertilizer gave significantly highest grain yield in the first year while the control had the lowest grain yields in both years. Furthermore, significant differences in dry matter yields among the treatments were also observed in both years of study. A comparison of the treatments indicated that the mulches and the NPK fertilizer resulted in significantly greater dry matter yields than the control; the NPK fertilizer gave significantly highest dry matter, followed by *Calopogonium mucunoides* and *Gliricidia sepium* mulches in the first and second years respectively (Tables 10 and 11). Higher shelling percentage were noted for the *Calopogonium mucunoides* mulch treatment and the NPK treatment in the first and second years respectively. These were however, not significantly different from some of the treatments in both cropping seasons. The *Moringa oleifera* and control recorded the lowest shelling percentage in 2013 and 2014, respectively but were also not significantly different from most of the treatments (Tables 10 and 11). Treatment effects exerted significant differences in harvest index in both years under study (Tables 10 and 11). *Gliricidia sepium* mulch and the NPK treatments recorded significantly greater harvest index in the first and second year respectively. The significant increases in yield parameters obtained with applications of the shrub and herbaceous mulch types over the control in this research can equally be ascribed to the steady and slow rate of nutrient release for plant uptake in the affected mulch-based plots. This is due to the adequate and regular supply of sufficient macro and micro nutrients needed for maize growth and yield. Pervaiz et al. (2009) observed that mulched treatments show significantly greater total uptake of N, P and K than corresponding un-mulched treatment. The slightly higher value recorded for *Gliridia sepium* may be ascribed to the fact that the treatment had high concentrations of N and P which after decomposition are released by mineralization for plant uptake. Egbe et al. (2012) reported that application of *Gliricidia sepium* leaf litter positively affected growth and yield of maize.

Effects of treatments on proximate and mineral composition of maize grain at the end of the 2013 and 2014 cropping season

There were significant differences in moisture contents of maize grains due to treatment effects in both years (Tables 12 and 13). The highest moisture content of maize grain was given by *Calopogonium mucunoides* and NPK in the first year while NPK had the highest moisture content in the second year (Tables 12 and 13). The results showed that different herbaceous and shrub mulch increased moisture content of maize grain as compared to the control. The high moisture content in grains obtained from *calopogonium mucunoides* mulch treatment and NPK fertilizer treatment might be due to the less evaporation of soil moisture (Rafiq et al., 2010) and weed density suppression. Thus, maximum moisture was utilized by the plant to increase grain moisture content and hence the yield (Ullah et al., 2010). Significant differences were found for ash contents amongst the treatments. The significantly highest ash content of maize grain was recorded by *Moringa oleifera* in both years (Tables 12 and 13). The significantly lowest ash content was given by *Gliricidia sepium* in the first year and Control in the second year (Tables 12 and 13). There were significant differences in fat content recorded amongst the treatments in both years (Tables 12 and13). The control treatment recorded the highest fat content in both years, which was not significantly different from *Calopogonium mucumoides* and *Moringa oleifera* in the first year. The lowest fat content was given by *Gliricidia sepium* in the first year and *Calopogonium mucunoides* in the second year (Tables 12 and 13). Crude fat is one of the most important components of maize grains; increase in fat content is essential for human health. Earlier studies by Farhad et al. (2009) reported mulching to be useful for the enhancement of maize grains quality. Significant differences in protein content occurred among the treatments in both years (Tables 12 and 13). Significantly the lowest protein content of maize grain was given by the control in both years while the highest protein content was given by *Gliricidia sepium* in the first year and *Moringa oleifera* in the second year (Tables 12 and 13). According to Rafiq et al. (2010), mulching helps in conserving moisture content as well as improve soil fertility which could in turn increase protein content of the grains. Boomsma et al. (2009) opined that availability of sufficient soil N and moisture for plants can lead to higher chlorophyll contents and photosynthetic activity which could produce grains with higher protein content. There were significant differences in crude fibre contents amongst the treatments in both years (Tables 12 and 13). Significantly the highest crude fibre of maize grain was recorded by NPK treatment in both years. The NPK treatment was not statistically better than that given by *Moringa oleifera* in both years. Significantly lowest crude fibre content was recorded by *Calopogonium mucunoides* in both years (Tables 12 and 13). Brunilda (2010), reported that the use of mulch could reduce fibre content of maize grains which could be beneficial for animal feed production and human health. Findings from the study indicate a significant CHO content in the *Tithonia diversifolia* mulch treatment when compared with other mulch treatments in the first year. Results from the second year indicate a statistical significant CHO content in the *Gliricidia sepium* mulch treatment and control treatment when compared with other mulch treatments (Tables 12 and 13). The increase or decrease in CHO content has implications on maize forage quality as there exist a positive relationship between CHO content and maize forage palatability and digestibility. An increase in the former causes an increase in the latter. This finding corroborates earlier report by Fonsca et al. (2000), who also reported the influence of higher CHO content on corn forage quality and palatability. There were significant differences observed in N contents recorded amongst the treatments in both years (Tables 12 and 13). Significantly, the highest N content of maize grain was given by *Gliricidia sepium* in both years while a significant lower N content of maize grain was given by control in both years. The N increase in maize grain from *Gliricidia sepium* mulched treatment is expected and can be ascribed to the high amount of utilizable N and organic matter content of the leguminous shrub *Gliricidia S.* due to its nitrogen fixing ability which are readily transferred, mineralized and absorbed by the maize plant after incorporation into the soil thereby increasing maize grain N content. Significant differences in P content occurred among the treatments in both years (Tables 12 and 13). *Tithonia diversifolia* and NPK treatments recorded significantly the highest P content in year one and two respectively. Values of proximate composition and mineral contents of maize grain were found to be significantly increased in the treatments involving application of mulches compared with the control. It is evident from the results obtained in this research that the values of the respective nutrient components obtained with the mulch-based treatments were generally comparable to those obtained from NPK and even better in some cases. Of all the treatments tested NPK significantly produced the highest grain yields in 2013 and 2014 cropping season while the mulch treatments improved soil organic carbon, soil nutrient status and nutrient composition of maize. The findings of this study has implication for resource poor farmers as it shows that soil fertility, maize yield and nutritional quality could be improved through the use of shrubs and herbaceous mulch with little or no recourse to inorganic fertilizer use.

Table 12. Effects of treatments on proximate and mineral composition of maize grain at the end of 2013 cropping season

Treatments	Moisture Content (%)	Ash (%)	Fat (%)	Crude Protein (%)	Crude fibre (%)	CHO (%)	N (%)	P (mg/100g)
NPK (20:10:10)	16.64a	1.48c	6.21b	5.74c	4.60a	58.40b	0.92b	5.09b
M. oleifera	13.85b	1.89a	6.74ab	7.71a	4.44a	55.43b	1.23a	3.74c
G. sepium	12.60b	1.09d	4.98c	8.26a	3.84b	60.21ab	1.32a	2.78d
T. diversifolia	12.76b	1.68b	5.96bc	5.77c	4.56a	69.26a	0.94b	6.35a
C. mucunoides	16.82a	1.61bc	6.78a	5.83c	2.95c	52.47c	0.93b	5.79a
Control	12.62b	1.89a	6.83a	5.00d	3.02c	61.09ab	0.52c	4.32bc

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD Test.

Table 13. Effects of treatments on proximate and mineral composition of maize grain at the end of 2014 cropping season

Treatments	Moisture Content (%)	Ash (%)	Fat (%)	Crude Protein (%)	Crude fibre (%)	CHO (%)	N (%)	P (mg/100g)
NPK (20:10:10)	22.42a	1.31de	5.66c	5.38c	5.13a	65.76b	1.04b	5.84a
M. oleifera	17.54b	1.98a	6.28b	6.18a	4.74a	69.27b	1.33a	4.14a
G. sepium	13.16c	1.86ab	5.96bc	5.46c	4.22b	75.30a	1.54a	4.00a
T. diversifolia	15.74bc	1.59bc	5.45c	5.74b	4.38b	72.55ab	0.96b	4.24a
C. mucunoides	18.32b	1.86ab	5.32c	5.46c	3.59c	70.77b	1.08b	4.21a
Control	14.11c	1.27de	6.74a	4.32d	3.74c	76.56a	0.48c	2.95b

*Means followed by the same letter within each column are not significantly different (P=0.05) as indicated by Tukey's HSD Test

Conclusion

The results of this study showed the advantages of using mulches for the production of maize in terms of growth, yield and nutrient composition. The trend of events in plant growth and yield observed in this research implies that organic mulch use could compete favorably with inorganic fertilizer. Plant growth, soil properties and yield monitored in this research work show that *Gliricidia sepium, Tithonia diversifolia* and *Calopogonium mucunoides* applied at 5 t/ha^{-1} enhanced the nutrient composition and yield of maize. This suggest that the above materials are good source of sustainable and efficient organic amendment which could be recommended to small holder maize farmers for improving soil properties, optimum growth and yield of maize in the study area. The nutrient composition of maize as influenced by mulches used in this research is also capable of meeting the nutritional requirement of the people. Therefore, the use of shrubs and herbaceous mulches has further lend credence to the possibility of organic materials increasing the yield, nutritional content of maize and improvement of soil properties on a tropical alfisol.

References

Adeniyan, B.O., Ojeniyi, S.O., Awodun, M.A., 2008. Relative effect of weed mulch types on soil properties and yield of yam in southwest Nigeria. *Journal of Soil and Nature* 2(3):1-5.

Adeoye, G.O., Agboola, A.A., 1985. Critical levels for soil pH, available P, K, Zn and Mg and ear leaf content of P, Cu and Mn in sedimentary soil of south western Nigeria. *Fertilizer Research* 6 (1):65-71.

Akinrinde, E.A., Obegbesan, G.O., 2000. Evaluation of fertility status of selected soil for crop production in five ecological zones of Western Nigeria. Proceeding of the 26th Annual Conference of Soil Science Society of Nigeria, 3:279-288. University of Ibadan October 30th - November 3rd 2000. 3: 279-288.

Anikwe, M.A.N., Mbah, C.N., Ezeaku, P.I., Onyia, V.N., 2007. Tillage and plastic mulch effects on soil properties and growth and yield of cocoyam (*Colocasia esculenta)* on an ultisol in south eastern Nigeria. *Soil and Tillage Research* 93(2): 264-273.

AOAC, 1997. Association of analytical communities official method 973.18, fiber (acid detergent) and lignin in animal feed. Official methods of analysis of AOAC International. 16th ed. Arlington: ASA-SSA Inc. pp 28–29

Aslam, M., Anwar, F., Nadeem R., Rashid, U., Kazi, T.G., Nadeem, M., 2005. Mineral composition of *Moringa oleifera* leaves and pods from different regions of Punjab, Pakistan. *Asian Journal Plant Science* 4(4): 417-421.

Atayese, M.O., Liasu, M.O., 2001. Arbuscular mycorrhizal fungi weeds and earthworm interactions in the restoration of soil fertility in the guinea savanna region of Nigeria. *Moor Journal of Agriculture Research* 3: 104-109.

Ayoola, O.T., Adeniyan O.N., 2006. Influence of poultry on yield and yield components of crops under different cropping systems in South west Nigeria. *African Journal of Biotechnology* 5(15): 1386-1392.

Awodun, M.A., Odogiyan, A., Ojeniyi, S.O., 2007. Effect of gliricidia pruning on soil and plant nutrient status and yield of cowpea. *International Journal of Agricultural Research* 2: 402-405.

Barzegar, A. R., Yousefi, V., Daryashenas, A., 2002. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. *Plant Soil* 247(2): 295-301.

Bhatt, R., Kheral, K.L., 2006. Effect of tillage and mode of straw mulch application on soil erosion in submontaneous tract of Punjab, India. *Soil and Tillage Res*earch 88(1-2): 107-115.

Boomsma, C.R., Santini, J.B., M. Tollenaar, M., Vyn, T.J., 2009. Maize morphophysiological response to intense crowing and low nitrogen availability: an analysis and review. *Agronomy Journal* 101(6): 1426-1452.

Bouyoucos, G. J. 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. *Agronomy Journal* 43(9); 434-438.

Egbe, E.A., Fonge, B.A., Mokake, S.E., Besong, M., Fongod, A.N., 2012. The effects of green manure and NPK fertilizer on the growth and yield of maize (*Zea mays* L.) in the mount Cameroon region. *Agriculture and Biology Journal of North America* 3(3); 82-92.

Erin, H., 2007. "Organic Farming" Microsoft Student 2008 (DVD).WA: Microsoft Corporation, 2007. Microsoft Encarta 2008(C) 1993-2007 Microsoft Corporation.

Enwenzor, W.O., Udo, B.J., Usoroh, N.J., Ayotade, K.A., Adepetu, J.A., Chude, V.A., Udegbe, C.A., 1979. Fertilizer use and management for crops in Nigeria (Series No 2). Fertilizer Procurement and Distribution Division, Federal Ministry of Agriculture, Water Resources and Rural Development, Lagos, Nigeria. 163pp.

Farhad, W., Saleem, M.F., Cheema, M.A., Hammad, H.M., 2009. Effect of different manures on the productivity of spring maize (Zea mays L). *The Journal of Animal & Plant Sci*ences 19(3): 122 – 125.

Folkard, G.K., Sutherland, J.P., 1996. *Moringa oleifera*: a tree and a litany of potential. *Agroforestry Today* 8(3): 5-8.

Fonsca, A.J.M., Cabrita, A.R.J., Lage, A.M., Gome, E., 2000. Evalution of the chemical composition and the partical size of the Maize silage produced in north west of Portugal. *Animal Feed Science Technology* 83: 173-183

Gardner, C., 2016. Soluble and insoluble fibre: what's the difference? Available at: http://www.webmd.com/diet/fiber-health-benefits-11/insoluble-soluble-fiber [access date: 05.09.2015]

Glab, T., Kulig, B., 2008. Effect of mulch and tillage system on soil porosity under wheat *(Triticum aestivum). Soil and Tillage Research* 99(2): 169-178.

Inyang, E.U., 2005. An evaluation of tillage and storage systems applied by traditional root crop farmers in Cameroon. *Agricultural and Environmental Journal* 7(2): 15–22.

Jaliya, A.M., Falaki, A.M., Mahmud, M., Sani, Y.A., 2008. Effects of sowing date and NPK fertilizer rate on yield and yield components of quality protein maize (*Zea mays* L.). *ARPN Journal of Agricultural and Biological Science* 3(2): 23-29.

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G., Amadalo, B., 2000. *Tithonia diversifolia* as a green manure for soil fertility mprovement in western Kenya. *A Review, Agroforestry Systems*. 49(2): 201-221.

Liasu, M.O., Achakzai, A.K., 2007. Influence of *Tithonia diversifolia* leaf mulch and fertilizer application in the growth and yield of potted tomato plants. *American Eurasian Journal of Agricultural & Environmental Sciences* 2: 335-340.

Mkhabelaa, M.S., Warmanb, P.R., 2005. The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops grown in a Pugwashsandy loam soil in Nova Scotia. *Agriculture, Ecosystem & Environment* 106(1): 57-67.

Olabode, O.S., Sola, O., Akanbi, W.B., Adesina, G.O., Babajide, P.A., 2007. Evaluation of *Tithonia diversifolia* (Hemsl.) A Gray for soil improvement. *World Journal of Agricultural Sciences* 3(4): 503-507.

Pervaiz, M.A., Iqbal, M., Shahzad, K., Hassan, A.U., 2009. Effect of mulch on soil physical properties and NPK concentration in maize (Zea mays) shoots under two tillage systems. *International Journal of Agriculture and Biology* 11: 120-124

Rafiq, M.A., Ali, A., Malik, M.A., Hussain, M., 2010. Effects of mulches and plant densities on yield and protein contents of autumn planted maize. *Pakistan Journal of Agricultural Sciences* 47(3): 201-208.

Rao, A.S., Chand, S., Srivastava S., 2002. Opportunities for integrated plant nutrient supply system for crops/cropping system in different agro-eco-regions. *Fertilizer News* 47(12): 75-78.

Sangakkara, U.R., Pietsch, G., Gollner, R.M., Freyer, B., 2005. Effect of incorporating rice straw or leaves of gliricidia (*G. sepium*) on the productivity of mungbean (*Vigna radiata*) and on soil properties. In: Proceedings of ISOFAR Conference, Adelaide, Australia.

Sarkar, S., Singh, S.R., 2007. Interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (*Hordium vulgare* L.). *Soil and Tillage Research* 92(1-2): 79-86.

Simon, T., Mikanová, O., Cerhanová, D., 2013. Long-term effect of straw and farmyard manure on soil organic matter in field experiment in the Czech Republic. *Archives of Agronomy and Soil Science* 59(9): 1193-1205.

Sobulo, R.A, Osiname, O.A. 1981. Soils and fertilizer use in Western Nigeria. *Research Bulletin* (11), I. A. R &T University of Ife. 20-26.

Sridhar, M.K.C., Adeoye, G.O., 2003. Organo-mineral fertilizer from urban wastes. *The Field* 68: 91-111.

Taiwo, I.B., Makinde J.O., 2005. Influence of water extract of Mexican sunflower (*Tithonia diversifolia*) on growth of cowpea (*Vigna unguiculata*). *African Journal of Biotechnology* 4(4): 355-360.

Tejada, M., Gonzalex, J.L., Garcia-Martinez, A.M., Parrado, J., 2007. Application of a green manure and green manure composted with beet vinasse on soil restoration; Effects on soil properties. *Bioresources Technology* 99(11): 4949-4957.

Ullah, I., Muhammad, A., Arifa. F., 2010. Chemical and nutritional properties of some maize (Zea mays L) varieties grown in NWFP-Pakistan. *Pakistan Journal of Nutrition* 9 (11): 1113 – 1117.

Uwah, D.F., Eneji, A.E., Eshietu U.J., 2011. Organic and mineral fertilizers on the performance of sweet maize (Zea Mays L. Saccharata Strut.) in South Rainforest zone of Nigeria. *International Journal of Agricultural Sciences* 3(1): 54-61.

Unagwu, B.O., Asadu C.L.A., Ezeaku P.I., 2013. Residual effects of organic and NPK fertilizers performance at different soil pH Levels. *Journal of Agriculture and Veterinary Science* (5): 47-53.

Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* 63: 251-263.

Yiridoe, E.K., Langyintuo, A.S., Dogbe, W., 2006. Economics of the impact of alternative rice cropping systems on subsistence farming: Whole-farm analysis in northern Ghana. *Agricultural Systems* 99(1-2): 102-121.

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Investigation of soil structure in Uzungöl settlement area by Shallow Seismic Methods

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Abstract

This study was performed to relase the soil structure of Uzungöl district of Trabzon city, a vocational area, where had been formed by a historical landslide and lake deposits and to evaluate its geotechnical characters by using seismic methods which are noninvasive, rapidly applicable and provide substantial information about the structure of investigated ground in a short time. For this purpose, seismic refraction, active-passive surface waves and seismic reflections in 16 profiles were gathered on four sub-areas and and evaluated by current favorable numerical methods. Although it considerably varies between profiles, the depth of basement, depositional base of deposits, was averagely obtained as 13.5-15m at upper elevation and 25-50m at lower elevation of the study area. Dynamic elastic parameters and average shear wave velocity of the upper 30m (V_{S30}) of soil in the area were calculated. The soil classification of study area was interpreted as locally Z1 and Z2 class for TEC, B and C class for EC-8 code, C and D class for NERHP. According to V_{S30} (394-530m/s), ground amplification and predominant vibration period of the study area are respectively obtained as 1.5-2.1 and 0.23-0.30sec. On the other hand, all deposits are characterized by stiffness-solid soil, excluding arable soil from surface to a few meters depth. In addition, the first meters of bedrock shows weathered character, but deeper parts are very compact and hard. Therefore, a scientific infrastructure has been formed to carry out the engineering projects to be planned for Uzungöl settlement safely and without damaging the environment.

Keywords: Uzungöl, Landslide, Soil Structure, Shallow Seismic Methods.

Introduction

Investigation of soil (or ground) structure and characterization is a vital to a proper design and lifelong performance of buildings in settlement areas (Coutinho and Mayne, 2012) and necessary to prevent from possible natural hazards. Various methods such detailed engineering geological studies, geotechnical investigations, and geophysical studies (Boominathan et al., 2007) have been used in recent years. In this scope, using seismic methods among the noninvasive geophysical techniques for near surface characterization of geotechnical sites has grown rapidly during the last few decades since information derived from drillings has become time consuming and costly. Seismic methods which are commonly used for geotechnical site investigation include seismic reflection and refraction (Cook, 1965), seismic surface waves (Park et al., 1999). These seismic techniques provide precisely to map a buried bedrock topography, sediments and strata, and frequently employed to study of dynamic behavior of soil properties at geotechnical sites, laterally and vertically (Poormirzaee and Moghadam, 2014; Rehman et al., 2016).

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Seismic methods are based on recording the elastic waves propagating in layered subsurface which were formed on the surface or in a hole by means of a source and these waves are recorded as the function of time at receivers placed on the surface. A seismic data includes reflection, refraction, surface waves and other seismic events such as environmental noises, multiples and diffractions. From the analysis of these records layered subsurface and seismic velocity (V_p for P-wave and V_s for S-wave) of each layer can be obtained as 1D, 2D and 3D as the function of the distance and the depth. Benefiting from this velocity information all dynamic elastic parameters of the target depth can be calculated, so geotechnical properties can be explained. When these operations are compared to drilling studies, they are quite advantageous owing to their properties of scanning a large area in a short time, quickly surveying, and not damaging the environment. Therefore, seismic methods are essential methods which have a wide application use in imaging the near-surface in detail, determining the soil characteristics for engineering purposes, geotechnical assessments, environmental studies, hydrogeological investigations, seismic hazard estimations and archaeological investigations. In recent 30 years, as well as traditional seismic refraction technique, some other techniques such as refraction microtremor (ReMi) with which passive sources are used, active sourced multichannel analysis of surface wave (MASW) based on surface wave analysis, and P-wave first arrival tomography from seismic refraction data have especially been used widely to determine geotechnical profile of the ground. While, especially, MASW and ReMi techniques are commonly used to obtain 1D and 2D shear wave (S-wave) velocity structure of the ground safely and to determine the stiffness-hardness profile of the ground (Xia et al., 1999), P-wave first arrival tomography is extremely beneficial for both vertical and lateral P-wave velocity variation and basement topography of the ground (Azwin et al., 2013). In addition to this, shallow seismic reflection technique is frequently used to map structural properties of the ground such as lateral discontinuities and shallow-stratigraphy (Steeples and Miller, 1990).

This is the first geophysical study carried out in the area of Trabzon-Uzungöl settlement, a vocational area, formed by a historical landslide and deposited by alluviums transported by rivers and extremely steep mountain slopes (Alkan, 1996) to determine underground tomography, structural properties, dynamic-elastic parameters, the thickness of the material and to interpret them geotechnical properties. In this scope, in 16 profiles, seismic refraction data, active and passive surface wave data and also seismic reflection data in 3 of those profiles were gathered. P-wave velocity tomographic sections and migrated reflection sections to image subsurface geometry and structure of the study area and 1D S-wave velocity depth profiles to soil classification were obtained for all profiles. In addition to 2D S-wave velocity sections were obtained by inverting the surface wave fields of reflection data for the 3 profiles. All the obtained outputs were comparatively interpreted in terms of the ground structure of the study area and geotechnical characteristics by taking general geology of the area into consideration.

Material and Methods

The location and geology of the study area

Uzungöl takes place in a deep valley surrounded by high mountains where Soğanlı and Kaçkar mount ranges are combined in East Pontid Tectonic Belt, where there are rainforests of Turkey, 1100m from sea level and 99 km from Trabzon (Figure 1).

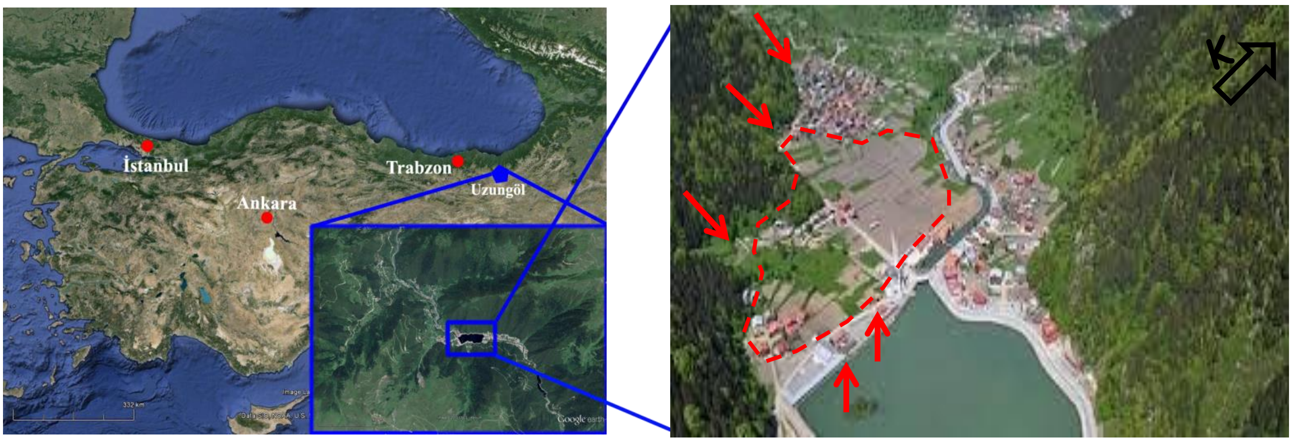

Figure 1. Location map of Uzungöl settlement including the investigated site (Google Earth). Data gathered area (red dashed line). Arrows shows directions of transportation of the materials composed of river-lake sediments and landslides

Geology map including the study area is given in Figure 2. According to this the oldest rocks observed in the region belongs to Mesozoic era, and there are a lot of around from Tertiary era. Jura-sub cretaceous aged andesite, basalt lava and Pyroclasts have a wide range in close vicinity of Uzungöl, and also while the basalts outcrop around Uzungöl are stiff-hard and durable, alluvial units in the study area consist of partly 10-15m thick and gravelly-sandy units including large blocks (Yeşilyurt, 2002). Simplified lithological column by Bulut (1989) in the study area was modified and it is given in Figure 3.

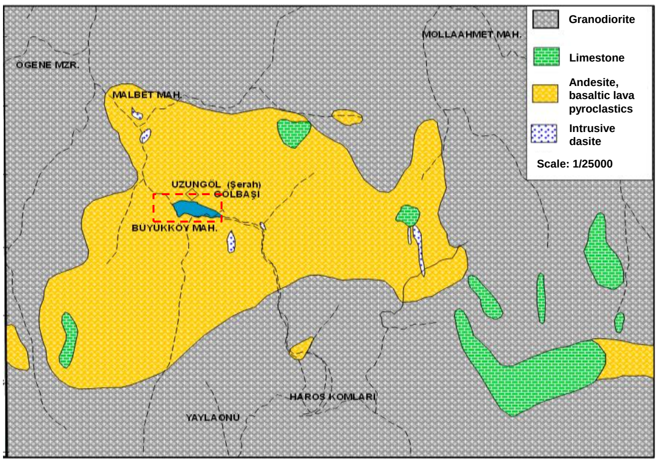

Figure 2. Geologic map of Trabzon- Çaykara- Uzungöl (Şerah) (MTA, 1985)

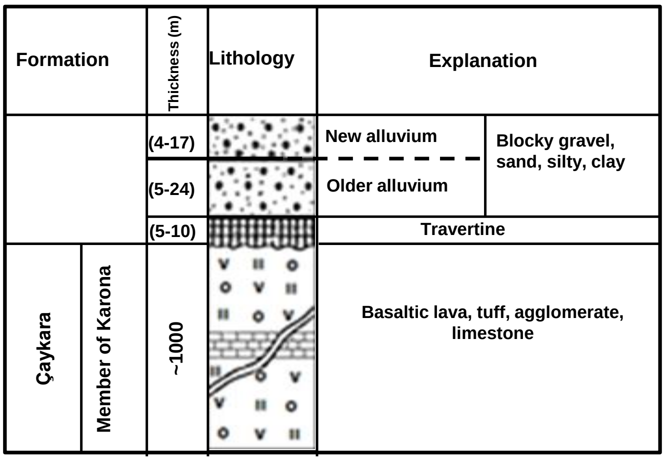

Figure 3. Simplified lithostratigraphy (modified from Bulut, 1989)

Also, the lithological column regarding drillings done in 5 different locations by DSİ (1982) and A-A' cross-section referring to S3-S5 drilling locations are given in Figure 4a and 4b. According to well inform, the ground is generally consist of sandy-silty clayey with the thicknesses of 10-15m according to S3 and S5 wells, while it is clearly seen that the bedrock is consist of basalts.

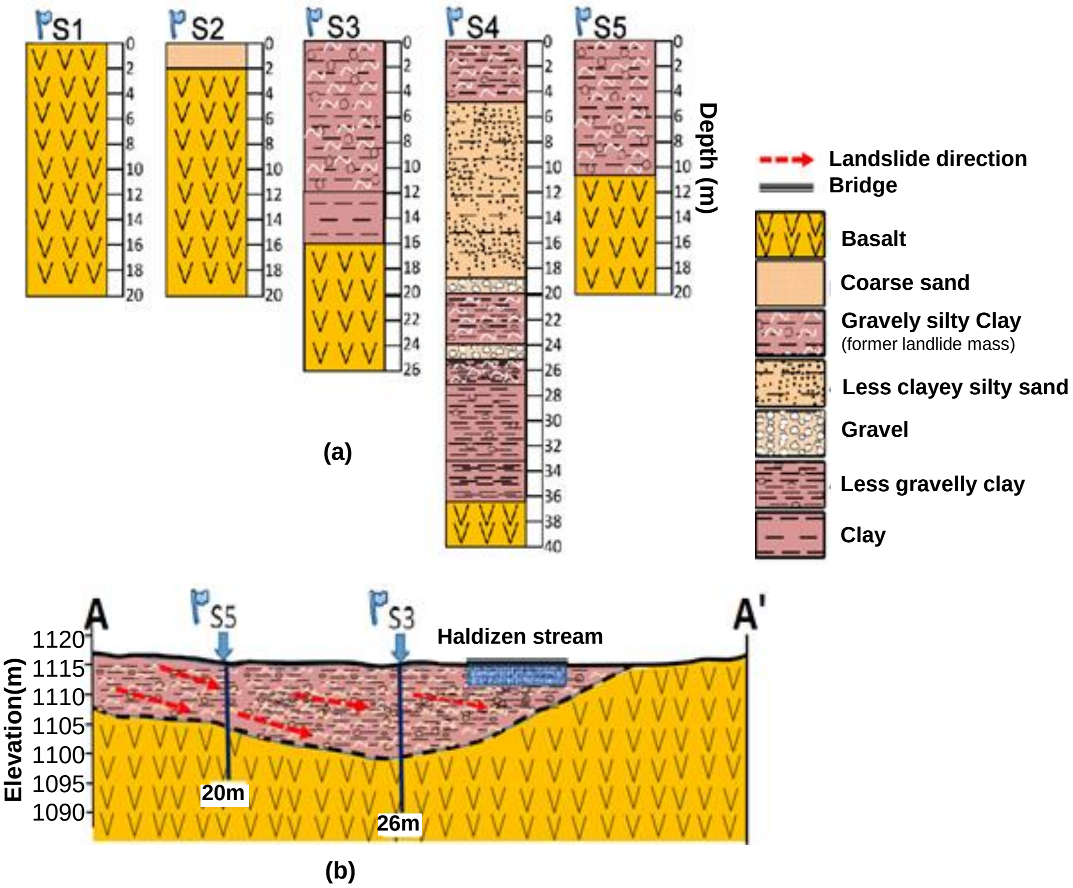

Figure 4. (a) Lithological column from drilling logs at coastal of Lake and (b) geological cross-section of A-A' (modified from DSİ, 1982)

Results and Discussion

Data set and assessment

All data were gathered on the suitable profiles which are determined by preliminary studies carried out in the study area and the interviews with residents. In data acquisition vertical component geophones with 4.5 (for refraction, MASW and ReMi) and 40 Hz (for reflection) and 24 channel exploration seismography were used. The location of 16 profiles is shown in Figure 5. 11 of the profiles were situated in the west of the lake where there are especially agricultural areas, while 4 other profiles were situated in the south part of the lake, which is very near to shore of the lake. As the north of the lake is used as a car park, there were no available places to collect data. However, some sample data were collected in the area which was suitable for a short spread and formed by filling the lake. Profiles were divided into 4 groups: Group 1 represents the area which was partly opened to settlement and where the structuring is considered to proceed rapidly. Group 2 presents an area where the construction is relatively low because of arable. Group 3 represents slope topography and any construction is not allowed there as it is in a location because of landslide hazard. Group 4 represents the profiles which were the nearest areas to the lake, and also structuring is proceeding at the present time. During data acquisition, 10kg sledge hammer and 30 cm radius 5 cm thick solid plastic panel was used in all profiles. To improve signal/noise rate of MASW and refraction records vertical stacking were used as 3 for each shot point and as 10 for ReMi records. The data acquisition parameters for all profiles are listed in Table 1.

Figure 5. The location of measurement profiles in the study area

Table 1. Summary of seismic data acquisition parameters

SURVEYING/PROFILES		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	16
REFRACTION	NS	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	ΔX (m)	3	2	2	2.5	2	3	2	2	2	1.5	1.5	2	3	3	3	2
	Δt(ms)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	T (s)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
MASW	X_0(m)	12	10	10	10	6	12	8	8	8	6	6	8	12	12	18	8
	ΔX(m)	3	2	2	2.5	1.5	3	2	2	2	1.5	1.5	2	3	3	3	2
	Δt(ms)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	T(s)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ReMi	ΔX (m)	3	2	2	2.5	2	3	2	2	2	1.5	1.5	2	3	3	3	2
	Δt(ms)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	T(s)	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
REFLECTION	X_0(m)	2		2			2										
	ΔX(m)	2		2			2										
	Δt(ms)	0.5		0.5			0.5										
	T(s)	1		1			1										
	NS	25		16			19										
	ΔS(m)	1		1			1										

NS: number of shots within profile, Δx: geophone interval, Δt: time sampling interval, T: record time, X_0: first offset, ΔS: shot interval. m: meters, s: second and ms:milisecond

In addition to MASW data, ReMi records were collected with 4.5 Hz receivers with using automatically triggering property of recording device. Data samples from recorded data are given in Figure 6. Except for ReMi records, the differences between the other data are basically related with the purposive data acquisition parameters such as record time and sampling time.

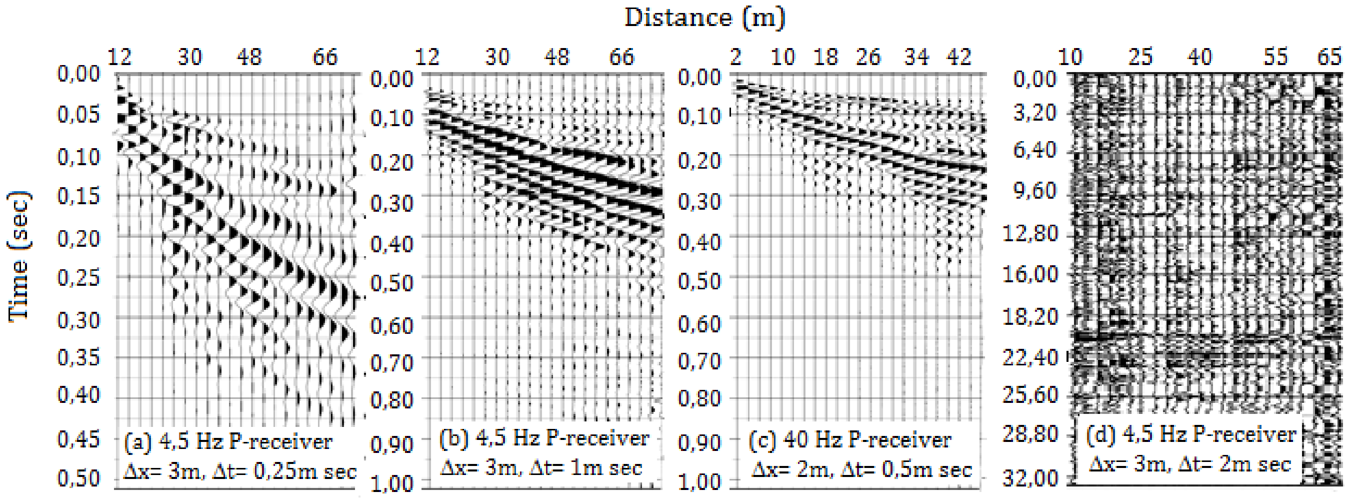

Figure 6. Field data samples gathered according to our purpose. (a) seismic refraction (b) MASW (c) seismic reflection and (d) ReMi data

To increase the reliability and the accuracy of first arrival tomographic inversion of seismic refraction data and therefore, to obtain high resolution P-wave velocity structure of the ground, more shots as possible were done. Number of these shots varies between seven and twelve and shots were organized as follow: two far offset shots, forward and reverse shots and inner-shot between geophones as possible. Thus, tomographic solutions produced more reliable and detailed results to determine both velocity model and bedrock topography when compared to traditional delay time methods. On the other hand, individual and combined analysis of MASW and ReMi data ensured to obtain 1D S-wave velocity-depth profile. Even though the data acquisition and dispersion curve (represents the phase velocity versus frequency of surface wave) extracting practices for the two methods differ, the inversion analysis is the same in both methods. In application, firstly dispersion curves from both data are separately extracted and then combined. The dispersion curve of ReMi data represents lower frequency information (generally 2-20Hz) or longer wavelength leading to obtain V_s values at deeper part of the ground, while the MASW data represents higher frequency (generally 5-70Hz) or short wavelength leading to obtain V_s values at shallow part of the ground. So the combination of both dispersion curves provides reliable and accuracy information about S-wave velocity-depth variation in the inversion. This strategy was demonstrated with Figure 2 in the paper of Uyanık et al. (2013). Therefore, when not reached to 30m by inversion of the MASW dispersion curve, it was utilized from dispersion curve of ReMi data. As seismic reflection data were gathered along the layouts forwarded to the directions of the receivers, 2D S-wave velocity sections for the measurement profile were formed by placing and combining 1D S-wave velocity profiles obtained from surface waves of these data into the middle of each layout. On the other hand, geometry and shot number of seismic reflection data were formed according to obtaining the most common midpoint (CMP) stacking number (folding) as soon as possible. First arrival tomographic inversion of seismic refraction data and the inversion of ReMi dispersion curve were evaluated with using SeisOpt software (Pullammanappallil and Louie, 1997), while MASW data were inverted with KriSis (Kritakis and Vafidis, 2011) code written in MatLab language. On the other hand, in the assessment of seismic reflection data, Promax (URL-1) software was used.

All of P-wave velocity sections obtained from first arrival tomographic inversion is illustrated in Figure 7 according to their surveying locations in UTM (Universal Transversal Mercator) coordinates. It is clear that P-wave velocity sections generally refer to the existing landslide materials, the thicknesses of which vary between 15-20m. At the same time, they explain that the depth of bedrock is quite variable between profiles. Accordingly, the thickness of the material on the bedrock increases towards the lake. As seen on sections, the stratigraphy has three units: (1) the unit (shown by purple and deeper part by blue color) is mostly composed of landslide materials and is available for agriculture. The P-wave velocity of the unit is nearly

V_p=~110-1600m/sec, and its thickness varies between the profiles. Especially the thickness of the unit is more for P7, P8 and P10 profiles since the locations of these profiles are on landslide-prone area. So that bedrock topography was not imaged for P7 profile because of very thick material deposition. (2) The unit is represented by dominantly green colors for all sections. P-wave velocity interval of the unit is mostly V_p=~1600-2800m/sec respectively. The unit is characterized by landslide deposits, but it is harder and the other (unit by purple color). (3) Units illustrated by yellow and red colors represent the bedrock consisting of basalts (Vp>~2800m/sec).

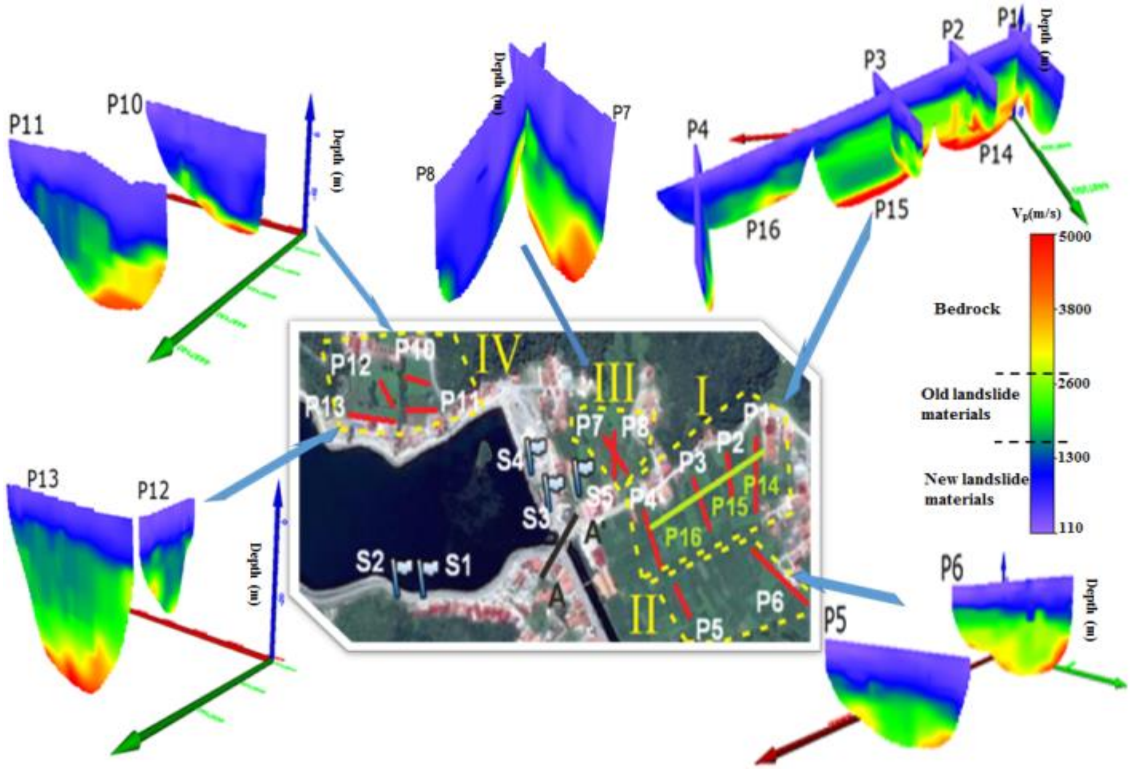

Figure 7. P-wave first arrival tomography sections obtained for profiles 1,2,3,4 and 1D S wave velocity-depth profiles

The dispersion curves were extracted from all MASW and ReMi records and 1D S-wave velocity-depth profiles for 30m depth are obtained by either individual or combined inversion of those curves. Here, the 1D-Vs profiles for Group I and III are shown in Figure 8. Aforementioned, in the area including Group I data, structuring activity is currently on going and if it continues like this, this area will be completely filled with buildings as soon as possible. On the other hand, despite the area of Group III is restricted area as landslide-prone area, structuring is moving to this area. So, S-wave velocity-depth profiles of these areas are given here. The results for Group I show similarly that the velocity increases gradually with depth. This means that the ground consolidates to depth. It is note that although P7 and P8 profiles are intersecting profiles, they show the similarity up to 16m but significant difference below 16m depth (see arrow). This is because the thickness of the deposited materials along the P8 profile is more, that is, the bedrock is deeper at this point. These velocity-depth profiles are quietly accordance with the tomographic results, and S-wave velocity meaningfully raises in the levels corresponding to P-wave velocity changes shows that stiffness-hardness of the material increases from the surface to the depth.

Reflection data gathered in profiles 1,3,6 were made ready to be interpreted by a sequential data processing techniques including data loading, geometry definition, editing-muting, bandpass filtering (15-90Hz), common midpoint sorting, velocity analysis, normal moveout correction, CMP stacking and Kirchoff depth migration. Produced seismic sections are comparatively presented with P-wave velocity tomographic sections in Figure 9 (right column). Possible interface between landslide material and bedrock was indicated by benefitting from amplitude and phase changes in the sections (red dotted line). Especially, bedrock level in tomography section for profile 6 could not be clearly determined, whereas this level was determined in the reflection section of the same profile. On the other hand, remarkable velocity drop in the tomography section of profile 3 was interpreted as lateral reflection discontinuity in the reflection section. It is obviously seen that landslide material, depending on bedrock topography variety, has different thicknesses between profiles in both tomographic and reflection sections.

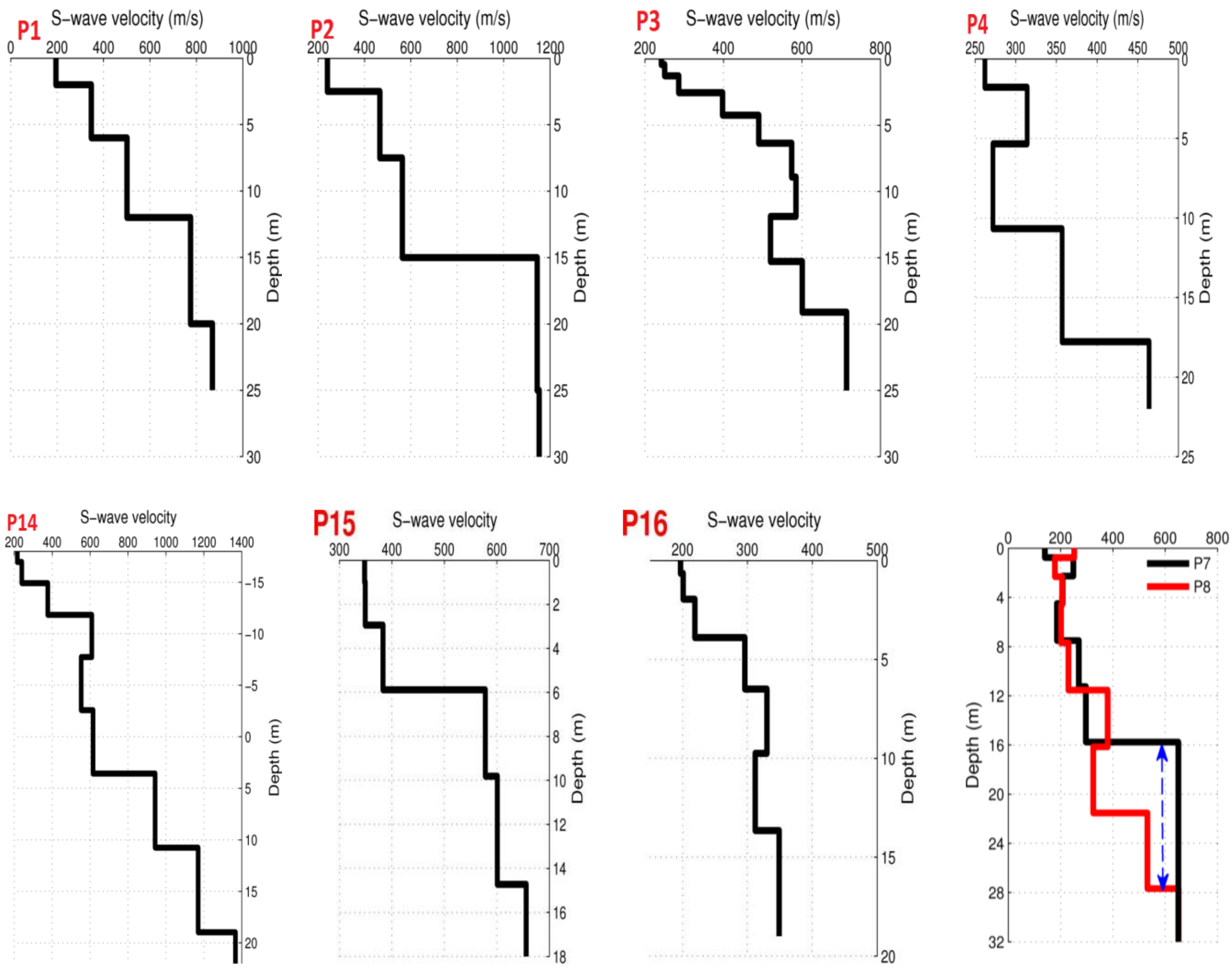

Figure 8. 1D S-wave velocity-depth profiles for Group I (except for P7 and P8) and III

1D S-wave velocity-depth profiles obtained by using surface waves of each consecutive reflection shot were placed into the middle point of each spread for profiles 1,3,6 and they were combined by interpolation. Thus, 2D S-wave velocity-depth sections were obtained and the soil character of the study area was determined (Figure 10). The vertical bar in middle of 2D-V_s section (right) is the inversion of MASW data of profile 1. This shows that 1D-V_s and 2D-V_s results are purely compatible. Therefore, landslide material thicknesses (V_s<600m/s), and accordingly, bedrock topography vary even though 2D S-wave velocity and tomographic sections supported each other. According to S-wave velocity variation, soil stiffness profile is shown on velocity scale with color bar in Figure 10.

The thickness, lateral and vertical variation, stiffness-hardness profile of the soil and the depth of bedrock and topography in the study area were determined with P- and S- wave velocity and reflection sections. Besides, elastic-dynamic parameters of the material were calculated for the first 30m by using this velocity information. S-wave velocity-depth sections in Figure 10 show to mostly 20-23m depth information as they are derived from the reflection data acquisited with 40Hz receivers. ReMi records of these profiles were benefitted for 30m and deeper parts. Therefore, for all profiles, the value of average S-wave velocity (V_{S30}) in the first 30m depth, necessary for national Turk Earthquake Codes (TEC, 2007) and international EURO Code 8 (EC-8) (CEN, 2004) and NEHRP (BSSC, 1997) ground classifications. Also, geotechnical information was obtained by calculating other parameters correlated with V_{S30} such as ground predominant vibration period, soil amplification, and stiffness-hardness, weathering and softness of the soil.

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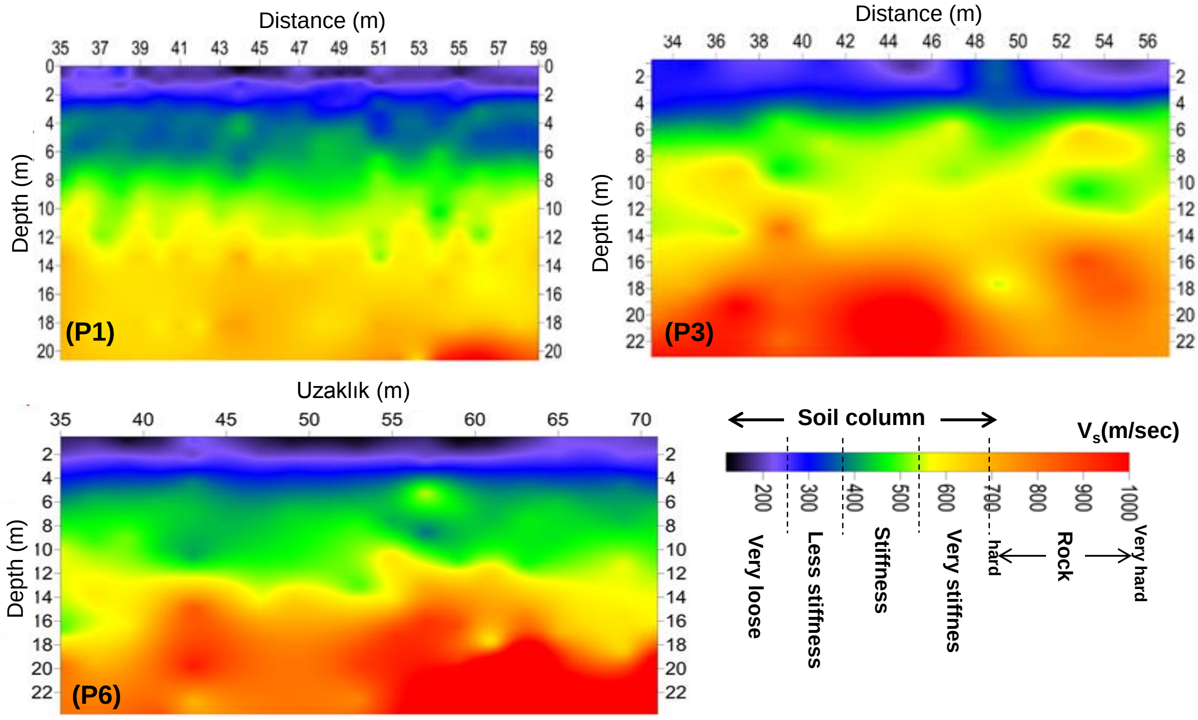

Figure 9: The comparison of P-wave velocity tomographic and reflection sections in profiles 1, 3, 6

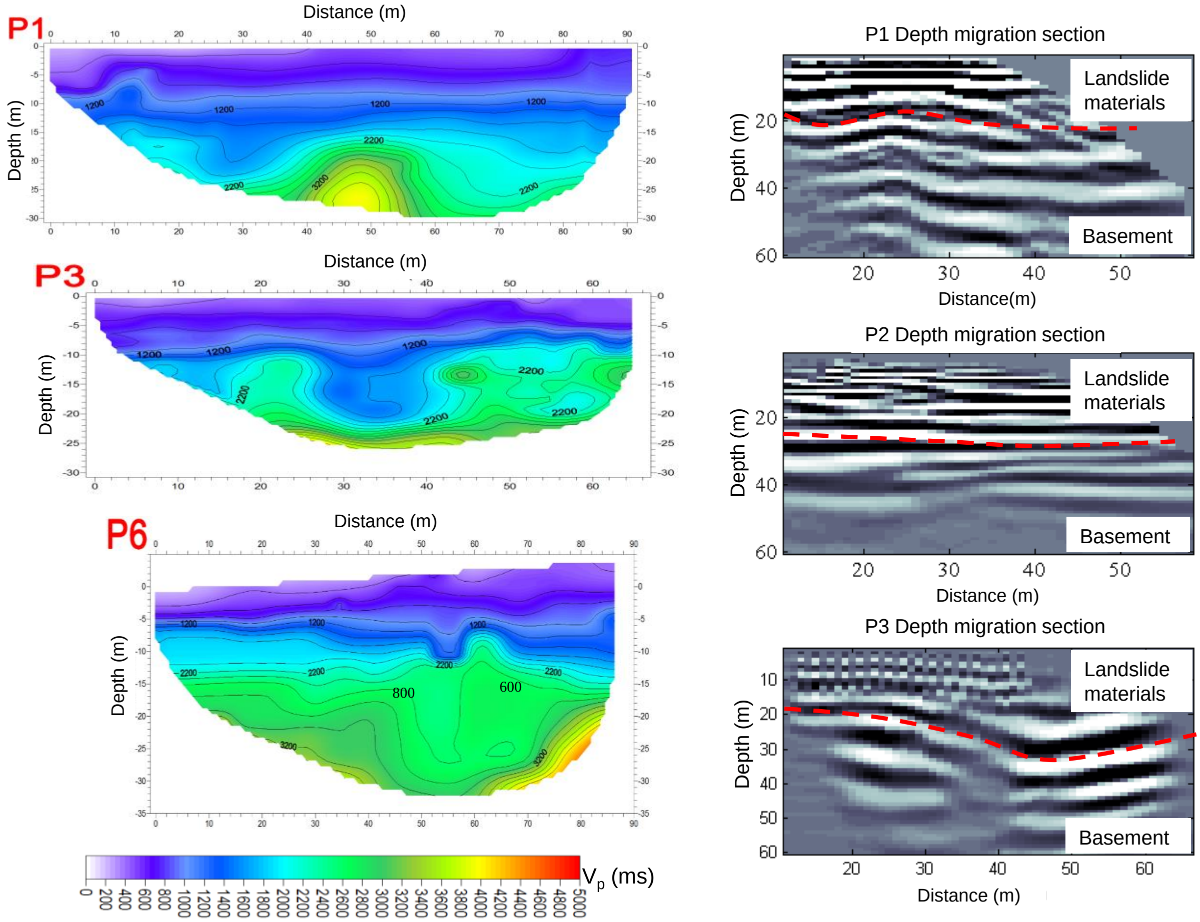

Figure 10. 2D S-wave velocity-depth sections obtained for profiles 1, 3, and 6. The geotechnical character of the ground is shown on color bar

Besides, elastic-dynamic parameters of the material were calculated for the first 30m by using this velocity information. S-wave velocity-depth sections in Figure 10 show to mostly 20-23m depth information as they are derived from the reflection data acquisited with 40Hz receivers. ReMi records of these profiles were benefitted for 30m and deeper parts. Therefore, for all profiles, the value of average S-wave velocity (V_{S30}) in the first 30m depth, necessary for national Turk Earthquake Codes (TEC, 2007) and international EURO Code 8 (EC-8) (CEN, 2004) and NEHRP (BSSC, 1997) ground classifications. Also, geotechnical information was obtained by calculating other parameters correlated with V_{S30} such as ground predominant vibration period, soil amplification, and stiffness-hardness, weathering and softness of the soil.

Conclusion

In this study, the structure and geotechnical properties of Uzungöl settlement area formed by a historical landslide materials and lake sediments were investigated with shallow seismic methods. On the other hand, the use of integrated seismic methods and the assessment of data in different analysis were proved to be extremely beneficial to discover ground structures and properties in high accuracy and reliability. The thickness of the soil in the study area is very irregular up to the bedrock. While thicknesses are 15-20m in the west of the study area, they are displayed ≥30m in the south and lake nearby. Thus, it is seen that the thickness of the soil in the study area increases towards the lake and it reaches the highest level in the areas near the lake. All lithological units were defined by taking the same coloring scale into consideration, depending on P- and S-wave velocity sections changing along the depth, and they are shown on the sections obtained for profile 1 in Figure 11. Generally 3 main geological units which were formed by; (1) arable, landslide materials whose the stiffness and hardness vary in different degrees and basalt from the surface and those units are divided into subunits in itself each. Therefore, soil profile is separated into 5 lithological and geotechnical subunits : (1) very loose gravelly-silty-clayey arable between 0-2.5m (V_p=300–480 m/sec, V_s=180–250 m/sec, (2) less stiffness silty-gravelly clay (V_p=480-1100m/sec, V_s=250-380 m/sec) between 2.5-7m, (3) stiffneess gravelly-clay (V_p=1100-2000 m/s, V_s=380-550 m/sec) between 7-15m, (4) very stiffness gravelly-clay or softness bedrock (V_p=2000-3200 m/sec, V_s=550-700 m/sec) and between 15-20m, (5) hard-very hard bedrock formed from basalt rock (V_p> 3200m/s, V_s >700 m/s) larger than ~20m depth.

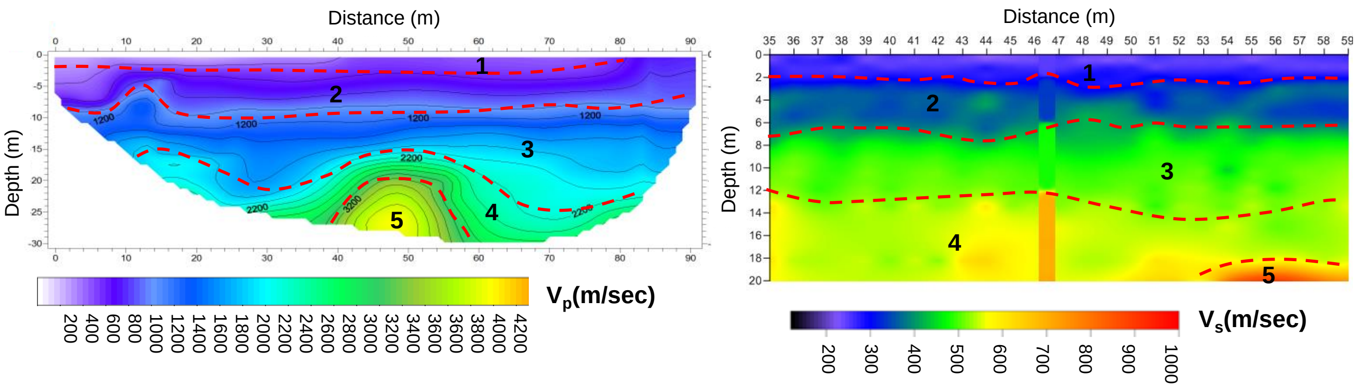

Figure 11: The lithological correlation between units from drillings and P-wave (left), S-wave (right) velocities for profile 1: (1) arable soil (2) silty-gravelly clay (3) medium-stiffness gravelly clay (4) very stiffness-solid gravelly clay (5) bedrock (basalt)

It was seen that P-wave velocity decreased until less than 2000 m/s because there is a transition level between the weathering in a few meters of bedrock and overlying very stiff-solid landslide material. Geotechnical assessment explaining the ground profile and its properties of the study area was done owing to the dynamic-elastic parameters calculated for each profile and V_{S30} values. Thus, the site classification of the study area is summarized in Table 2. Consequently, we suggest that the information will make an important contribute to make the development planning of Uzungöl settlement.

Acknowledgements

This study was supported by Karadeniz Technical University Scientific Research Projects Unit (Project no: 11512). We thank Municipality of Uzungöl and Çaykara and landowners for their permission to enable us to collect data during the project. We would like to special thank Dr. Satish Pullammanappallil and Dr. George Kritakis for contributions in tomographic, ReMi and MSW solutions of data.

Table 2. The site classification of the study area according to V_{S30}, which was calculated as an average value for each group shown in Figure 5 and 7.

Site classification according to V_{s30}, the eighted average value of S-wave velocity up to 30m								
Area No	V_{s30} (m/s)	$A_0=68*(V_{s30})^{-0.6}$ (Midrokowa, 1987)	$T_0=4*H/V_{s30}$ (s) (H=30m)	T_A (s)	T_B(s)	TEC (Turkish Earthquake Code)	EC-8 (Eurocode-8)	NEHRP (National Earthquake Hazard Reduction Program)
I	530	1.56	0.23	0.15	0.35	B and C class	B and C class	C and D class
II	474	1.69	0.25	0.17	0.38			
III	336	2.10	0.36	0.24	0.54	Local soils class:	(Hard soil)	(Stiff-hard soil or soft
IV	394	1.89	0.30	0.20	0.45	Z2-Z3 (moderate stiff-hard soil)		rock)

References

Alkan, S., 1996. Uzungöl'e taşınan yığıntı materyalin tespiti ve taşınan materyal ile gölün dolmasını engelleyen önlemler üzerine bir araştırma, Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü. Yük. Lis. tezi, Trabzon. [in Turkish]

Azwin, I.N, Saad, R., Nordiana, M., 2013. Applying the seismic refraction tomography for site characterization, 4th International Conference on Environmental Science and Development ICESD 2013. *APCBEE Procedia* 5: 227-231.

Boominathan, A., Dodagoudar, G., Suganthi, A., Uma Maheswari, R., 2007. Seismic hazard assessment considering local site effects for microzonation studies of Chennai city. In: Proceedings of Microzonation. A workshop at Indian Institute of Science, Bangalore, pp. 94–104. Available at: [Access date: 10.07.2016] http://civil.iisc.ernet.in/~microzonation/workshop_files/paper%2011.pdf

BSSC (Building Seismic Safety Council), 1997. NEHRP recommended provisions for seismic regulations for new buildings and other structures: Part 1, Provisions (FEMA 302). Building Seismic Safety Council. 334 p. Available at: [Access date: 10.07.2016] http://www.nehrp.gov/pdf/fema450provisions.pdf

Bulut, F., 1989. Çambaşı (Trabzon-Çaykara) barajı ve Uzungöl hidroelektrik santral yerlerinin mühendislik jeolojisi açısından incelenmesi. Karadeniz Teknik Üniversitesi Fen Bilimleri Enstitüsü Doktora Tezi. Trabzon. [in Turkish]

CEN, 2004. Eurocode 8-design of structures for earthquake resistance. Part 1: General rules. (December 2004) Seismic actions and rules for buildings. European Standard EN 1998-1. European committee for standardization, Brussels.

Cook, J.C., 1965. Seismic mapping of underground cavities using reflection amplitudes. *Geophysics* 30(4): 527–538.

Coutinho, R. Q., Mayne, P. W., 2012. Geotechnical and geophysical site characterization 4. CRC Press, Boca Raton.

DSİ, 1982. Of Solaklı projesi Uzungöl 1 ünitesi mühendislik jeolojisi raporu (planlama aşaması), Devlet Su İşleri 22. Bölge Müdürlüğü, Trabzon, [in Turkish]

Kritikakis, G.S., Vafidis, A., 2011. Different alternatives of surface waves data ınversion. Applications on environmental and geotechnical case studies. 6th Congress of the Balkan Geophysical Society, 3-6 October 2011. Budapest, Hungary.

MTA, 1985. Arşiv, Trabzon Çaykara Uzungöl (Şerah) yöresinin jeolojik haritası, Maden Tetkik Arama Trabzon Bölge Müdürlüğü, Trabzon. [in Turkish]

Park, C.B., Miller, R.D., Xia, J., 1999. Multichannel analysis of surface waves, *Geophysics* 64(3): 800–808.

Poormirzaee, R., Moghadam, R.H., 2014. Determination of S-Wave structure via refraction microtremor technique in urban area: A case study. *Journal of Tethys* 2(4): 347 356.

Pullammanappallil, S.K., Louie, J.N., 1997. A combined first-arrival travel time and reflection coherency optimization approach to velocity estimation, *Geophysical Research Letters* 24(5): 511-514.

Rehman, F., El-Hady, S.M., Atef, A.H., Harbi, H.M., 2016. Multichannel analysis of surface waves (MASW) for seismic site characterization using 2D genetic algorithmat Bahrah area, Wadi Fatima, Saudi Arabia. *Arabian Journal of Science* 9: 519-532.

Steeples, D.W., Miller, R.D., 1990. Seismic-reflection methods applied to engineering, environmental, and ground-water problems. In: Investigations in geophysics: Geotechnical and environmental geophysics: Volume I: Review and Tutorial Ward, S. (Ed.), No.5 , Society of Exploration Geophysicst pp. 1–30.

TEC, 2007. Türk Deprem Yönetmeliği. Deprem bölgelerinde yapılacak binalar hakkında esaslar. AFAD Deprem Dairesi Başkanlığı, Ankara. p. 159. [in Turkish]

Uyanık, O., Ekinci, B., Uyanık, N.A., 2013. Liquefaction analysis from seismic velocities and determination of lagoon limits Kumluca/Antalya example. *Journal of Applied Geophysics* 95: 90-103.

Xia, J., Miller, R.D., Park, C.B., 1999. Estimation of near-surface shear-wave velocity by inversion of Rayleigh wave, *Geophysics* 64(3): 691-700.

Yeşilyurt, C., 2002, Uzungöl yöresi rekreasyon kaynaklarının coğrafi yönden değerlendirilmesi, Yüksek Lisans Tezi, Çanakkale Onsekiz Mart Üniversitesi Fen Bilimleri Enstitüsü, Çanakkale. [in Turkish]

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Response of fodder sorghum (*Sorghum bicolor* (L.) to sewage sludge treatment and irrigation intervals in a dryland condition

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Abstract

A field experiment was conducted in the Experimental Research Farm of Omdurman Islamic University, Sudan to determine short-term effect of irrigation intervals (7 and 10 days) and sun-dried or composted sewage sludge, recommended mineral fertilizer on straw dry matter yield (SDMY) and N, P and K content of fodder sorghum and soil properties. In the 7 and 10 days irrigation intervals, composted, sun-dried sludge and mineral fertilizer have significantly increased SDMY over the control by 51, 98, 67 and 78, 19, 33%, respectively. Apparent N use efficiency (ANUE) in composted and sun dried plots irrigated at either 7 or 10 days was 9 - 36 and 16 - 74%, respectively. Reducing the irrigation interval has significantly increased salinity by 13%. Increasing irrigation interval has decreased bulk density by 5%. It could be concluded that, application of composted sludge is a useful practice for improvement of soil properties and consequent yield increase.

Keywords: Compost, cultivation, fresh, soil chemical and physical properties, yield.

Introduction

Soil degradation is quite serious problem in Sudan which is one of the largest countries in the North Africa and Near East region with high agricultural potential (Ayoub, 1999). In the last 35 years, the 46 million ha lying in the semi-arid zone which is the centre of production of field crops, the gum Arabic tree (*Acacia senegal* L.) and cattle region has encountered intensive soil degradation (Abdalla, 2015). Restoration of soil productive capacity in this region is largely based on increasing the soil organic carbon content. Some authors have studied the changes of physical characteristics of soils by additions of urban organic wastes (Diaz et al., 1994; Spaccini et al., 2002).

Use of chemical fertilizers was most crucial input for enhancing crop yield, but intensive application of these fertilizers has adversely affected the environment. Moreover, the production of chemical fertilizers, in both monetary and energy terms and the need for conservation of resources, forced the third world countries, including Sudan, to look for alternatives. Hence, organic fertilizers assumed great importance compared to mineral fertilizer, although they contain relatively low concentration of nutrients. Using organic amendments can be an important component of a strategy for achieving sustainable agricultural practices.

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Manure, compost and other organic amendments can be added to soil in order to increase soil organic matter content (Sneh et al., 2005) especially in arid, semi-arid and marginal lands.

Sewage sludge is the solid product of the municipal wastewater treatment process. This material can be a useful source of nutrients for the soil environment by turning wastes into valuable resources (Ghoniem, 2007; Dawi, 2014) that contained total N ranging from 1.5% in air-dried lime treated biosolids to 7.5% in liquid mesophilic anaerobic digested biosolids (Rigby et al., 2016). On the other hand, increasing doses of municipal solid wastes could be associated with sharp decrease in soil NO_3-N and as a result inhibition of plant growth (Giannakis et al., 2014) or soil properties may not improve or even worsen beyond 40 t ha^{-1} of sewage application (Roig et al., 2012).

Composting is a mean of biologically degrading organic materials while stabilizing a residual organic fraction as humus (Schnitzer and Kahn, 1987). The negative impact on plant growth may be caused by reduction in oxygen and available nitrogen or the presence of phytotoxic compounds (Zheljazkova and Warman, 2002). Furthermore, composting is of great significance in reducing the hazards of weed seeds, plant pathogens, public hygiene, pollution, thus, better environment (Lampkin, 1990; Rynk et al., 1992). Composting of sewage sludge is recommended as a technique to turn a less stabilized waste into a material that is no longer classified as a waste (Alvarenga et al., 2015) while others indicated that turning a less stabilized waste (e.g. sewage sludge) into a non waste material necessitates composting (Alvarenga et al., 2015). Additionally, fresh sludge has many problems, namely its high water content, contamination with pathogenic microorganisms, lack of stability, and even, in some cases, contributing to a lowering of the availability of heavy metals in amended soils (Smith, 2009).

In the capital, Khartoum State, there are enormous quantities of sewage sludge that can be recycled for cultivation and amelioration of desert soils. However, fresh use of compost is not advisable as many pathogens are reported and requires removal through composting. Therefore, our main objective was to determine the effects of incorporation of composted or air-dried sewage sludge on some soil properties and performance of fodder sorghum (*Sorghum bicolor*) under semi-arid conditions.

Material and Methods

Site

The experiment was conducted in the Experimental Research Farm, Faculty of Agriculture, Omdurman Islamic University (Latitude 15°19.9´N Longitude, 32°39´E and 381 m above the sea level). The area falls in the semi-arid tropics with mean annual rainfall of about 67.5 mm and mean monthly temperature ranges from 21°C (in winter) to 40°C (in summer). The soil of the study site belongs to the order Aridisols and classified according to the National Research Centre (1994) as sandy clay loam, hyperthermic, mixed, gypsic Cambiorthid (Table 1).

Table 1. Some physico-chemical properties of the top soil

pH (past)	SP	OC	TN	$CaCO_3$	Sand	Silt	Clay	ECe dSm^{-1}
				g kg^{-1}				
8.9	19.0	3.6	0.23	126	460	250	290	1.33
Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	Cl^{-}	P	Bd	SAR
			meq l^{-1}			ppm	g cm^{-3}	
3.5	0.5	9.3	12.6	1.9	3.4	1.8	1.82	6.6

Compost preparation

Air-dried sewage sludge was collected from Khartoum State-Soba Station for treatment of sewage sludge. For compost preparation (21/05/2012 to 21/08/2012), four pits were dug in the ground with dimensions of 2m x 2m and a depth of 0.5 m (i.e. 2 m^3). A plastic sheet (6 m x 4 meter) was placed on the bottom of each pit to prevent seepage. About 250 kg of sludge was placed in each pit, watered (135 l) to 75-80% of the water holding capacity (WHC) and finally covered with the same the plastic bag. After one week the pits were opened, the temperature was measured every two weeks using digital thermometer, mixed and covered. The compost was considered mature (temperature used as quality parameter) when the inside temperature was the same as ambient temperature. Then after, the compost was air dried under the sun and about 1 kg of the final material was taken to the laboratory for characterization (n=4). Initial and final composition of the air-dried and final compost is shown in Table 2.

Table 2. Chemical analysis of the air-dried sludge and the final compost (Mean ± standard deviation)

Type	pH (1:10)	ECe dSm^{-1}	OC	TN	Lignin g kg^{-1}	PP	WHC	SP	C/N
Initial	7.43±.05	11.5±0.2	112±0.1	14±0.1	133.8	48.6±0.2	625±5	980±13	7.9±0.1
Final	7.37±0.2	4.29±0.2	248±2.9	68±2	nd	nd	nd	331±10	3.6±0.4
P≤0.05	0.03	0.001	0.003	0.001				0.005	0.001
	P ppm	Ca^{++}	Mg^{++}	K^+	Na^+ meq l^{-1}	HCO_3^-	Cl^-	SAR	
Initial	2.36±0.1	9.37±0.6	5.06±0.1	1.72±0.5	3.38±0.2	9.37±0.4	10.67±0.2	1.26±0.09	
Final	0.34±0.1	13.68±4	6.85±1.2	2.46±0.8	3.38±0.2	5.60±0.5	16.19±2.5	0.24±0.01	
P≤0.05	0.002	0.05	0.23	0.36	0.25	0.02	0.002	0.003	

nd= not determined

P: Probability ≤ *0.05*, LSD: Least Significant Difference

Compost application for sorghum production

In April 16th 2012, an area was disc-ploughed, leveled and 32 plots (6 m x 7 m) were prepared. Treatments include two factors:

1) Amendments: Control (C), recommended dose (55 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} as triple super phosphate) of mineral fertilizer (IN), sun dried sewage sludge (AD) and composted sludge (CS) applied at rates of 15.7 (1.4% TN) and 3.2 (6.8% TN) t ha^{-1}, respectively.

2) Irrigation: 10 and 7 days irrigation interval (i.e. 8 treatments and replicated 4 times). Sludge was manually incorporated (7 days before sowing) into the top 0-30 cm depth and irrigated twice a week before sowing. Plots were arranged in a randomized complete block design (RCBD). At sowing, 119 kg ha^{-1} of fodder sorghum (*Sorghum bicolor* L.) was scattered in each plot and mineral N was applied at sowing to relevant treatments. Plots were immediately irrigated (1000 m^3 ha^{-1}) from a canal with pH and electrical conductivity (ECi) of the irrigation water were 7.5 and 0.56 dSm^{-1}, respectively. Then after, irrigation was applied according to treatments (7 or 10 days interval).

At physiological maturity (70 days), plants were cut by sickle at about 5cm above the soil surface. For determination of straw dry matter (SDM) yield, 5 plants were randomly harvested from each plot, chopped to 10-15 cm, weighed in the field and oven dried (at 70-80 ^{o}C for 48 hrs) and moisture content was determined. Then after, each plot was totally harvested, weighed in the field and SDM (t ha^{-1}) was calculated using previous moisture content of each plot. The five plants (leaves and stem) were crushed (0.5 mm sieve) and analyzed for TN (Bremner and Mulvaney, 1982), P and K content (Chapman and Pratt, 1961). From each plot, soil samples were taken from the top 0-30 cm depth using 5 cm diameter auger, air dried (one part was used to determine field moisture content), crushed (2.00 mm) and analyzed for pH (McLean, 1982), TN (Bremner and Mulvaney, 1982), SOC (Nelson and Sommers, 1982), ECe (Richard, 1954), available P (Olsen and Sommers, 1982), soluble Ca^{2+}, Mg^{2+}, Na^+ (Chapman and Pratt, 1961), SAR and $CaCO_3$ (Goh et al., 1993). Undisturbed soil samples from the top 0-30 cm were also taken from each plot for determination of bulk density (Blake and Hartge, 1986). Apparent N use efficiency (ANUE) was calculated as follows:

%ANUE = (straw N content in sludge plots kg ha^{-1}- TN straw in C plots)/ TN added x100

The software of SAS (1999) was used to determine significant differences between treatment means (ANOVA).

Results and Discussion

Effects of sludge on dry matter yield (DMY) and straw nutrient content

The highest SDM yield (12.5 and 11.2 t ha^{-1}) was recorded in AD7 and CS10, respectively (Table 3). Main effects of fertilizer source showed that, irrespective of irrigation interval, percent increase over the control was in the order of CS (68%) > AD (62%) > IN (53%). On all sources of fertilizer added, reducing irrigation interval to 7 days has increased yield over the 10 days by 18%. Similar to yield, plants in AD7 plots recorded the highest (248 kg ha^{-1}) N content whereas those in C10 plots recorded the lowest (69 kg ha^{-1}) N content (Table 3). On average, 7 days irrigation interval increased N content over 10 days by about 25%. The ANUE in FS plots with reduced irrigation interval was exceptionally high and almost more than two fold that recorded in plots with compost application whereas ANUE of the mineral N was averaged 65% (Figure 1).

Table 3. Effects of sludge treatment on straw dry matter in yield and N, P, K content of sorghum (Mean ± standard deviation)

Treatments	SDMY (t ha^{-1})	TN	P	K
			kg ha^{-1}	
			7 days	
C	06.3±0.5	85.7±19.7	4.88±0.7	88.99±38.7
IN	10.5±0.5	137.1±53.6	8.3±2.6	134.7±12.5
AD	12.5±3.0	248.3±94.2	9.6±1.9	155.2±9.2
CS	9.5±1.0	105.8±30.6	9.78±1.9	161.15±10.8
			10 days	
C	06.1±0.7	69.8±9.7	6.1±0.4	90.0±8.6
IN	08.4±1.6	89.6±4.7	6.9±1.5	111.7±7.2
AD	07.5±0.8	104.9±9.2	5.8±0.5	87.9±5.9
CS	11.2±1.9	147.7±7.5	9.1±2.2	113.45±8.9
P value	0.0002	0.0007	0.07	0.7
LSD	2.3	76.4	3.77	94.6

P: Probability ≤ *0.05*, LSD: Least Significant Difference

Increasing irrigation interval reduced ANUE by 100%. The ratios of N uptake from mineral fertilizer, sun dried sludge and composted sludge to that of the soil ranged from 1.29-1.5, 1.5-2.88 and 1.23-2.11, respectively. Generally, application of air-dried compost increased plant N content over the control, mineral fertilizer and compost by almost 128, 49 and 39%, respectively. Regardless of irrigation interval, plants supplied with mineral fertilizer and composted sludge has very similar N content. Although P content in the straw was not significantly affected by fertilizer source or irrigation interval (CV of 34%), incorporation of sun dried sludge produced plants with P content similar to those supplied with mineral fertilizer. Irrigation interval (on all sources of P) has no effect on plant P content. However, P content in composted plots was not affected by irrigation interval and recorded an increase over the control and both mineral and sun dried sludge of 72 and 23%, respectively. The content of straw K was not significantly (CV of 55%) affected by treatments where on average fresh sludge and mineral fertilizer has similar straw K content. It was observed that application of composted sludge has resulted in an increase of K content over mineral source by almost 43%.

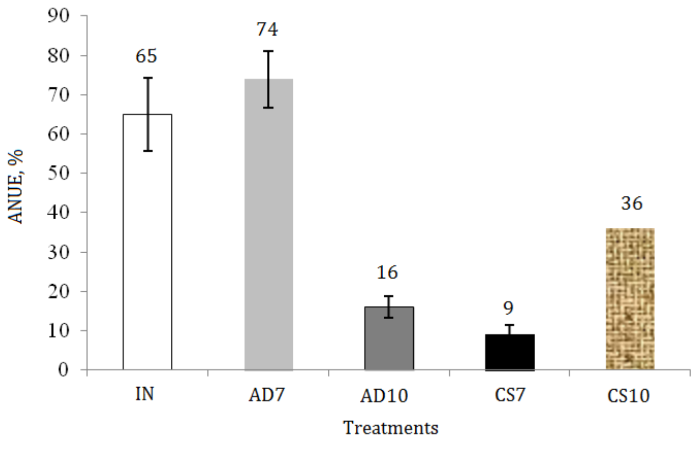

Figure 1. Effect of sludge treatment on ANUE ($P \leq 0.04$, LSD=44.7)

Effects of sludge treatment on soil properties

The effects of application of sewage sludge and irrigation interval on soil properties is shown in Table 4. The application of sludge whether sun dried or composted has generally increased pH over plots without sludge by 0.3 units whereas irrigation interval showed no significant effects.

The highest soluble salts were found in the control and plots with mineral fertilizer (with reduced irrigation interval) and all plots treated with sun dried sludge. The lowest EC values were recorded in plots treated with composted sludge. Interestingly, it was observed that on all levels of fertilizer source, increasing irrigation interval from 7 days to 10 days has decreased soluble salts by about 14%.

Table 4. Effects of sludge treatment on soil properties (Mean ± standard deviation)

Treatments	$pH_{(paste)}$	ECe dSm^{-1}	TN	OC g kg^{-1}	$CaCO_3$	P ppm	Ca^{2+}	Mg^{2+}	K^+ meq l^{-1}	Na^+	SAR
					7 days						
C	8.07±0.16	1.7±0.34	0.14±0.07	17.33±4.7	4.6±0.15	1.33±0.12	3.53±0.46	2.9±0.4	0.25±0.09	25.9±1.50	14.4±1.40
IN	8.43±0.33	1.6±0.09	0.23±0.07	22.33±6.4	5.7±0.83	1.56±0.01	3.33±0.47	1.6±0.5	0.32±0.16	26.5±0.92	16.9±1.40
AD	8.33±0.21	1.6±0.19	0.20±0.05	27.73±3.2	4.7±0.45	1.28±0.25	5.08±1.05	1.1±0.1	0.39±0.31	21.4±1.59	12.2±0.78
CS	8.33±0.22	1.4±0.22	0.18±0.09	22.90±1.7	5.87±3.1	1.38±0.11	6.60±0.94	7.3±1.3	0.20±0.06	20.9±1.30	07.9±1.72
					10 days						
C	8.38±0.33	1.34±0.22	0.13±0.01	18.18±3.2	5.1±0.87	1.29±0.09	4.7±0.73	0.7±0.17	0.19±0.03	22.42±1.39	13.6±1.6
IN	7.98±0.13	1.34±0.23	0.15±0.01	28.18±3.7	4.9±1 .00	1.26±0.15	4.3±0.90	0.9±0.48	0.22±0.08	20.39±2.20	12.7±0.9
AD	8.33±0.46	1.56±0.41	0.13±0.02	30.50±3.6	4.5±0.63	1.32±0.35	3.4±0.33	1.5±0.13	0.27±0.13	18.78±2.81	12.0±0.6
CS	8.16±0.05	1.38±0.09	0.43±0.01	41.43±3.2	4.3±0.43	1.26±0.15	5.8±0.62	4.0±0.30	0.17±0.03	21.64±1.30	09.8±0.6
P Value	0.03	0.04	0.04	0.0001	0.63	0.83	0.0001	0.000	0.25	0.0002	0.0001
LSD	0.34	0.31	0.06	0.86	1.89	0.27	1.13	1.02	0.21	2.63	1.6

P: Probability ≤ 0.05, LSD: Least Significant Difference

The highest TN was found in plots treated with composted sludge (CS10) followed by mineral N (IN7). On average for all irrigation intervals application of composted sludge has increased soil N over the control, mineral fertilizer and air dried sludge by 126, 61 and 85%, respectively. Also, on average for all N sources, plots irrigated in 10 days interval contained significantly higher N than those irrigated in 7 days by 27%.

On average for all irrigation intervals the content of SOC was in the order of composted sludge > sun dried sludge > mineral fertilizer > control. The highest SOC content was found in the CS10 plots while the lowest was found in the C7 plots. Accordingly, on average SOC content in composted plots was higher than C, IN and AD plots by 81, 27 and 11%, respectively. Additionally, increasing irrigation interval to 10 days has increased SOC by 39%. The content of P, soluble K and $CaCO_3$ in the soil was not significantly changed along with addition of either air-dried or composted sludge. Both soluble Ca^{2+} and Mg^{2+} were significantly higher in plots treated with composted sludge than treated with air-dried sludge by 46 and over 300%, respectively. The content of soluble Na^{+} in the soil solution was significantly reduced by composted and air-dried application by about 17 and 12%, respectively. Unexpectedly on average for all fertilizer sources, decreasing irrigation interval to 7 days has significantly increased soluble Na^{+} by 12%. The lowest SAR values were found in plots treated with compost sludge whereas the highest values were found in control and plots with mineral fertilizer. Accordingly, application of composted and air-dried sludge has reduced initial SAR values by 37 and 14%, respectively. However, on average irrigation interval has not significant effects on SAR values.

The soil moisture content after harvest (Figure 2) was not significantly different among treatments. Application of sun dried sludge and composted at short irrigation interval has significantly increased bulk density of the sandy clay loam soil from 1.35 to a maximum of 1.43 g cm^{-3} (i.e 6%) whereas compost application and increasing irrigation interval has significantly decreased bulk density by 5% (Figure 3).

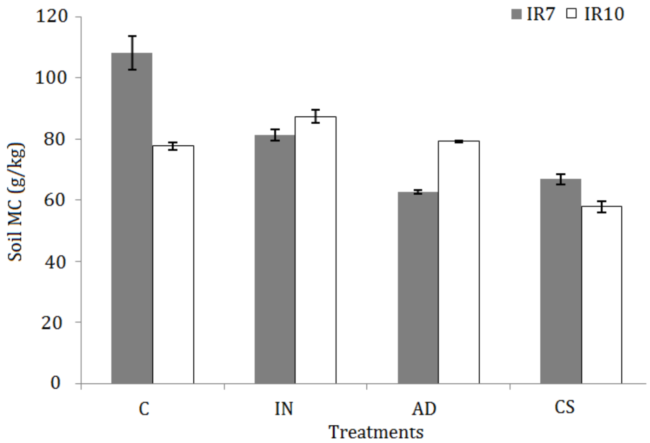

Figure 2. Effect of sludge treatment on soil MC after harvest ($P \leq 0.2$, LSD=35.3)

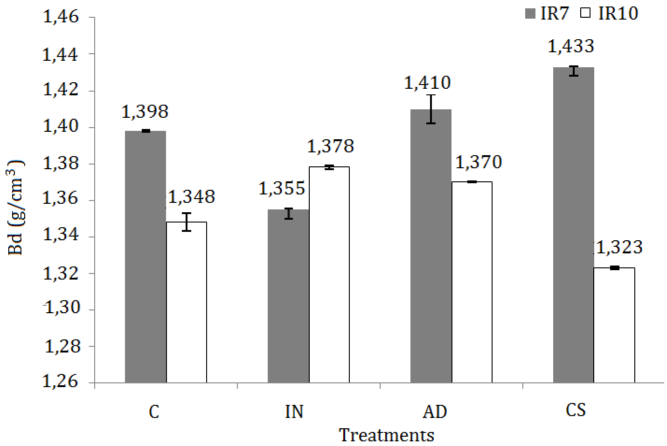

Figure. 3. Effect of sludge teratment on soil bulk density after harvest ($P \leq 0.0001$; LSD=0.009)

Effects of sludge treatment on dry matter yield (DMY) and straw nutrient content

In our study we aimed to determine the differences in effect of applying either air dried or composted sludge on crop-soil systems. It was also important to economize water through determining whether we can extend irrigation interval with organic amendments. Many studies have shown that sewage sludge is a good source of plant nutrients and it contains most of the essential nutrients for plant growth. On the contrary, we found that 10 days irrigation interval has significantly reduced yield over 7 days. Application of sewage sludge enhances soil fertility through increasing soil organic matter (Casado-Vela et al., 2006; Rezig et al., 2013) and consequently have positive effects on both the quantity and the quality of the biomass produced by crops (Seleiman et al., 2013; Mañas et al., 2014). Recently, Lag-Brotons et al. (2014) found that application of composted sludge at a rate of 70 t ha^{-1} to soils with poor physical structure, calcareous and with low organic matter has increased above ground yield of *Cynara cardunculus* L. (cynara) by 68% over the control. Although mineral N (NH_4-N + NO_3-N) in air dried compost was not determined, we expect that initial content to be high (Alvarenga et al., 2015) rendering it available for plant uptake. Therefore, plants supplied with fresh compost showed significantly high N content. Many previous studies have indicated that fresh sludge contains beside sanitary risk (Sidhu and Toze, 2009), extra mineral N that could be leached downwards and threatens pollution of water with NO_3-N. During composting, soluble mineral N decreased due to consumption by decomposing organisms that convert this portion into organic N (immobilization). Accordingly, N release from added compost is known to be slow and environmentally acceptable. This process is very important in nutrients cycling especially N turnover and it improves N synchrony between application and absorption. Fresh application of organic materials provides the soil with different types of organic compounds than composted materials. For instance, fresh residues are rich in polysaccharides and low molecular weight compounds (Said-Pullicino et al., 2007), which contribute to the initial stages of aggregate formation (Roldán et al., 1996; Abiven et al., 2009). In contrast, composted residues exert influence due to humic substances and are related to long-term aggregate stabilization (Abiven et al., 2009). Therefore, we assume that there was immediate soluble mineral N from sun dried sludge and could possibly increased ANUE. However, average ANUE from composted sludge (22.5%) seemed to be lower than that reported in air-dried sludge (average of 45%). The low ANUE from composted sludge may possibly indicates slow release of N during the growing season. In a glasshouse experiment, Asagi and Ueno (2008) reported NUE by *Brassica campestris var. perviridis* to be 19.7 and 12.1% for mineral N and sewage sludge, respectively. They also reported similar ratios of N to soil uptake for mineral fertilizer and sewage sludge of 3.1 and 1.88, respectively. Application of sewage sludge sun dried or composted has significantly increased N content of fodder sorghum plants (*Sorghum bicolor*). Composting of sewage sludge has resulted in N content in plants lower than the sun dried sludge which was also interpreted in low ANUE in composted plots. This may be attributed to either volatilization of NH_3 during composting or leaching of soluble nitrate at early stage of growth**.** On the contrary**,** significant increase in N content in plants after application of sewage sludge was reported by Kabirinejad and Hoodaji (2012). They also reported that application of sewage sludge increased significantly P and K content in the plant. The low content of P and K in sludge treatments may possibly be due to their initial low content. Also, the alkalinity of the soil may negatively affect the uptake of P content in the soil. These differences in results may be attributed to their high application rates (25 and 50 t ha^{-1}) and also the study of previous authors was carried out under controlled conditions (pot experiment).

Effects of sludge treatment on soil properties

In this study, the alkaline nature and presence of considerable salts (Table 2) used in sludge may justify the increase in soil reaction. It was stated by Alvarenga et al. (2015) that "typically, pH values for mature composts are close to 8.0, which identify its basic nature, usually due to compounds of calcium and sodium. This value leads to admit that the product has, at least in the short term, a certain mineral alkalizing effect when applied to soils, especially when they have low buffering capacity". However, the effect of sewage sludge application on soil reaction was not significant. For example, because of acidity, sewage sludge was generally reported to decrease soil pH (e.g. Veeresh et al., 2009; Latare et al., 2014) but application of up to 90 t ha^{-1} was reported not to be significantly changed soil pH (Delibacak et al., 2009). Additionally, application of stabilized municipal sewage sludge to a degraded acid mine soil for 45 days was reported to slightly increase soil pH (Mingorance et al., 2014). The increase in total salts with air-dried sludge could possibly be due to high initial ECe values. However, compared to the control plots, application of stable compost in this study decreased soluble salts that might be due to the formation of macro-aggregates and therefore increasing leaching of salts. Our results are inconformity with several workers who reported that application of sewage sludge improves soil physical properties such as bulk density, aggregate stability, water holding capacity, total porosity, and saturated hydraulic conductivity (Sort and Alcañiz, 1999; Aggelides and Londra, 2000; Mondal et al., 2015). In this study, compost application and reducing irrigation interval have positive effects on soil TN. The content of nitrogen in composted sludge used in our experiment (Table 2) is almost five folds more that of air-dried sludge. Accumulation of TN in plots treated with composted sludge is in line with several earlier studies (e.g. Jin et al., 2011; Roig et al., 2012; Latare et al., 2014). However, increasing irrigation interval may delay decomposition and N release due to less available moisture content for biological activity and may consequently result in N compositions build up. The order of increase in SOC found in our study supports earlier studies that composting sludge is a useful practice to obtain stable material that provides soil with organic matter. Many studies have reported positive effects from application of composted sludge on soil C in semi-arid regions. Many previous studies found increase of SOC up to six folds more, 36% higher than control or increase linearly with sludge dose (Salazar et al., 2012; Jin et al., 2015; Peña et al., 2015). The relatively high content of Ca^{+2} and Mg^{+2} in the composted sludge as compared to air-dried sludge may justify the accumulation of such elements in amended plots. On the contrary, Wen et al. (1999) did not find change in concentration of Ca^{+2} and Mg^{+2} in the bean pods due to application of 10, 20, 30 and 40 t ha^{-1} of composted sludge for two years. Our results showed that application of composted sludge could be a useful management practice for amelioration of sodic soils since SAR was significantly reduced. Application of composted sludge elsewhere was reported to reduce exchangeable sodium percentage from initial values of a saline sodic soil by 51% (Ors et al., 2015).

It is not known from our research why application of air-dried and composted sludge at a reduced irrigation interval has increased bulk density of the sandy clay loam soil. The only possible interpretation is that based on readily dissolved organic materials that brought together single fine sand grains, thereby increasing weight of soil particles per unit volume area. The decrease in bulk density with compost application found in this study is in line with other studies (Aggelides and Londra, 2000; Celik et al. 2004; Mondal et al., 2015). However, many long term experiments indicated contrasting effects of soil density with biosolids application. For example, Jin et al. (2011, 2015) reported that application of either 22 t ha^{-1} for 25 years or up to 67 t ha^{-1} of biosolids for 8 years has little or no effects on bulk density of the 0-10 cm depth of a silty loam to silty clay loam soil. Haney et al. (2015) found that in fields receiving annual application of 20 t ha^{-1} for 8 years consequently, soil bulk densities (0–30 cm) increased linearly with biosolids application rate and consistent with soil compaction due to wheel traffic. In a sandy soil (87, 9 and 4% sand, silt and clay, respectively), Glab (2014) reported positive decrease of bulk density with increase in compost application rate (R^2=0.991).

Conclusion

In general, application of composted sewage sludge has improved soil conditions which have been reflected in yield increase of fodder sorghum (*Sorghum bicolor)*. The combination of composted sludge and increasing irrigation interval had resulted in increasing yield by more than 47% in comparison with air-dried sludge treatment with similar irrigation interval.

References

Abdalla, M.A., 2015. Regional assessment of soil changes in the Near East and North Africa. In: Status of the World's Soil Resources (SWSR) - Main Report, FAO and ITPS. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy. pp. 399-441.

Abiven, S., Menasseri, S., Chenu, C., 2009. The effects of organic inputs over time on soil aggregate stability-a literature analysis. *Soil Biology and Biochemistry* 41(1): 1-12.

Aggelides, S.M., Londra, P.A., 2000. Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. *Bioresource and Technology* 71(3): 253-259.

Alvarenga, P., Mourinha, C., Farto, M., Santos, T., Palma, P., Sengo, J., Morais, M.C., Cunha-Queda, C., 2015. Sewage sludge, compost and other representative organic wastes as agricultural soil amendments: Benefits versus limiting factors. *Waste Management* 40: 44-52.

Asagi, N., Ueno, H., 2008. Determination of application effects of sewage sludge on growth, soil properties, and N uptake in Komatsuna by using the indirect ^{15}N isotope method. *Communications in Soil Science and Plant Analysis* 39(13-14): 1928-1942.

Ayoub, A.T., 1999. Land degradation, rainfall variability and food production in the Sahelian zone of the Sudan. *Land Degradation and Development* 10(5): 489-500.

Blake, G.R., Hartge, K.H., 1986. Bulk density by core method. In: Methods of soil analysis, Part 1. Physical and mineralogical methods, 2nd ed., A. Klue (ed.), American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 364-367.

Bremner, J.M., Mulvaney, C.S., 1982. Nitrogen-total. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Page, A.L. Miller, R. H., Keeney, D.R. (eds.). American Society of Agronomy, Madison, WI, USA. pp. 595-663.

Casado-Vela, J., Sellés, S., Navarro, J., Bustamante, M.A., Mataix, J., Guerrero, C., Gómez, I., 2006. Evaluation of composted sewage sludge as nutritional source for horticultural soils. *Waste Management* 26(9): 946-952.

Celik, I., Ortas, I., Kolics, S., 2004. Effects of compost, mycorrhiza, manureand fertilizer on some physical properties of a chromoxerert soil. *Soil Tillage and Research* 78(1): 59-67.

Chapman, H.D., Pratt, P.F., 1961. Methods of analysis for soil, plant and water. Riverside University of California. Division of Agricultural Sciences. Berkeley, USA. 309 p

Dawi, B.S.I., 2014. Use of Three Organic Amendments for Cultivation of Grain Sorghum (*Sorghum bicolor* L.) and Soil Quality Changes under Desert Conditions. PhD Thesis. University of Khartoum, Sudan.

Deliback, S., Okur, B., Ongum, A.R., 2009. Effects of treated sewage sludge levels on temporal variations of some soil properties of a Typic Xerfluvent soil in Menemen Plain, Western Anatolia, Turkey. *Environmental Monitoring and Assessment* 148(1): 85-95.

Diaz, E., Rodlan, A., Lax, A., Albaladejo, J., 1994. Formation of stable aggregates in degraded soil by amendment with urban refuse and peat. *Geoderma* 63(3-4): 277-288.

Giannakis, G.V., Kourgialas, N.N., Paranychianakis, N.V., N.P Nikolaidis, N.V., Kalogerakis, N., 2014. Effects of municipal solid waste compost on soil properties and vegetable growth. *Compost Science and Utilization* 22(3): 116-131.

Ghoniem, A., 2007. Effect of nitrogen supplied from poultry manure and sewage sludge on growth, yield and nitrogen uptake of rice. *Bulletin of Experimental Farm, Faculty of Agriculture, Ehime University* 29: 11-16.

Glab, T., 2014. Water retention and repellency of a sandy soil amended with municipal compost. *Compost Science and Utilization* 22(2): 47-56.

Goh, T.B., AanaulL, R.J. St., Mermut, A.R., 1993. Carbonates. In: Soil sampling and Methods of Analysis. M.R. Carter (ed.) Lewis Publishers, Boca Raton, FL, pp. 177-185.

Goyal, S.K., Dhull, S.K., Kapoo, K.K., 2005. Chemical and biological changes during composting of different organic wastes and aassessment of ccompost mmaturity. *Bioresource Technology* 96(14): 1584-1591.

Haney, R. L., Jin, V.L., Johnson, M.V.V., White, M.J., Arnold, J.G., 2015. On-site assessment of extractable soil nutrients after long-term biosolids applications to perennial forage. *Communications in Soil Science and Plant Analysis* 46(7): 873-887.

Jin, V.L., Johnson, M.V.V., Haney, R.L., Arnold, J.G., 2011. Potential carbon and nitrogen mineralization in soils from a perennial forage production system amended with class B biosolids. *Agriculture, Ecosystems and Environment* 141(3-4): 461-465.

Jin, V.L., Potter, K.N., Johnson, M.V., Harmel, R.D., Arnold, J.G., 2015. Surface-applied biosolids enhance soil organic carbon and nitrogen stocks but have contrasting effects on soil physical quality. *Applied and Environmental Soil Science* Volume 2015.

Kabirinejad, S., Hoodaji, M., 2012. The effects of biosolid application on soil chemical properties and *Zea mays* nutrition. *International Journal of Recycling of Organic Wastes in Agriculture* 1:4.

Lag-Brotons, A., Gómez, I., Navarro-Pedreno, J., Mayoral, A.M., Curt, M.D., 2014. Sewage sludge compost use in bioenergy production - a case study on the effects on *Cynara cardunculus* L energy crop. *Journal of Cleaner Production* 79: 32-40.

Lampkin, N., 1990. Organic Farming. Farming Press Books, Ipswich, UK. 701 p.

Latare, A.M., Kumar, O., Singh, S.K., Gupta, A., 2014. Direct and residual effect of sewage sludge on yield, heavy metals content and soil fertility under rice-wheat system. *Ecological Engineering* 69: 17-24.

Manas, P., Castro, E., Heras, J.D.L., 2014. Application of treated wastewater and digested sewage sludge to obtain biomass from *Cynara cardunculus* L. *Journal of Cleaner Production* 67: 72-78.

Mclean, E.O., 1982. Soil pH and lime requirement. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Page, A.L. Miller, R. H., Keeney, D.R. (eds.). American Society of Agronomy, Madison, WI, USA. pp. 199-223.

Mingorance, M.D., Rosini Oliva, S., Valdés, B., Pina Gata, F.J., Leidi, E.O., Guzmá, I., Peña, A., 2014. Stabilized municipal sewage sludge addition to improve properties of an acid mine soil for plant growth. *Journal of Soils and Sediments* 14(4): 703-712.

Mondal, S., Singh, R.D., Patra, A.K., Dwivedi. B.S., 2015. Changes in soil quality in response to short-term application of municipal sewage sludge in a typic haplustept under cowpea-wheat cropping system. *Environmental Nanotechnology, Monitoring and Management* 4: 37-41.

National Center for Research. 1994. Environmental and Natural Resources Research Institute, Annual Scientific Report.

Nelson, D.W., Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Page, A.L. Miller, R. H., Keeney, D.R. (eds.). American Society of Agronomy, Madison, WI, USA. pp. 539-577.

Olsen, S.R., Sommers, LE., 1982. Phosphorous. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Page, A.L. Miller, R. H., Keeney, D.R. (eds.). American Society of Agronomy, Madison, WI, USA. pp. 403-430.

Ors, S., Sahin, U., Khadar, R., 2015. Reclamation of saline-sodic soils with the use of mixed flyash and sewage sludge. *Arid Land Research and Management* 29(1): 41-54.

Peña, A., Mingorance, M.D., Oliva, S.R., 2015. Soil quality improvement by the establishment of a vegetative cover in a mine soil added with composted municipal sewage sludge. *Journal of Geochemical Exploration* 157: 178-183.

Rezig, F. A.M., Mubarak, A.R., Elhadi, E.A., 2013. Impact of organic wastes and mineral fertilizer application on soil-crop system II: Soil attributes. *Archives of Agronomy and Soil Science* 59(9): 1245-1261.

Richard, L.A., 1954. Diagnosis and improvement of saline and alkali soils. Agriculture Handbook Vol. 60. United States Department of Agriculture, Washington, DC, USA. 160 p.

Rigby, H., Clarke, B.O., Pritchard, D.L., Meehan, B., Beshah, F., Smith, S.R., Porter, N.A., 2016. A critical review of nitrogen mineralization in biosolids-amended soil, the associated fertilizer value for crop production and potential for emissions to the environment. *Science of the Total Environment* 541: 1310-1338.

Roig, N., Sierra, J., Marti, E., Schumacher, M., Dommingo, J.L., 2012. Long-term amendment of Spanish soils with sewage sludge: Effects on soil functioning. *Agriculture, Ecosystems and Environment* 158: 41-48.

Roldán, A., Albadalejo, J., Thomes, J.B., 1996. Aggregate stability changes in a semiarid soil after treatment with different organic amendment. *Arid Soil Research and Rehabilitation* 10(2): 139-148.

Rynk, R. 1992. On-farm composting handbook. Northeast Regional Agricultural Engineering Service, Cornell University, Ithaca, New York, USA. 186 p.

Said-Pullicino, D., Kaiser, K., Guggenberger, G., Gigliotti, G., 2007. Changes in the chemical composition of water-extractable organic during composting: distribution between stable and labile organic matter pools. *Chemosphere* 66(11): 2166-2176.

Salazar, I., Millar, D., Lara, V., Muñez, M., Parada, M., Alvear, M., Baraona, J., 2012. Effects of the physical application of biosolids on some chemical, biological and physical properties in an Andisol from southern Chile. *Journal of Soil Science and Plant Nutrition* 12(3): 441-450.

SAS Institute Inc. 1999. SAS/STAT User's Guide, Version *8*, Cary, NC: SAS Institute Inc.

Schnitzer, M., Kahn, M., 1987. Humic Substances in the Environment. Marcel-Dekker, New York, USA.

Seleiman, M.F., Santanen, A., Jaakkola, S., Ekholm, P., Hartikainen, H., Stoddard, F.L., Mäkelä, P.S.A., 2013. Biomass yield and quality of bioenergy crops grown with synthetic and organic fertilizers. *Biomass and Bioenergy* 59: 477-485.

Sidhu, J.P.S., Toze, A.G., 2009. Human pathogens and their indicators in biosolids: a literature review. *Environment International* 3(1)5: 187-201.

Smith, S.R., 2009. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste compost compared to sewage sludge. *Environment International* 35(1): 142-156.

Spaccini, R., Piccolo, A., Conte, P., Haberhauer, G., Gerzabek, M.H., 2002. Increased soil organic carbon sequestration through hydrophobic protection by humic substances. *Soil Biology and Biochemistry* 34(12): 1839-1851.

Sort, X., Alcañiz, J.M., 1999. Effects of sewage sludge amendment on soil aggregation. *Land Degradation and Development* 10(1): 3-12.

Veeresh, H., Tripathy, S., Chaudhuri, D., Ghosh, B., Hart, B., Powell, M., 2009. Changes in physical and chemical properties of three soil types in India as a result of amendment with fly ash and sewage sludge. *Environmental Geology* 43(5): 513-520.

Wen, G., Bates, T.E., Voroney, R.P., Winter, J.P, Schellenberg, M.P., 1999. Influence of application of sewage sludges, and sludge and manure composts on plant Ca and Mg concentrations and soil extractability in field experiments. *Nutrient Cycling in Agroecosystems* 55(1): 51-61.

Zheliazkov, V.D., Warman, P.R., 2002. Comparison of three digestion methods for the recovery of 17 plant essential nutrients and trace elements from six composts. *Compost Science and Utilization* 10(3): 197-203.

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DTPA-extractable micronutrients: A geostatistical study from Ordu, Turkey

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Abstract

In present study, geostatistical techniques were applied to assess the spatial variability of DTPA-extractable micronutrients which are named heavy metals as chemistry such as; iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) in the non-tillaged layer in Ordu province- Altınordu district, Black sea region, Eastern part of Turkey. Study area was approximately 40095.8 ha where was divided into grids with 2500 x 2500 m spacing with including 66 sampling points from 0-0.2 m in depth. Soil reaction (pH) was the least variable property while electrical conductivity (EC) was the most variable. While the highest nugget effect occurred for Ext-Cu with moderate spatial dependence, the lowest for Ext-Mn with strong spatial dependence. The greatest range of influence (17424 m) occurred for Ext-Cu and the least range (692 m) for Ext-Zn.

Keywords: DPTA-extractable micronutrients, spatial variability, site specific management.

Introduction

The micronutrients B, Cl, Cu, Fe, Mn, Mo, and Zn are the seven essential elements for plants at requirement levels of less than 0.10% in the plant's dry matter. They are essential for healthy growing of plants which are only needed in very small quantities. Micronutrients are nutrients required by humans and other organisms throughout lifetime even in small quantities, to manage a range of physiological functions. Plants require very small amounts of micronutrients for optimal growth and excessive amount of micronutrients concentrations in soil can be harm for plants. Soil micronutrient deficiency is considerably important for yield, food quality and nutrient balance in human and animal nourishments. Also, they have huge important for environmental conservation On the other hand, for the better management in agricultural production areas, determination of soil micronutrient content has a vital importance (Epstein, 1972; Singh et al., 1985; Glass, 1989; Römheld and Marschner, 1991; Singh, 2008; Akbaş et al., 2009; Thakur et al., 2011; Sharma and Jassal, 2013).

Soil properties in all ecosystems are controlled by a variety of factors that operate at different spatial and temporal scales. Soil physical, chemical and biological properties are all likely to change markedly across small distances, within a few hectares of agricultural fields (Cambardella et al., 1994; Chien et al., 1997; Benayas et al., 2004; Akbaş et al., 2009). Analysis of wide-scale variability has practical usage in managing soil fertility and sustainability for a chosen area (Singh et al., 1985; Brady and Weil, 2002; Akbaş et al., 2009; Sharma and Jassal, 2013). Geostatistics, increasingly popular in soil science, are useful to predict the spatial distribution of spatially dependent soil properties in the field with a number of samples (McBratney and

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Webster, 1983; Oliver, 1987; Kerry and Oliver, 2004, Aşkın and Kızılkaya, 2006; Akbaş et al., 2009; Aşkın, 2010). DTPA-extractable Fe, Cu, Mn and Zinc are the dominant micronutrients in soils and hence, to understand the spatial variability was expected to better understanding of the related soil chemical parameters for long-term study within district-scale (Singh et al., 1985; Gao and Tong, 2007; Akbaş et al., 2009).

Our aim with this present study was to assess the spatial variability of soil DTPA-extractable micronutrients in district-scale using by geostatistical techniques.

Material and Methods

Study site

The study area is located in Ordu province, Altınordu district, Eastern Black sea Region, Turkey in 2015 (Figure 1).

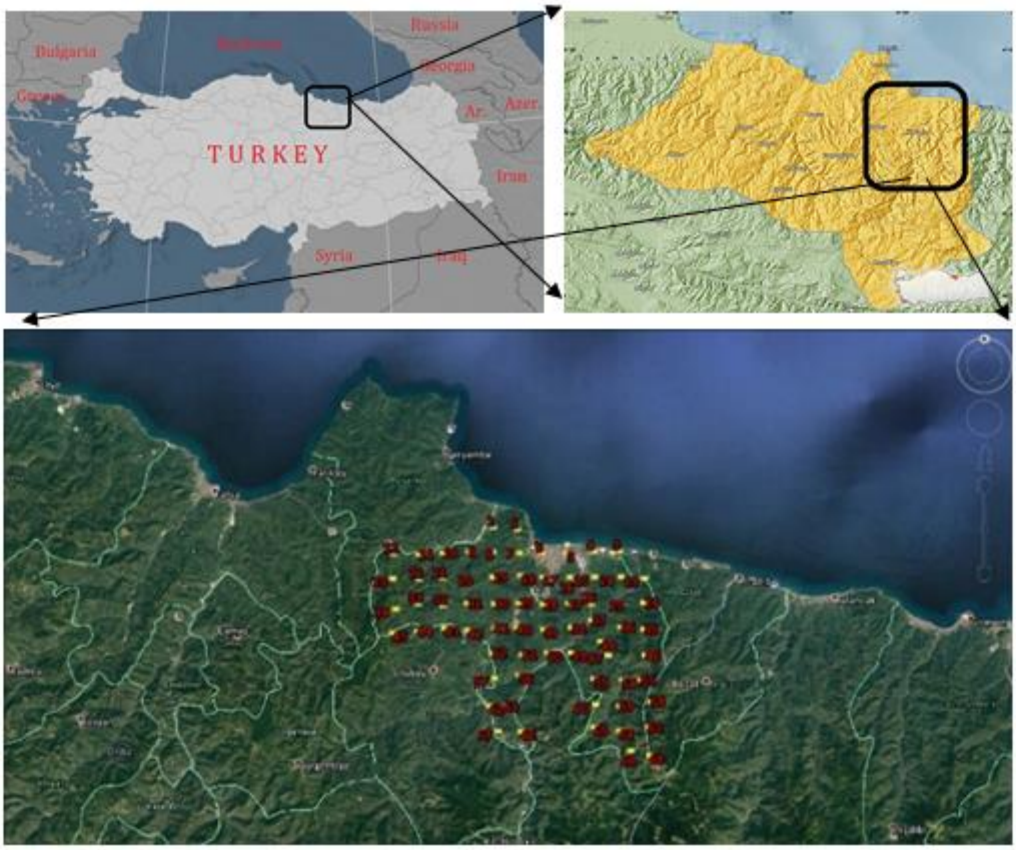

Figure 1. Location map of the study area showing the sampling design (The coordinates are in meters in UTM datum).

This area is characterized hardly sloping with a well-drained and moderate to clayey textured soil. Ordu is a center of hazelnut growing area of Turkey located near the Black sea, has typical Black sea climate with warm summers and cool winters. The highest and the lowest the temperature was from -7.2 to 37.3 °C. The annual mean temperature was 14.3 °C and the annual mean precipitation was 1035.1 mm based on a 65 years period. The study site was marked with regular rectangle grids (2500 x 2500 m each) and including 66 sampling points (Figure 1).

Soil analyses

Soil samples were air-dried and ground to pass from 2 mm sieve for chemical analysis. Selected soil physicochemical properties were determined by the following methods: organic carbon content by the modified Walkley-Black method (Nelson and Sommers, 1982), particle size distribution by the hydrometer method (Gee and Bauder, 1979), soil pH and electrical conductivity (EC) in 1:1 (w/v) soil-water ratio using pH-meter and EC-meter (Peech, 1965). Fe, Cu, Mn and Zn in soil samples were extracted with a DTPA solution (0.005M DTPA + 0.01 M CaCl2 + 0.1M triethanolamine, pH 7.3 as outlined by Lindsay and Norvell. The concentration of micronutrients in the extract was determined by atomic absorption spectrophotometer (Lindsay and Norvell, 1978).

Statistical analysis

Descriptive statistics, ie, mean, standard deviation, median, minimum, maximum and data normality, were calculated using SPSS 15.0 software. Isotropic semivariances on data were calculated using GS+ 10.0 geostatistical software (GS+, 2014). Semivariance γ(h) is defined in the following equation:

$$\gamma(h)=\frac{1}{2N(h)}\Sigma\left[\,Z(x_i)-Z(x_i+h)\,\right]^2 \tag{1}$$

where, N(h)=the number of sample pairs at each distance interval

Z (X_i,) and Z (X_i + h)= the values of variable at any two places separated by distance h.

The semivariogram is the plot of the semivariance against the distance. Its shape indicates whether the variable is spatially dependent. Experimental semivariograms were fitted by theoretical models that have well-known parameters nugget (C_0), sill (C_0 + C) and range (A) of spatial dependence (Cambardella et al., 1994).

GS+ has several models that can be fitted to estimate semivariograms, but in this study, we used the isotropic spherical (2) and Gaussian models (3):

$$\gamma(h) = Co + C\left[1,5\left(\frac{h}{A}\right) - 0,5\left(\frac{h}{A}\right)^3\right] \tag{2}$$

$$\gamma(h) = Co + C\left[1 - \exp\left(\frac{-h^2}{A^2}\right)\right] \tag{3}$$

Where Co is the nugget variance
C is the structural variance
Co+C is the sill variance
A is the range of spatial correlation

In this study, point kriging was used before constructing of contour maps to provide enough estimated data. The contour maps of DTPA-extractable Fe, Cu, Mn and Zn contents were constructed using ArcGis software.

Results and Discussion

Soil properties and DTPA-extractable micronutrients

The soils had 39.2% sand, 26.0 silt and 34.9% clay fraction and soil textural class was named as clay loamy. Also descriptive statistics of soil properties are given in Table 1.

Table 1. Summary statistics on the some soil properties and DTPA-extractable micronutrients (*n=66*)

Soil Properties	Mean	Minimum	Maximum	S_d	CV
Clay (C), %	34.9	11.9	69.3	12.86	36.9
Silt (Si), %	26.0	15.7	43.8	5.76	22.2
Sand (S), %	39.2	10.7	68.3	13.24	33.8
pH	5.97	4.54	7.97	0.73	12.3
EC, dS m^{-1}	0.09	0.02	0.37	0.08	86.3
OMC, %	2.75	0.43	6.50	1.48	53.8
DTPA-Extractable micronutrients mg kg^{-1}					
Ext-Fe	47.75	10.1	189.6	36.48	76.57
Ext-Cu	1.47	0.14	5.49	1.06	72.55
Ext-Mn	38.8	1.2	136.9	31.47	81.21
Ext-Z)	0.77	0.16	2.64	0.56	71.71

S_d, standard deviation; CV, variation of coefficient

The soils were mostly clayey in texture, slightly acid in soil reaction, medium in organic matter content (average of 2.75%) and very low in electrical conductivity (<0.98 dS m^{-1}) (Soil Survey Staff, 1993).

Spatial variability of DTPA-extractable micronutrients

Distances between Ext-Fe, Ext-Cu, Ext-Mn and Ext-Zn pairs and semivariance values were calculated using the GS+ package program. The spherical and Gaussian models with the smallest reduced sums of squares values and the biggest R^2 values were selected for evaluating spatial variability of these micronutrients in the study area by the GS+ package program (Table 2).

Table 2. Isotropic models fitted to variograms of DTPA-extractable micronutrients

Micro nutrients	Co	Co+C	A m	NE %	R^2	Model	SD
Ext-Fe	0.011	0.444	3723	2.5	0.50	Gaussian	S
Ext-Cu	0.594	1.609	17424	36.9	0.94	Gaussian	M
Ext-Mn	0.001	1.193	3600	0.1	0.30	Spherical	S
Ext-Zn	0.019	0.386	692	4.9	0.29	Gaussian	S

NE, nugget effect (Co/Co+C); SD, spatial dependence; M, moderate; S, strong

The nugget effect (NE), representing the undetectable experimental error and field variation within the minimum sampling space, was quite large relative to the sill, which represents total spatial variation. The NE expressed in percentages can be regarded as a criterion for classifying the spatial dependence of soil properties. If the NE is less than 25%, then the variable has strong spatial dependence; between 25 and 75%, the variable has moderate spatial dependence; otherwise, the variable has weak spatial dependence (Chien et al., 1997).

The ranges for Fe, Cu, Mn and Zn were 3723 m, 17424 m, 3600 m and 692 m, respectively. The highest NE occurred for Ext-Cu and with moderate spatial dependence. The lowest NE occurred for Ext-Mn with strong spatial dependence. Akbaş et al (2009) interpreted strong and moderate spatial variability as interactions among field-scale variability of soil DTPA-extractable micronutrients.

The Gaussian model for Ext-Fe, Ext-Cu and Ext-Zn and the spherical model for Ext-Mn showed the best fitting value for the computed semivariance values. The model parameters and the experimental variograms for Ext-Fe, Ext-Cu, Ext-Mn and Ext-Zn are illustrated in Figure 2a,b,c, and 2d, respectively.

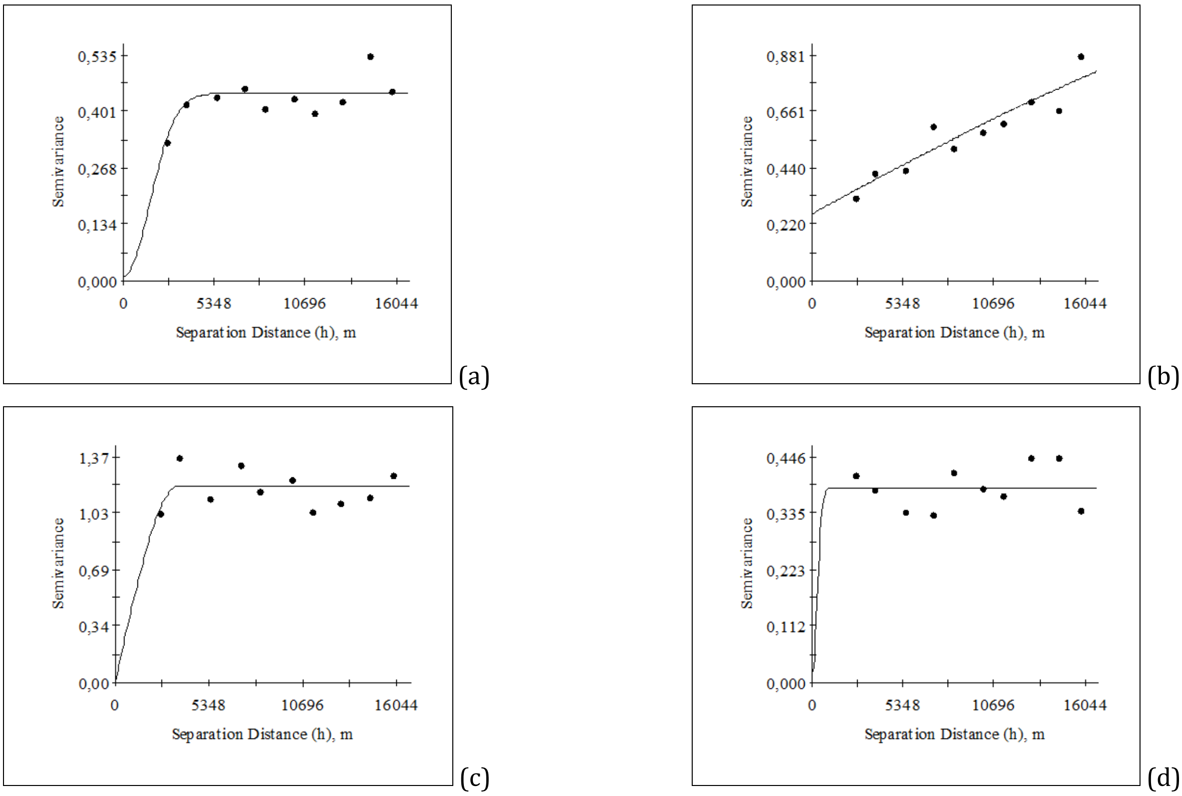

Figure 2. Isotropic semivariograms for a) Ext-Fe b) Ext-Cu c) Ext-Mn d) Ext-Zn

DTPA-extractable micronutrients were point-kriged based on the isotropic models in 250 x 250 m dimensions by 8811 points using the sixteen nearest neighboring points. The descriptive statistics are presented in Table 3 for observed and point-kriged on the studied micronutrients.

Table 3. Descriptive statistics on the observed and point-kriged values of DTPA- extractable micronutrients

Statistics	Ext-Fe		Ext-Cu		Ext-Mn		Ext-Zn	
	mg kg^{-1}							
	Obs*	Prd**	Obs	Prd	Obs	Prd	Obs	Prd
N	66	8811	66	8811	66	8811	66	8811
Minimum	10.1	10.9	0.14	0.28	1.2	1.2	0.16	0.19
Maximum	189.6	186.2	5.49	4.00	136.9	131.1	2.64	1.66
Mean	47.7	44.3	1.47	1.62	38.8	30.9	0.77	0.61
Sd	36.5	11.7	1.06	0.51	31.47	17.99	0.56	0.13
Prediction errors								
Mean	0.059		0.005		0.02		0.07	
RMSs***	1.02		1.06		0.47		0.93	

*Obs., observed; **Prd., predicted; ***RMSs, Root-Mean-Square Standardized

As seen from Table 3, the mean reduced errors were near to zero and the squared differences between the predicted and the original values, the variance of the reduced error, were the lowest for the fitted models. This means that the kriging estimates are accurate, and the spatial relationships derived from the studied part of the research site may be applicable to similar areas with this area (Trangmar et al., 1985; Öztaş, 1996; Ardahanlıoğlu et al., 2003; Başkan, 2004; Akbaş et al., 2009; Aşkın, 2010; Aşkın et al., 2011). The range of point-kriged Ext-Fe values (10.9-186.2 mg kg^{-1} with a mean of 44.3 mg kg^{-1}) were somewhat narrower than the range of the measured Ext-Fe (10.1-189.6 mg kg^{-1} with a mean of 47.7 mg kg^{-1}). The standard deviation of the kriged Ext-Fe values were lower than on the measured that this mean of selected model was true. Figure 3a shows a point-kriged map of Ext-Fe illustrated using the 8811 points.

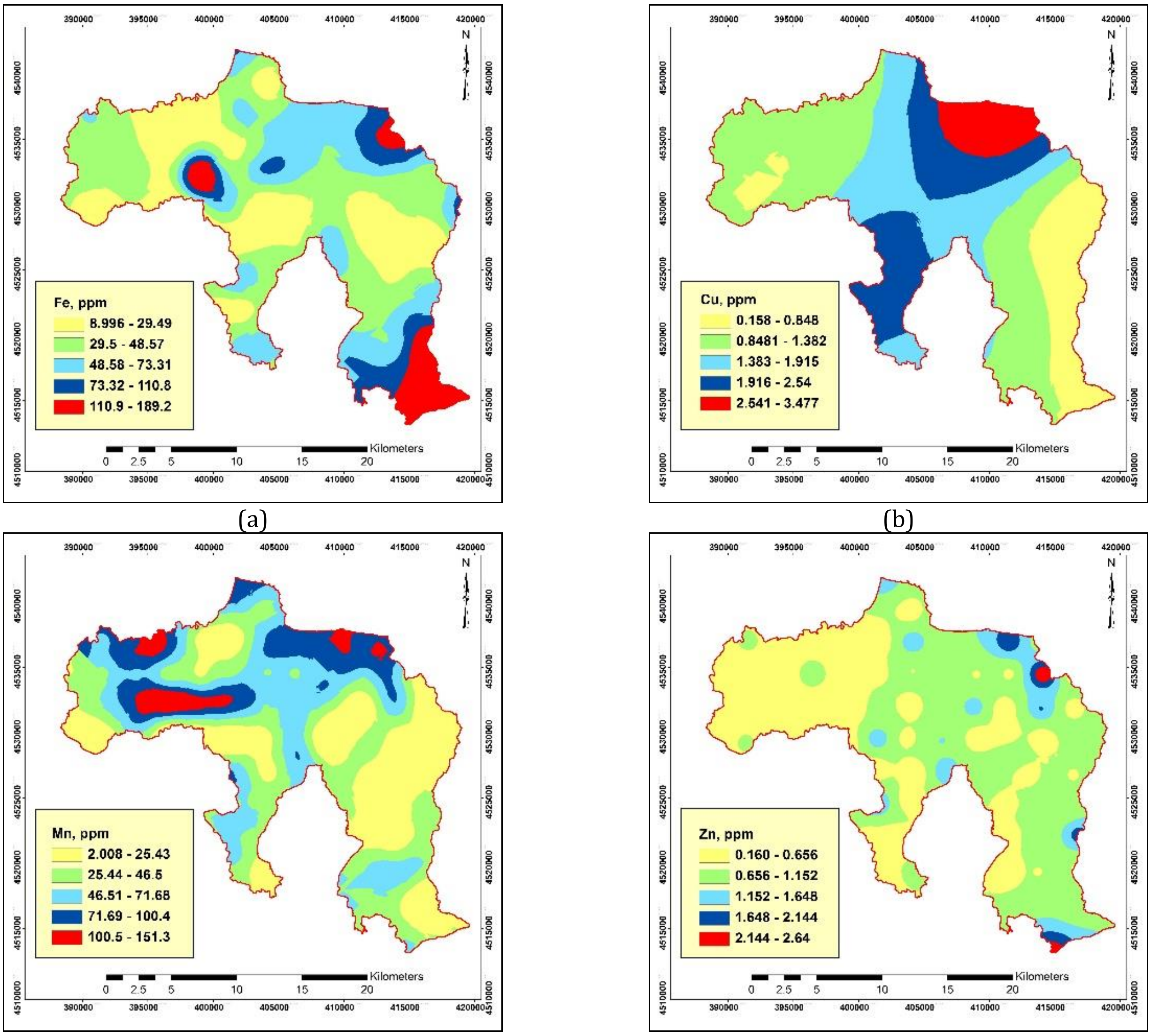

Figure 3. Point-kriged maps for a) Fe b) Cu c) Mn d) Zn

The range of point-kriged Ext-Cu values (0.28-4.00 mg kg^{-1} with a mean of 1.62 mg kg^{-1}) were somewhat narrower than the range of the measured Ext-Cu (0.14-5.49 mg kg^{-1} with a mean of 1.47 mg kg^{-1}). The standard deviation of the kriged Ext-Cu values were the lower than the measured values which means of selected model is true. Figure 3b shows a point-kriged map of Ext-Cu illustrated using the 8811 points.

Also Ext-Mn kriging values ranging from 1.2 to 131.1 mg kg^{-1} with a mean of 30.9 mg kg^{-1} that were somewhat narrower than the range of the measured Ext-Mn (1.2-136.9 mg kg^{-1} with a mean of 38.8 mg kg^{-1}). The standard deviation of the kriged Ext-Mn values were the lower than at the measured values. Figure 3c shows a point-kriged map of Ext-Mn illustrated using the same points.

The point-kriged Ext-Zn values ranged 0.19-1.66 mg kg^{-1} with a mean of 0.61 mg kg^{-1} that were somewhat narrower than the range of the measured Ext-Zn (0.16-2.64 mg kg^{-1} with a mean of 0.77 mg kg^{-1}). The standard deviation of the point kriged Ext-Zn values were the lower than on the measured values so that the selected model is true. Figure 3d shows a point-kriged map of Ext-Zn illustrated using the same points.

Huichun et al. (2015) reported that spatial variability of available soil Fe, Mn, Cu, and Zn contents were evaluated in an ecological functional zone located at Yanqing County, Beijing, China, and their influence factors were analyzed. Their results revealed that the available soil Cu had a widest spatial correlation distance (e.g., 9.6 km), which for available soil Fe, Mn, and Zn were only 1.29, 2.58, and 0.99 km, respectively.

Conclusion

Assessing of the spatial variability of soil DTPA-extractable micronutrients and its affect factors are huge importance for applications such as fertilization, sustainable soil use and environmental protection especially for agricultural ecosystems. The range of spatial dependence ranged from 692 to 17424 m, indicating that the grid scale was adequate for assessing of the spatial variability of the DTPA-extractable micronutrients. In this area or a similar land, in soil productivity and fertility research studies to be done about sampling interval can be chosen. Although the Gaussian isotropic model was the best semivariogram model for Ext-Fe, Ext-Cu and Ext-Zn and the spherical model was the best for Ext-Mn. The information obtained from geostatistical techniques can be used to gain a better understanding of the spatial distribution of DTPA-extractable micronutrients status in the district topsoil. This approach enabled mapping of soil plant nutrients in the district-scale. Our results suggested that the use of kriging should decrease the required sampling density in the district-scale. Spatial analysis on soil micronutrients could be useful for assessing soil fertility status and soil quality, as well as developing appropriate sampling strategies. Also our results should help goals on site specific management applications in study area or similar lands.

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References

Akbaş, F., Günal, H., Gökmen, F., Gezgin, S., Erşahin, S., 2009. Spatial variation of micronutrients in topsoil and subsoil of Vertic Haplustepts. *Agrochimica* 53(2): 101-116.

Ardahanloğlu, I., Öztas, T., Evren, S., Yılmaz, T., Yıldırım, Z.N., 2003. Spatial variability of exchangeable sodium, electrical conductivity, soil pH and boron content in salt- and sodium-affected areas of the Iğdır plain (Turkey). *Journal of Arid Environment* 54(3): 495-503.

Aşkın, T., Kızılkaya, R., 2006. Assessing spatial variability of soil enzyme activities in pasture topsoils using geostatistics. *European Journal of Soil Biology* 42(4): 230-237.

Aşkın, T., 2010. Evaluation of some soil properties as related to landscape position using geostatistical techniques, International Scientific and Practical Conference on Scientific Support – To Innovative Development of the Agro-Industrial Complex), 18-19 November, Perm State Agricultural Academy, Perm, Russia, p. 34-40.

Aşkın, T., Sinitsa, Y.N., Kızılkaya, R., 2011. The spatial variability of arylsulphatase activity: A study from agricultural ecosystems, International Conference on "Resource Potential of Soils – The Basis of the Food and Ecological Safety of Russia", 1-4 March, Saint Petersburg State University, Saint Petersburg, Russia, p. 324-327

Başkan, O., 2004. Gölbaşı yöresi topraklarının mühendislik, fiziksel özellik ilişkilerinde jeoistatistik uygulaması. Ankara Üniversitesi Fen Bilimleri Enstitüsü Toprak Anabilim Dalı, Doktora Tezi, Ankara. [in Turkish]

Benayas, J.M.R., Sachez-colomer, M.G., Escudero, A., 2004. Landscape- and field-scale control of spatial variation of soil properties in Mediterranean montane meadows. *Biogeochemistry* 69(2): 207-225.

Brady, A.C., Veil, R.R., 2002. The nature and properties of soils. 13th edition, Prentice Hall. New Jersey, USA.

Cambardella, C.A., Moorman, A.T., Novak, J.M., Parkin, T.B., Karlen, D.R., Turco, R.F., Konopka, A.E., 1994. Field-scale variability of soil properties in central Iowa soils. *Soil Science Society America Journal* 58(5): 1501-1511.

Chien, Y.J., Lee, D.Y, Guo, H.Y., Houng, K.H., 1997. Geostatistical analysis of soil properties of mid-west Taiwan soils. *Soil Science* 162(4): 291–298.

Epstein, E., 1972. Mineral Nutrition of Plants: Principles and Perspectives, John Wiley & Sons, New York, USA.

Gao, Y.M., Tong, Y.A., 2007. Spatial variability and distribution of five soil microelements content in farmland of Guanzhong Plain. *Journal of Northwest A & F University (Natural Science Edition)* 53: 121-127.

Gee, G.W., Bauder, J.W., 1979. Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measured parameters. *Soil Science Society America Journal* 43(5): 1004-1007.

Glass, D.M. 1989. Plant Nutrition: An Introduction to Current Concepts. Jones and Bartlett Publishers, Boston, MA, USA.

GS+, 2014. Gamma Design Software LLC.. P.O. Box 201, Plainwell, Michigan, USA.

Huichun Y., Chongyang S., Yuanfang H., Wenjiang H., Shiwen Z. ,Xiaohong J., 2015. Spatial variability of available soil microelements in an ecological functional zone of Beijing. *Environmental Monitoring and Assessment* 187:13.

Kerry, R., Oliver, M.A., 2004. Average variograms to guide soil sampling. *International Journal of Applied Earth Observation and Geoinformation* 5(4): 307-325.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, iron, mangasese, and copper. *Soil Science Society America Journal* 42(3): 421-428.

McBratney, A.B., Webster, R., 1983. Optimal interpolation and isarithmic mapping of soil properties: V. Co regionalization and multiple sampling strategy. *European Journal of Soil Science* 34(1): 137-162.

Nelson, D.W., Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Page, A.L. Miller, R. H., Keeney, D.R. (eds.). American Society of Agronomy, Madison, WI, USA. pp. 539-577.

Oliver, M.A., 1987. Geostatistics and its application to soil science. *Soil Use and Management* 3(1): 8-19.

Öztas, T., 1996. Identifying spatial variability of soil depth lost to erosion in a rolling landscape using Kriging analysis. Symposium on Agriculture-Environment Relations, p. 327-335, Mersin, Turkey.

Peech, M., 1965. Hydrogen-ion activity. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A. (ed.). American Society of Agronomy, Madison, WI, USA. pp. 914-925,

Römheld, V., Marschner. H., 1991. Function of micronutrients in plants. In: Micronutrients in Agriculture. Morvedt, J.J., (ed.). 2nd ed., Soil Science Society of America Book Series Number 4, Madison, WI, USA. pp. 297–328.

Sharma, B.D., Jassal, H.S., 2013. Study of a toposequence for variability in micronutrients from the moist subhumid Siwalik agro-ecological subregion of Punjab. *Archives of Agronomy and Soil Science* 59(4): 573-591.

Singh, J.P., Karamanos, R.E., Kachannoski, R.G., 1985. Spatial variability of extractable micronutrients in a cultivated and native prairie soil. *Canadian Journal Soil of Science* 65(1): 149-156.

Singh, M.V., 2008. Micronutrient fertility mapping for Indian soil, Technical Bulletin. AICRP Micronutrients, IISS, Bhopal. 7: 1-60.

Soil Survey Staff, 1993. Soil Survey Manual. USDA Handbook No. 18, United States Government Printing Office, Washington, DC, USA.

Thakur, R., Kauraw, D.L., Singh, M., 2011. Profile distribution of micronutrient cations in a Vertisol as influenced by long-term application of manure and fertilizers. *Journal of the Indian Society of Soil Science* 59(3): 239–244.

Trangmar, B.B., Yost, R.S., Uehara, G., 1985. Application of geostatistics to spatial studies of soil properties. *Advances in Agronomy* 38: 45-93.

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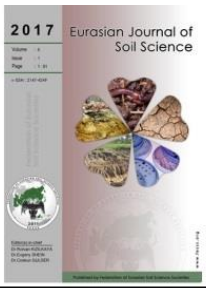

Polluted soil leaching: unsaturated conditions and flow rate effects

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Abstract

In this study, soil samples are extracted from a polluted site at different depths. Soils texture and pollutant presence are different with depth. Preliminary analyzes showed pollution by heavy metals. To simulate soil leaching operation in static condition, a series of leaching tests are conducted in laboratory column under conditions of upflow unsaturated soil. Electrical conductivity and pH measurements on the recovered leachate are performed. Different flow rates are tested. Comparison of different profiles shows that the dissolved pollutants are concentrated in the upper soil levels and disperse weakly in the lower parts which confirm the nature of anthropogenic pollution of heavy metals. Water mobilizes a high amount of dissolved ionic substances up to 80% of the initial concentration. The increase in flow rate requires more pore volume injected to achieve the maximum clearance rate. The down flow condition extracts a small amount of dissolved substances.

Keywords: Soil column, soil leaching, unsaturated soil, flow rate effect.

Introduction

Leaching by rainwater is the phenomenon frequently found in nature. It allows the passage of various fine and soluble materials through the different soil layers. Different ions from soluble material in water are mobilized. These substances may be salts, various inorganic or organic. This method is also used as a method of depollution of certain types of soils. The leachate can be water associated with appropriate reagents enabling a more efficient separation of the extracted products. The reactants are used in the case of organic or metallic contamination. These pollutants having a low solubility in pure water, several studies have developed various reactants to improve the leaching performance such as acids, sodium hydroxide, cations, complexing agents or oxidation/reduction agents, (Mulligan et al., 2001 ; Dermont et al., 2008; Viglianti et al., 2008 ; Yang et al., 2012 ; Fedje et al., 2013). For the most pollutants the use of an active agent improves the extraction efficiency to 100 times (AAEE, 1993).

Leachability depends on some physical parameters (homogeneity, particle size, porosity, permeability of the solid phase influencing the flow rate and contact time between solution and solid, and temperature). Other parameters such as pH value, redox conditions, total organic carbon content, chemical reaction kinetics, chemical speciation of contaminants, and complexation with other constituents could affect leachability performances.

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Several studies have focused on the interactions between heavy metals "HM" and water. These works are developed largely in the context of soil remediation studies by chemical washing. Most studies have focused on identifying the important parameters which influence the mobilization of HM, by changing the chemical conditions of the environment by the use of different mineralogy of soil (Matos et al., 2001; Kumar et al., 2013) or different acidities of the washing solution (Lo et al., 2011; Jean-soro et al., 2012 ; Fedje et al., 2013) or different salinities (Chappell et al., 2013 ; Li et al., 2011). Kumar et al. (2013) made a soil column leaching using a mixture of deionized water and highway road dust to mimic condition of urban runoff received by artificial infiltration facilities. The competition retention and mobility in the presence of different HM have been the subject of study of Lafuente et al. (2008).

Some works have studied the mobility of some organic and mineral compounds by comparison of results from different experimental methods as column, batch, sequential extraction and in-situ experiment (Plassard et al., 2000; Kalbe et al., 2008; Beesley et al., 2010 ; Wennrich et al., 2012, Colombani et al., 2015). A batch test may not be representative of natural conditions. In particular for batch tests, equilibrium conditions are assumed to have been reached, the pH value does not represent the pH of the on-site leaching environment. The continued leaching of contaminants into the environment is not addressed. Column studies seem to reflect leaching conditions more realistic.

Few studies have examined the influence of flow rate on the mobility of HM (Pang et al., 2002; Wehrer and Totche 2008; Lo et al., 2011). In these works, the washing liquid which is a mixing of water and a reagent is operated in saturated columns. Wehrer and Totsche (2008) have performed experiments at different flow rates for two different sorts of soils. They highlighted that the mobility of pollutants is influenced by the imposed rates. Their experiments are conducted in an environment full of organic and inorganic pollutants. Lo et al. (2011) found different results depending on the metal to be extracted. For the same performance some metals are extracted with a low flow rate using less pore volume than with a high flow rate. Other kind of heavy metals requires less pore volumes with high flow rates to achieve the same performance as using a low flow.

The purpose of this work is to identify the impact of flow on leaching and therefore the mobility of dissolved and desorbed ionic mineral substances in unsaturated soil conditions. The experimental results on leaching column tests of three soils extracted from three depths are first analyzed. Different rates are applied to assess its impact on leaching protocol.

Material and Methods

Soils characterization

Soil samples are extracted from an old service station site located south west of Lyon, at an altitude of about 182 m from the surface of the sea. According to the Geological Map No. 698 Lyon (France) edited by the BRGM (BRGM, 1978). The site is located to the right of wurmiennes fluvial sediments, called "terrace of Villeurbanne." Taking into account lithological sections of the site and observations on land, the nature of soil is sandy.

Three soil models are extracted from the site at different depths (Figure 1):

- Soil 1 : at depth of 1.5 m;
- Soil 2 : at depth of 2.3 m;
- Soil 3 : at depth of de 3.5 m.

(a) Soil 1 at 1.5 m (b) Soil 2 at 2.3 m (c) Soil 3 at 3.5 m

Figure 1. Photos of soil samples

All samples are prepared by air-dried at 30 °C during 48h and sieved between 50 µm and 10 mm. The clay and silt fractions are then removed. Particle size distribution curves are determined in agreement to French norm P 94-056. The densities are determined by pycnometers according to French standard P 94-054. The contents of water samples are determined by drying in an oven according to the French standard P 94-050. The measurement of soil permeability was carried out under the procedure, called a "constant loads." The soils 1 and 2 have comparable properties. They exhibit a high Uniformity coefficient "*Cu*" indicating graded size distribution. They contain 20 to 25% of fine sand out of a 40% of sand total. The other 60% have a particle size between 2 mm and 10 mm. The soil 3 is a sandy soil homogeneous and uniform (*Cu* = 2.62), with a higher water content than the other two soils. The curvature factor shows that the three soils are not well graded. Table 1 summarizes the main properties of used soils.

Table 1. Soils properties

	Soil 1	Soil 2	Soil 3
Buk density ($Kg.m^{-3}$)	2600	2500	2778
Water content (%)	1.51	1.5	5.03
Permeability K_s($m.s^{-1}$)	7.95 10^{-4}	7.92 10^{-4}	0.17 10^{-4}
Particle size distribution			
D50 (mm)	4.4	4.6	0.14
Uniformity coefficient Cu	76.47	72.22	2.62
Coefficient of curvature Cc	0.42	0.26	0.87

Pollution analysis

Chemical analyzes are made by the Alcontrol laboratory (France) on samples of the same study site. The found pollutants in this site can be classified into three families:

- Heavy metals ;
- Polycyclic aliphatic hydrocarbons PAH, light hydrocarbons (C5-C10), heavy hydrocarbons (C10-C40) ;
- BTEX (Benzene, Toluene, Xylene and Methyl-benzene).

Table 2 summarizes the concentrations of the various found pollutants for a mixture of equal masses of 3 samples at different depths and the concentration limits in order to classify a soil as contaminated (BRGM, 2008). The considered reference values are determined from the total contents of trace elements in soils in France to rank the value ranges in "ordinary" values and natural anomalies (BRGM, 2008). These results show pollution from copper, mercury and lead. Arsenic, cadmium and zinc concentrations exist with the limit of the maximum permissible concentrations.

Table 2. Soil concentrations in HM, hydrocarbons, BETEX and PAH

Pollutant	Concentration ($mg.kg^{-1}$)	Values observed on « ordinary » soils ($mg.kg^{-1}$) (BRGM, 2008)
	Heavy metals	
Arsenic (As)	22	1 to 25
Cadmium (Cd)	0.5	0.05 to 0.45
Chromium (Cr)	18	10 to 90
Copper (Cu)	46	2 to 20
Mercury (Mg)	1	0.02 to 0.1
Nickel (Ni)	14	2 to 60
Lead (Pb)	120	9 to 50
Zinc (Zn)	99	10 to 100
	Hydrocarbons	
Hydrocarbon index (HCT) C10-C40	24,8	75
Hydrocarbon index C5-C10	<10	5
	BTEX	
All the BETEX	<0.1	0.1
	PAH	
Total of 16 PAH	0.136	24

Experimental device

The soil sample is placed in a Plexiglas column of 20 cm height and 7 cm inside diameter. It disposes of orifice of 0.9 cm at the outlet. The column is placed in vertical position. The sample is placed in layers and compacted manually using a cylindrical mass. The solution used here is deionized water with a conductivity of 81 µS/cm and a pH of about 6.3. A conductimeter is used to measure the electrical conductivity of the leachate. That measure allows quantifying the ionic compound restitution rate downstream of the soil sample.

First experiments called “Up flow tests” allow having information on leaching of a polluted soil near to the saturation. This can be the case of high rainfall approaching the soil from saturated condition. Tests are conducted with the flow direction from bottom to top of the column. The porous bed has 19 cm height. At the inlet and outlet of the column, a textile filter is disposed to prevent the migration of the soil grains due to the flow. The column is saturated with CO_2 to avoid air bubbles. A constant rate flow was applied using a peristaltic pump at the inlet of the column to maintain the saturation of soil sample. The output pressure is equal to the atmospheric pressure. The experiment is then composed of transient column saturation phase equal approximately to one porous volume and a saturated phase.

Various flow values are applied during these tests: 4.7; 10; 20; 40 and 60 ml.min^{-1}. These values are within the validity range of Darcy’s law. A pH meter is used to measure the pH of the leachate. Table 3 summarizes the experimental conditions of the different column tests. During rain events, the most realistic situation corresponds to a downward leaching. Second experiments called “Down flow tests” are conducted with the flow direction from top to bottom of the column. At the entrance of the column, bed of glass beads of 2 mm in diameter are placed in a thickness of 2 cm to obtain a homogeneous distribution of the water flow. The porous bed has 17 cm height.

The experiment consists in passing a quantity of 1 liter of water corresponding approximatively to 5 pore volumes. The output condition is the atmospheric pressure. Two flows are used: 4.7 ml min^{-1} and 113.6 ml.min^{-1}. Once the injected amount of water is complete, the pump is stopped. The leachate is recovered over time and analyzed. The output flow is then variable.

Results and Discussion

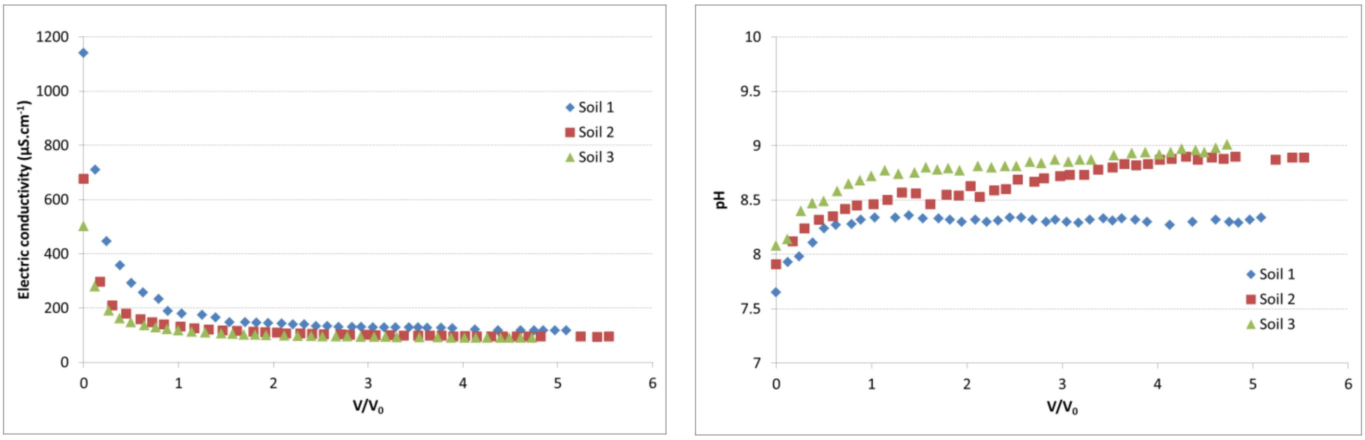
Up flow tests

The pH and conductivity are measured in the case of 3 soils at flow of 4.7 ml.min^{-1} as showed in Figure 2. Electrical conductivity which is proportional to mixture pollutant concentrations and pH are plotted against number of exchanged pore volumes (V/V_0) where V is the injected volume and V_0 is the porous volume.

The pH value is basic along experiment (Figure 2b). The soil is more basic with depth. The eluate pH value increases by one unit whatever the used soil. This result is in agreement with some literature results (Jean-Soro et al., 2012; Kumar et al., 2013). Wehrer and Totsch (2008) found a constant pH during leaching demolition waste and the municipal waste incineration ash. Authors assumed that the effluent pH of the demolition waste and the municipal waste incineration ash is due to apparent equilibrium dissolution of a readily available mineral phase. In these cases, the mineral phase is linked to the cement phase’s composition. pH increases during leaching while the electric conductivity decreases (Figure 2). This result is also found in the works of Jean-Soro et al. (2012) which show that the most pH variation is corresponding to the large electric conductivity decrease and so pollutant concentration decrease. During the first V/V_0, an easily mobilized fraction of elements is leached. It is a mixture of mineral and organic mobilized species. The sampling of the soil, which is the pre-treatment (drying, sieving) are well known to destroy the soil structure. Then, a loosely bound fraction of organic or mineral elements could be leached in soluble or colloidal form (Zhang et al., 2010; Lo et al., 2011).

Moreover, the initial electric conductivity decreases with soil depth (Figure 2a). It can be due to the anthropic heavy metal pollution witch always found in the first meters of the soil and decreases with the soil depth (Walden, 1964; Sposito, 1989). Indeed, the heavy metals from external inputs accumulate on the surface of the soil due to their very strong bond with the different solid phases. Thus, their concentrations decrease with depth. On the contrary, in the case of soils formed mainly from rocks particularly rich in metallic elements, the heavy metal content increases with depth. We can’t conclude about the relationship between compounds migration and soil type. In fact, the dissolved compounds concentration is different in the case of soil 1 and soil 2 even though the same soil type.

Moreover, The basicity of soil promotes the formation of hydroxides which may also in a basic medium to associate with OH- ions and form anionic complexes such as Pb $(OH)_3$ for lead, Zn $(OH)_3^-$ and Zn $(OH_4)_2$ for Zn, Cd $(OH_3)^-$ for cadmium and CrO_2^-, CrO_4^{2-} for chromium. The increased pH contributes so to the reduction of the protons compete with respect to the metal ions and thus promotes their binding to the surface.



(a) (b)

Figure 2. Electric conductivity (a) and pH (b) in the eluate solution for the three soils at 4.7 ml.min^{-1} flow leaching

In this study, it is considered that the maximum of the electric conductivity value to pollution concentration equal to 100%. A depollution rate is defined as the extracted fraction. For the three tested soils, the depollution rate is about 85%. The rate is more important in the case of the more polluted soil, which is of the order of 90% for equivalents injected pore volumes.

Influence of the leaching flow rate

In order to investigate the influence of flow rate on the leaching test efficiency, different flow rates are applied (4.7; 10; 20; 40 and 60 ml min^{-1}). In this experiment, the used soil is a sample of Soil 3. For different considered flow rates, the end of the experiment is set by obtaining a level corresponding to a constant concentration at the column outlet. This constant level corresponds to an average decrease in conductivity of 80% compared to baseline (Figure 3). The highest flow provides the most effective pollution control, since the bearing is obtained after several injected pore volumes (10 V_p). For the same V_p, the higher rate allows to extract more pollutants.

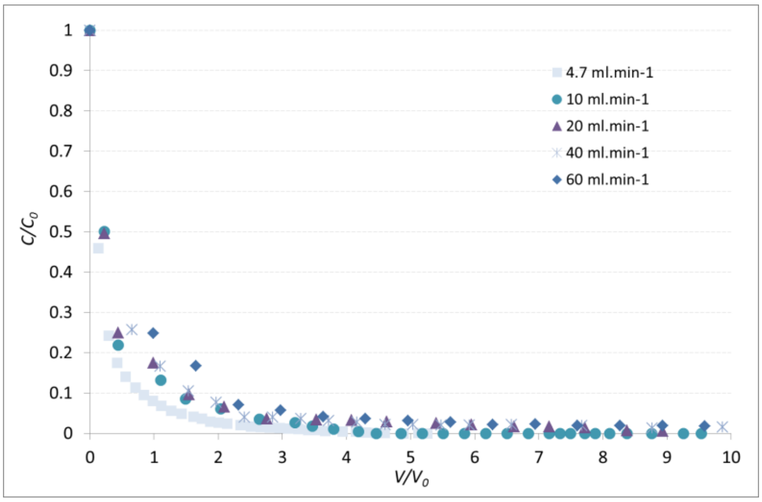


Figure 3. Experimental curve at different flow (soil 3)

The leached ions rate increases with velocity increase. This may be attributed to the effects of hydrodynamic chromatography resulted in a non-uniform distribution of pore velocities especially at high flow rate. Indeed, the minimum velocity is close to the grain surfaces according to Poiseuille's law.

This can increase the exchange kinetics between the immobile phase, pollutant set on the skeleton of the porous medium, and the mobile phase, the water flow. Thus, the rate of pollutants molecules desorption and dissolution were better. The efficiency of the leaching is thus not dependent on the water contact time with the polluted soil. These results are in agreement with, Wehrer and Totsche (2008) and Naka et al. (2016) study's conclusions. Wehrer and Totsche (2008) confirm that the electrical conductivity is independent on flow velocity and residence time in the case of MSWI ash. They suggest that it can be attributing to the near equilibrium conditions. For demolition debris, the leached solutions have a lower electrical conductivity in the case of lower velocity than the case of higher flow. They not explain this by non-equilibrium conditions, but they suggested a possible higher dissolution of inorganic colloids with high velocity. Naka et al. (2016) tested two flowrates on soil leaching and observed that the tested flow rates had little or no effect on the release of cations and anions.

Down flow tests

Figure 4 provides a description of leaching test results under unsaturated conditions at flow rates of 4.7 ml.min^{-1} and 113.6 ml.min^{-1}. Results show different initial conductivities for leaching throughout the 3 soils for the two applied flow rates. Initials conductivities are smaller than those of the up flow tests. A constant conductivity is quickly achieved at the end of these experiments.

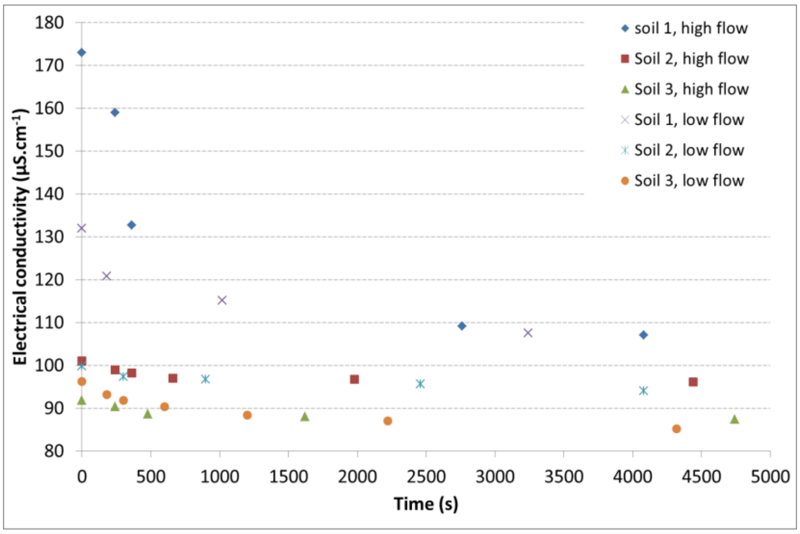


Figure 4. Evolution of electrical conductivity as function of the time for the three soil samples (4.7 ml.min^{-1}, 113.6 ml.min^{-1})

In the case of soils 2 and 3, there is slight effect of the velocity on the evolution of the conductivity of the effluent. The electrical conductivity is near to water conductivity for all points showing a little extracted matter. Both used flow rates provide dissolved equivalent yields of extracted pollutant for different soil samples. Indeed, only 1 L of injected water which is equivalent to 6.08 VP, 6 VP and 6.21 VP respectively for Soil 1, Soil 2 and Soil 3.

The comparison between the leaching under up flow and down flow conditions shows that the first case allows greater depollution rate. Soils under those conditions present greater conductivity values than in the case of down flow conditions. This is due to the fact that the contact surface between water and the soil grains is larger than in the second case. The water flow can be considered homogeneous in the case of up flow but in the case of down flow, and with the addition of the gravity effect a "channeling" or "by pass" system takes place in the porous media. The injected pore volumes are equivalent in both cases, but the recovered volumes are less important in the case of down flow trials which are due to the amount of residual water in the soil. The leaching effectiveness is higher in up flow conditions. This trend can be observed after an intense rain event. The soil is at first non-saturated and then a saturated condition is followed that increase dissolved material transport.

Conclusion

Leaching experiments under conditions of up flow and down flow unsaturated soils have been carried in this work. Soils used are mainly real soils polluted with heavy metals. The results of the leaching are analyzed by monitoring electrical conductivity and pH. The change in leaching flow rate is investigated in this work. It shows that a low flow rate is as effective as a high values for the dissolved material extraction. Such choice has the advantage of using smaller amount of water, but there is a disadvantage of high required time for this operation. The extracted pollution decreases according to the depth of the samples, which may be due to the dominant nature of anthropogenic pollution by heavy metals from the soil. The soil type influences the amount of dissolved material, and thus the migration of pollution between the various layers. During a rain event: each layer is different filter pollution and will transmit it to the next layer. Down flow unsaturated experiments have shown lower mobilization of the dissolved pollutants compared to up flow conditions.

References

AAEE, 1993. American Academy of Environmental Engineers. Soil Washing/Soil Flushing, Innovative Site Remediation. Anderson, W.C. (Ed), vol3, WASTEC.

Beesley, L., Moreno-Jimenez, E., Celemente, R., Lepp, N., Dickinson, N., 2010. Mobility of arsenic, cadmium and zinc in a multi-element contaminated soil profile assessed by in-situ soil pore water sampling, column leaching and sequential extraction. *Environmental Pollution* 158 (1) : 155-160.

BRGM, 1978. Carte géologique n°698 de Lyon, BRGM editions

BRGM, avril 2008. Bases de données relatives à la qualité des sols : contenu et utilisation dans le cadre de la gestion des sols pollués, V.0.1

Chappell, M., Middleton, M., Price, C., 2013. Chemical and physical changes in tropical soils from seawater exposure and subsequent rainwater washes. *Procedia Earth and Planetary Science* 7: 131-134.

Colombani, N., Mastrocicco, M., Di Giuseppe, D., Faccini, B., Coltorti, M., 2015. Batch and column experiments on nutrient leaching in soils amended with Italian natural zeolitites. *Catena* 127: 64-71.

Dermont, G., Bergeron, M., Mercier, G., Richer-Laflèche, M., 2008. Soil washing for metal removal : A review of physical/chemical technologies and field applications. *Journal of Hazardous Materials* 152(1): 1-31.

Fedje, K.K., Yillin, L., Strömvall, A.M., 2013. Remediation of metal polluted hotspot areas through enhanced soil washing- Evaluation of leaching methods. *Journal of Environmental Management* 128: 389-496.

Jean-Soro, L., Bordas, F., Bollinger, J.C., 2012. Column leaching of chromium and nickel from a contaminated soil using EDTA and citric acid. *Environmental Pollution* 164: 175-181.

Kalbe, U., Berger, W., Eckardt, J., Simon, F.G., 2008. Evaluation of leaching and extraction procedures for soil and waste. *Waste Management* 28(6): 1027-1038.

Kumar, M., Furumai, H., Kurisu, F., Kasuga, I., 2013. Potential mobility of heavy metals through coupled application of sequential extraction and isotopic exchange: Comparison of leaching tests applied to soil and soakaway sediment. *Chemosphere* 90(2): 796-804.

Lafuente, A.L., González, C., Quintana, J.R., Vázquez, A., Romero, A., 2008. Mobility of heavy metals in poorly developed carbonate soils in the Mediterranean region. *Geoderma* 145(3-4): 238-244.

Li, Q.S., Liu, Y.N., Du, Y.F., Cui, Z.H., Shi, L., Wang, L., Li, H.J., 2011. The behavior of heavy metals in tidal flat sediments during fresh water leaching. *Chemosphere* 82(6): 834-838.

Lo, I.M.C., Tsang, D.C.W., Yip, T.C.M., Wang, F., Zhang, W., 2011. Influence of injection conditions on EDDS-flushing of metal-contaminated soil. *Journal of Hazardous Materials* 192(2): 667-675.

Matos, A.T., Fontes, M.P.F., da Costa, L.M., Martinez, M.A., 2011. Mobiblity of heavy metals as related to soil chemical and mineralogical charactristics of Brazilian soils. *Environmental Pollution* 111(3): 429-435.

Mulligan, C.N., Yong, R.N., Gibbs, B.F., 2001. Remediation technologies for metal-contaminated soils and groundwater: an evaluation. *Engineering Geology* 60(1-4): 193-207.

Naka, A., Yasutakab, T., Sakanakuraa, H., Kalbec, U., Watanabed, Y., Inobad, S., Takeoe, M., Inuie, T., Katsumie, T., Fujikawaf, T., Satof, K., Higashinog, K., Someyag, M., 2010. Column percolation test for contaminated soils: Key factors for standardization. *Journal of Hzardous Materials* 320: 326-340.

Pang, L., Close, M., Schneider, D., Stanyon, G., 2002. Effect of pore-water velocity on chemical nonequilibrium transport of Cd, Zn, and Pb in alluvial gravel columns. Journal of Contaminant Hydrology 57(3-4): 241-258.

Plassard, F., Winiarski, T., Petit-Ramel, M., 2000. Retention and distribution of three heavy metals in a carbonated soil: comparison between batch and unsaturated column studies. *Journal of Contaminant Hydrology* 42(2-4): 99-111.

Sposito, G., 1989. The chemistry of soils. Clarendon Press, Oxford, 277p.

Viglianti, C., De Brauer, C., Laforest, V., Bourgois, J., 2008. Meilleures techniques disponibles de lavage de sols contaminés par les HAP : Etude d'un procédé basé sur les cyclodextrines. *Congrès International Gestion Déchets Solides et Développement Durable (GDS/DD)*, Hammamet, Tunisia. 6p,

Walden, R., 1964. Complément de chimie générale chimie descriptive, Tome II.

Wehrer, M., Totsche, K.U., 2008. Effective rates of heavy metal release from alkaline wastes — Quantified by column outflow experiments and inverse simulations. *Journal of Contaminant Hydrology* 101(1-4): 53-66.

Wennrich, R., Daus, B., Müller, K., Stärk, H.J., Brüggemann, L., Morgenstern, P., 2012. Behaviour of metalkoids and metals from highly polluted soil samples when mobilized by water –Evaluation of static versus dynamic leaching. *Environmental Pollution* 165: 59-66.

Yang, Z., Zhang, S., Liao, Y., Li, Q., Wu, B., Wu, R., 2012. Remediation of heavy metal contamination in calcareous soil by washing with reagents: A column washing. *Procedia Environmental Sciences* 16: 778-785.

Zhang, W., Huang, H., Tan, F., Wang, H., Qiu, R., 2010. Influence of EDTA washing on the species and mobility of heavy metals residual in soils. *Journal of Hazardous Materials* 173(1-3): 369-376.

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Genesis and classification of soils developed on gabbro in the high reliefs of Maroua region, North Cameroon

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Abstract

The purpose of this work was to examine the genesis, properties and classification of soils resulting from the weathering of gabbro rock in the high reliefs of Maroua in the Far North Region of Cameroon. The studied soils were ~ 2 m thick, made of four horizons which consisted of coarse saprolite, fine saprolite, loose loamy clayey horizon and humiferous horizon. From petrographical view point, at the bottom of the soil profile, the preservation of the bedrock structure was marked by numerous remnants of altered plagioclases shapes. The groundmass was characterized by a double spaced fine, ranging to equal, enaulic c/f related distribution pattern. It was yellowish, characterized by weakly separated granular microstructure in the fine saprolite and had a speckled and cloudy limpidity in the loose loamy clayey horizon. Secondary minerals consisted of montmorilonite, kaolinite, goethite, quartz, gibbsite, lepidocrocite, sepiolite, feldspar and calcite. Globally, Si/Al ratio ranged between 2.85 and 3.24. The chemical index of alteration ranged from 50.95 to 55.27 % while the mineralogical index of alteration values were between 1.90 and 10.54 %. Physicochemically, soil pH varied from slightly acidic to slightly above neutral. Soil organic carbon contents were low to very low. Exchangeable bases contents were high, mostly represented by Ca^{2+} and Mg^{2+}. The CEC of soils and the CEC of clay were also high, ranging respectively between 53.68 and 82.88 cmol(+).kg^{-1}, and 116.80 and 181.38 cmol(+).kg^{-1}. The studied soils were classified as dystric haplustepts clayey isohyperthermic. They were developed *in situ* by the collapse of primary mineral structures from the bottom of the coarse saprolite, due to leaching as a result of bisiallitisation and monosiallitisation. This is accompanied by a progressive ferruginization of materials, confirmed by the densification under the microscope of goethitic brown veil from the base to the loamy clay horizon and the increase in iron contents from the bedrock to the humiferous surface horizon.

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Introduction

Parent material and geomorphologic processes have long been recognized as key soil-forming factors, particularly at the regional level (Bockheim et al., 2005; Badía, et al., 2013). Slope-dependent pedogenic processes play an essential role in increasing the diversity of soil cover in the mountainous tropics and subtropics (Gracheva, 2011; Badía, et al., 2013). In semiarid environments, geomorphic processes such as erosion may overprint climate and lithological signatures differing from those in more humid environments

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(Driessen et al., 2001; Badía, et al., 2013). The loss of soil from land surfaces by erosion is widespread globally and adversely affects the productivity of all natural ecosystems as well as agricultural (Lal and Stewart, 1990; Pimentel, 1993; Pimentel et al., 1995; Pimentel and Kounang, 1998; Pimentel, 2006). The impact of soil erosion is intensified on sloping land, where often more than half of the surface soil is carried away as the water splashes downhill into valleys and waterways (Pimentel, 2006). This leaves the soil barren and fully exposed to rain and wind forces of erosion (Pimentel, 2006). The phenomenon is especially widespread in developing countries where populations are large, and agricultural practices are often inadequate to protect topsoils. One of the major factors limiting optimum crop production in the tropics is the lack of detailed information on soil and land characteristics. In Cameroon, the Far North Region is the most populated area of the country. It differs from the rest of the other regions mainly by its sudano-sahelian climate, its landscape globally flat with high reliefs here and there, and a large volcanic massive, the Mandara massive, who from its about 1450 m a.s.l., overlooks a vast peneplain whose altitude ranges between 300 and 400 m. All lands are cultivated, and today there is a generalized decline in soil fertility (Tsozué et al., 2014; 2015). This led people to cultivate up to the mountainous spaces around Maroua, spaces reserved exclusively for cattle rearing in the past. This agriculture is practiced on soils whose characteristics are badly known. The purpose of this work is to examine the genesis, properties and classification of soils resulting from weathering of gabbro rock in the high reliefs of Maroua region.

Material and Methods

Study site

The study was conducted in Maroua, in the Far North Region of Cameroon (10°35'00''-10°40'30'' N and 14°16'04''-14°21'34'' E) (Figure 1). The climate is Sudano-Sahelian, characterized by a mean annual rainfall of 757.2 mm and mean annual air temperature of about 28.53°C. The aridity index of De Martonne (1926) shows a dry season from November to May (I < 20) and a raining season from June to September (I > 20). The rains are concentrated in the two humid months of the year July and august (I > 50). The relief is mountainous, characterized globally by gentle to steep slopes. The vegetation is mostly composed of grasses, but highly cultivated, event steep slopes where fine earth can exist between blocks of gabbro. The main human activities in the region are agriculture and breeding.

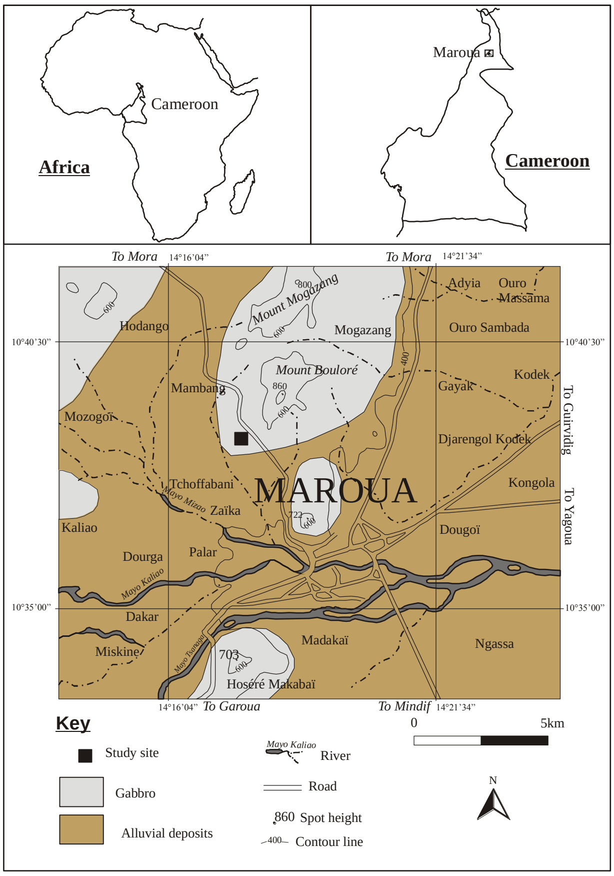

Figure 1. Location of the study site

Methods

Based on several soil surveys conducted up to date, supported by a reconnaissance of the studied area, about fifteen soil profiles representative of the area were studied through boreholes. The most representative profile was selected on gabbro and described in detail. Soil samples and fresh rocks were collected at different depths for analyses. Soil thin sections were described following the guideline of Stoops (2003). Soil mineralogy was determined by X-ray diffraction on total soil powder and minerals were identified using XRD coupled with standard saturation (K), solvation (ethylene glycol), and heat (550 °C) treatments (USDA, 2004). For geochemical analyses, the package uses the whole rock package by combustion furnace to quantify the major elements in the sample by ICP-AES finish. The chemical index of alteration (CIA) corresponds to $[Al_2O_3/(Al_2O_3+CaO^*+Na_2O+K_2O)] \times 100$, where CaO* is the amount of CaO incorporated in the silicate fraction of fresh rock while Na_2O, K_2O and Al_2O_3 are their concentrations in the analyzed soil samples (Nesbitt and Young, 1982). The mineralogical index of alteration (MIA) was [2.(CIA-50)] (Voicu et al., 1996). The sesquioxide content (SOC) was the Fe_2O_3 and Al_2O_3 content in a sample which are insoluble oxides (Irfan, 1996). For soil texture analysis, soil organic matter and carbonates were removed with hydrogen peroxide and diluted hydrochloric acid, respectively. Then, soil samples were dispersed with sodium hexametaphosphate and particle size distribution was analysed by the pipette method. Soil pH was measured potentiometrically in a 1:2.5 soil : solution ratio. Exchangeable bases and cation exchange capacity (CEC) were determined using atomic absorption spectrophotometry in a solution of ammonium acetate at pH 7. Total nitrogen was obtained after heat treatment of each sample in a mixture of concentrated sulfuric acid and salicylic acid. Organic carbon (OC) was determined by the Walkley–Black method (Walkley and Black, 1934). Soil organic matter (OM) content was obtained by multiplying soil organic carbon content by 1.724 (Walkley and Black, 1934). Available phosphorus was determined by Bray-2 method (Bray and Kurtz, 1945). The mean annual soil temperature (MAST) was calculated according to the following equation: MAST= 6.84 + (0.925*MAAT) - (0.0031*Precipitations) (Bai, 2009). In this equation, MAAT is the mean annual air temperature. The studied soils were classified according to Soil Survey Staff (2010).

Results

Morphological, mineralogical and geochemical characteristics of soils

The studied soil profile was ~ 2 m thick. Four main horizons were distinguished from the bedrock to the surface: a coarse saprolite, a fine saprolite, a loose loamy clayey horizon and a humiferous horizon. The parent soil material was a gabbro. It was dark, massive, characterized by white slight linings and the absence of any observable mineral. Under polarizing microscope, all primary minerals were slightly weathering. The main minerals were plagioclase, green amphibole, biotite and calcite. From the geochemical view point, SiO_2 was the main oxides (48.90%), followed by Al_2O_3 (16.95%), Fe_2O_3 (10.55%), CaO (9.55%), MgO (6.87%) and Na_2O; the others were in smaller quantities (Table 1). The boundary was regular and gradual.

Coarse saprolite (200-75 cm). The coarse saprolite was yellowish (10YR 7/8), compact, massive, with many fissures surrounding compact undifferentiated blocks. The original structure of the bedrock was preserved. Under the microscope, all the primary minerals had disappeared, and the preservation of the bedrock structure was marked by numerous remnants of altered plagioclases shape (Figure 2A). The groundmass was characterized by a double spaced fine, ranging from equal to enaulic c/f-related distribution pattern. It showed a yellowish red birefringent micromass. The main secondary minerals were montmorilonite, kaolinite, goethite, associated to small amount of quartz, gibbsite, lepidocrocite, sepiolite, feldspar, calcite (Figure 3 and Table 1). From the geochemical view point, SiO_2 was the most represented oxide (53.90-53.10 %). It was followed by Al_2O_3 (15.00-14.70 %), Fe_2O_3 (10.75-10.90 %), Na_2O (4.11-4.33 %), CaO (1.02-2.06 %) and MgO (1.76-2.06 %) (Table 1). Globally, there was an increase in SiO_2 and Na_2O contents, and a decrease in CaO and MgO contents (Table 1). The boundary was regular and gradual.

Fine saprolite (75-30 cm). The fine saprolite was reddish yellow (7.5YR 6/8), loamy and massive. There were many fissures surrounding small gray compact blocks, globally embedded in loose loamy texture matrix. The structure of the bedrock was preserved only in gray compact blocks. Under the microscope, remnants of altered plagioclases shape had almost disappeared. The groundmass was yellowish, characterized by weakly separated granular microstructure (Figure 2B). The main secondary minerals were montmorilonite, kaolinite, goethite, associated to small amount of quartz, gibbsite, lepidocrocite, sepiolite, quartz, feldspar, calcite (Figure 3 and Table 1). From the geochemical view point, SiO_2 remained the dominant oxide (52.10%), followed by Al_2O_3 (15.55 %), Fe_2O_3 (11.20%), Na_2O (4.76 %) and CaO (3.23 %) (Table 1). The boundary was regular and gradual.

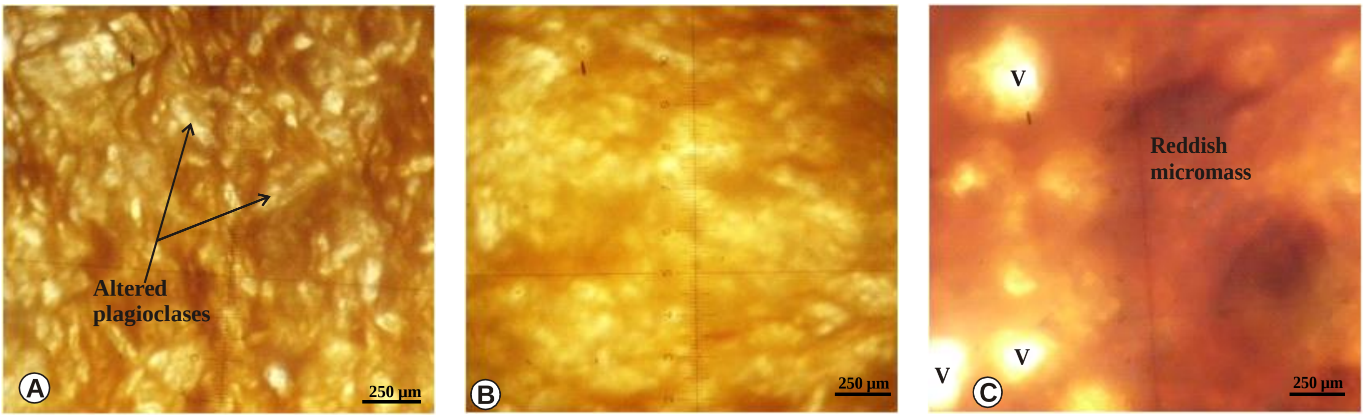

Figure 2. Microscopic organization of the studied soils
(A: Coarse saprolite LN ; B : Fine saprolite LN; C: Loose loamy clayey horizon LN)

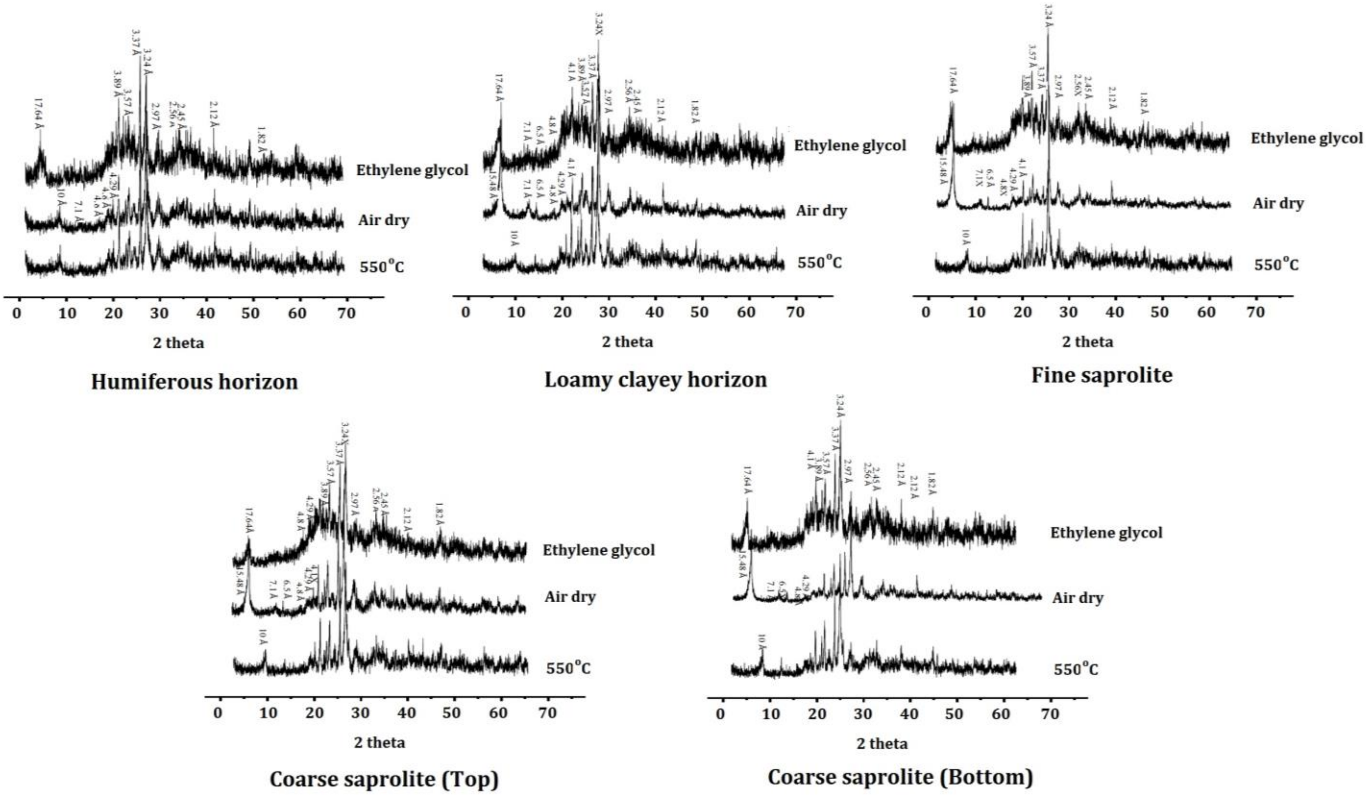

Figure 3. XRD patterns of different horizons for the study soil

Loose loamy clayey horizon (30-7 cm). The horizon was reddish yellow (5YR 6/8), loose and loamy clayey. It was weakly blocky to massive, characterized by high matrix porosity and the presence of many rootlets. Under the microscope, remnants of altered plagioclases shape were not visible. The groundmass had a vughy microstructure and reddish micromass (Figure 2C). It had a speckled and cloudy limpidity (Figure 2C). The mineralogical composition was similar to that of saprolite, largely dominated by montmorillonite (Figure 3 and Table 1). From geochemical view point, compared to the coarse and fine saprolite, all the major oxides contents showed very little variation and remained largely dominated by SiO_2 (Table 1). The boundary was regular and gradual.

Table 1. Major elements contents (wt.%) and mineralogy of the studied soils.

Horizons		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	Total	Si/Al	CIA	MIA	SOC	Mineralogy
Humiferous horizon		50.80	15.90	11.85	5.12	1.76	3.02	0.30	1.20	0.27	0.10	10.30	100.62	2.86	55.27	10.54	27.75	M K G Q F Gi C L S
Loamy clayey horizon		51.60	16.25	11.80	3.02	1.68	3.55	0.24	1.23	0.31	0.08	11.50	101.26	2.85	54.92	9.84	28.05	M K G Q F Gi C L S
Fine saprolite		52.10	15.55	11.20	3.23	1.78	4.76	0.31	1.20	0.24	0.21	10.10	100.68	3.00	51.54	3.08	26.75	M K G Q F Gi C L S
Coarse saprolite	Top	53.10	14.70	10.90	4.22	1.76	4.33	0.27	1.14	0.23	0.28	8.88	99.81	3.24	50.95	1.90	25.60	M K G Q F Gi C L S
	Bottom	53.90	15.00	10.75	1.02	2.06	4.11	0.46	1.06	0.22	0.22	9.05	100.85	3.22	51.51	2.2	25.75	M K G Q F Gi C L S
Gabbro		48.90	16.95	10.55	9.55	6.87	2.50	1.17	1.15	0.17	0.20	3.38	101.39	2.59	56.18	12.36	27.50	A F B C

M= montmorillonite: 10Å, 15.48Å, 17.64Å; K= kaolinite: 7.1Å, 3.57Å; G= goethite: 4.1Å, 2.45Å; Gi= gibbsite: 4.8 Å, 2.39 Å; L= lepidocrocite: 6.5Å, 2.97Å; S= sepiolite: 4.29Å, 2.56Å; Q= quartz: 4.29Å, 3.37Å, 2.12Å, 1.82Å; F= feldspath: 3.24; C= calcite: 3.89Å; B: biotite; A: amphibole.

Table 2. Physicochemical characteristics of the studied soils.

Horizons	Sand (%)	Silt (%)	Clay (%)	pH_{water}	pH_{KCl}	OC (%)	OM (%)	N (%)	C/N	Ca	Mg	K	Na	S	CEC	CEC_{Clay}	$\frac{S}{CEC}X100$ (%)	P_2O_5 (mg/kg)
										Cmol(+).kg^{-1}								
HH	19.00	36.00	45.00	5.90	5.20	0.65	1.13	0.11	6.15	14.56	3.28	0.78	0.65	29.27	53.68	116.80	54.53	8.77
LCH	39.00	16.00	45.00	6.20	4.80	0.73	1.25	0.09	7.70	21.52	4.48	0.42	1.09	27.51	82.88	181.38	33.19	10.31
FS	29.00	24.00	47.00	7.50	6.00	0.55	0.94	0.10	5.73	35.28	7.64	0.42	0.87	44.21	73.52	154.41	60.13	33.02
CS	39.00	16.00	45.00	6.80	5.00	0.36	0.63	0.07	5.09	26.32	9.48	0.42	0.87	37.09	60.72	133.55	61.08	61.01
Minimum	19.00	16.00	45.00	5.90	4.80	0.36	0.63	0.07	5.09	14.56	3.28	0.42	0.65	27.51	53.68	116.80	33.19	8.77
Maximum	39.00	36.00	47.00	7.50	6.00	0.73	1.25	0.11	7.70	35.28	9.48	0.78	1.09	44.21	82.88	181.38	61.08	61.01
Mean	31.50	23.00	45.50	6.60	5.25	0.573	0.988	0.093	6.168	24.420	6.220	0.510	0.870	34.52	67.700	146.535	52.23	28.278
CV (%)	26.30	35.60	1.90	9.30	8.70	24.20	23.70	16.00	15.60	30.90	39.60	30.60	17.90	19.30	16.70	16.50	21.60	75.00

HH: Humiferous horizon LCH: Loamy clayey horizon FS: Fine saprolite SP: Coarse saprolite (Top) CV: Coefficient of variation

Humiferous horizon 7-0 cm. The humiferous horizon was yellowish red (5YR 5/8), loamy clayey, characterized by weakly expressed lumpy structure, high matrix porosity and the presence of many rootlets. The mineralogical composition was similar to that of the horizons below, largely dominated by montmorillonite (Figure 3 and Table 1). From geochemical view point, compared to the below horizons, all the major oxides contents showed very little variation and remained largely dominated by SiO_2 (Table 1). This oxide was followed by Al_2O_3, Fe_2O_3, CaO, Na_2O and MgO as the well represented oxides (Table 1).

Globally, Si/Al ratio was high, ranging between 2.85 and 3.24 (Table 1). The chemical index of alteration (CIA) ranged from 50.95 to 55.27 % while the mineralogical index of alteration (MIA) values obtained in the studied soil were between 1.90 and 10.54 %. The sesquioxide content (SOC) values varied little, ranging between 25.60 and 28.05 % (Table 1). A representation in the triangular diagram SiO_2-Al_2O_3-Fe_2O_3 showed that all sample were localized on SiO_2-Al_2O_3 axis (Figure 4), toward SiO_2 pole in line with high Si/Al ratio. This is indicative of an excess of SiO_2 in the studied soils and confirmed the presence of 2:1 phyllosilicates of montmorillonite type.

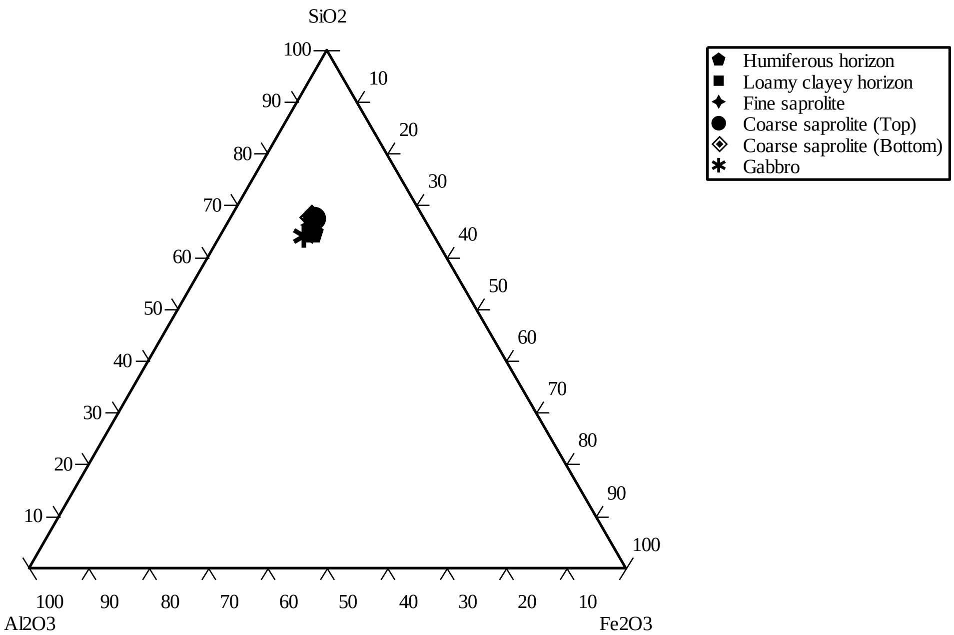

Figure 4. Geochemical composition of the studied soils in SiO_2-Al_2O_3-Fe_2O_3 diagram

Physicochemical characteristics of soils

The studied soil profile contained more than 45% clay fraction (Table 2). Sand content ranged from 19% to 39%, silt content from 16% to 36% and clay from 45% to 47%, corresponding respectively to mean values of 31.50%, 23% and 45.50%. Clay contents are not varied (CV< 15%). Sand contents on the contrary vary moderately (15% <CV< 35%) while those of silts are highly varied (CV> 35%). There is a negative significant correlation between silt and sand (r=-0.99, p<0.05) (Table 3). pH values vary slightly along the profile (CV< 15%). They ranged from slightly acidic (5.90) in the humiferous horizon to slightly above neutral (7.50) in the fine saprolite. pH_{KCl} values are below those of pH_{Water} in all horizons. A significant positive correlation is noted between pH_{Water} and Ca^{2+} (r=0.987, p< 0.05), sum of bases (S) (r=.96, p<0.05). Organic carbon (OC) contents are low to very low, ranging from 0.36 in the lower horizon to 0.65-0.73% in the upper part of the profile. Similarly, nitrogen contents are low to very low. C/N ratios are globally low, < 10. There is a significant negative correlation between OC and P_2O_5 (r=-0.97, p< 0.05) and a negative significant correlation between base saturation and C/N (r=-0.97, p<0.05). Exchangeable bases contents are high, mostly represented by Ca^{2+} and Mg^{2+}, whose contents vary from 14.6 to 35.28 cmol(+).kg^{-1} and from 3.28 to 9.48 cmol(+).kg^{-1} corresponding to mean values of 24.42 and 6.22 cmol(+).kg^{-1} respectively (Table 2). The Cation exchange capacity is high, ranging between 53.68 and 82.88 cmol(+).kg^{-1}, corresponding to a mean value of 67.70 cmol(+).kg^{-1}. The CECclay is also high, ranging between 116.80 and 181.38 cmol(+).kg^{-1}, values in line with the predominance of montmorillonite in the studied soils and the high Si/Al ratios which range between 2.85 and 3.24 (Table 2). Available phosphorus contents are low in humiferous surface horizon (8.77 mg/kg), but increase with depth, reaching 61.01mg/kg in the coarse saprolite at the bottom of the soil profile.

Table 3. Pearson correlation matrix for linear relationships between selected soil parameters of the studied site.

Variables	Sand	Silt	Clay	pH_{Water}	pH_{KCl}	OC	OM	N	C/N	Ca^{2+}	Mg^{2+}	K^+	Na^+	S	CEC	CEC_{Clay}	$\frac{S}{CEC}X100$	P_2O_5
Sand	1																	
Silt	-0.995*	1																
Clay	-0.174	0.071	1															
pH_{Water}	0.246	-0.339	0.849	1														
pH_{KCl}	-0.430	0.335	0.951*	0.753	1													
OC	-0.289	0.303	-0.094	-0.531	-0.153	1												
OM	-0.306	0.322	-0.117	-0.556	-0.168	0.999*	1											
N	-0.866	0.847	0.293	-0.248	0.427	0.682	0.688	1										
C/N	0.148	-0.122	-0.263	-0.514	-0.426	0.900	0.894	0.296	1									
Ca^{2+}	0.354	-0.447	0.832	0.987*	0.690	-0.448	-0.476	-0.284	-0.382	1								
Mg^{2+}	0.545	-0.588	0.333	0.776	0.263	-0.900	-0.913	-0.753	-0.711	0.749	1							
K^+	-0.870	0.917	-0.333	-0.660	-0.063	0.324	0.351	0.683	-0.011	-0.755	-0.688	1						
Na^+	0.853	-0.864	0.000	0.173	-0.310	0.205	0.181	-0.478	0.570	0.327	0.172	-0.816	1					
S	0.037	-0.126	0.841	0.964*	0.828	-0.618	-0.636	-0.151	-0.690	0.908	0.758	-0.455	-0.093	1				
CEC	0.594	-0.633	0.298	0.274	-0.001	0.426	0.398	-0.124	0.656	0.424	0.003	-0.717	0.915	0.019	1			
CECClay	0.645	-0.673	0.188	0.192	-0.115	0.432	0.406	-0.180	0.694	0.348	-0.018	-0.711	0.946	-0.070	0.993*	1		
$\frac{S}{CEC}X100$	-0.334	0.296	0.404	0.539	0.592	-0.782	-0.777	-0.078	-0.973*	0.398	0.597	0.118	-0.669	0.735	-0.662	-0.721	1	
P_2O_5	0.487	-0.507	0.129	0.610	0.115	-0.973*	-0.978*	-0.795	-0.791	0.560	0.967*	-0.531	0.026	0.635	-0.209	-0.212	0.653	1

* Significant at $p<0.05$

Soil classification

The studied soil profile has ~ 2 m thick, with a B horizon more than 15 cm thick (23 cm). It is characterized by weakly blocky to massive structure, loamy clayey texture, high chroma, high value and redder hue (5YR 6/8), characteristic of a cambic horizon. There is globally high supply of bases in the soil profile (S > 27.09 cmol(+).kg^{-1}), with base saturation greater than 33.19%. The cambic horizon is within 100 cm of the mineral soil surface and has a lower boundary at a depth of ~25 cm below the mineral soil surface. These characteristics are those of inceptisols. These soils experienced drought for more than 90 cumulative days but less than 180 days according to the aridity index of de Martone (1926), characteristic of ustic moisture regime. This permitted their classification in ustepts suborder. Since the studied soils do not have any particular character, they belong to haplustepts great group. The studied soils have a base saturation (by sum of cations) of less than 60% in the humiferous horizon and the loamy clayey horizon. This permits them to be classified in the dystric haplustepts subgroup. The texture was clayey and the mean annual soil temperature was higher than 22°C, leading to the classification of the soil in the clayey isohyperthermic family. The studied soil is thus a dystric haplustepts clayey isohyperthermic.

Discussion

In the sudano-sahelian zone of North Cameroon, weathering of gabbro lead to the differentiation of thin (~2m) soils classified as dystric haplustepts clayey isohyperthermic according to Soil Survey Staff (2010). They are mainly composed of montmorillonite, associated to kaolinite, goethite and in lesser quantity quartz, feldspar, gibbsite, calcite, lepidocrocite and sepiolite. Compact undifferentiated weathered blocks with the preservation of the original structure of the bedrock observed in the saprolite and the presence of numerous remnants of weathered plagioclases shape observed under the microscope, characterize an *in situ* weathering of the parent materials (Costantini and Priori, 2007). Soil pH values ranging from 5.90 to 7.50 indicate that hydrolysis is the dominant weathering process implicated in the formation of secondary minerals in the studied soils (Pedro, 1966). It occurs through dilute solutions in the pH range 5 - 9.6 and may be total or partial. Total hydrolysis lead to the removal of all elements including silica, and to the precipitation of gibbsite, whereas partial hydrolysis, under different conditions leads to the formation of kaolinite and smectite minerals (Pedro, 1982). The predominance of montmorillonite in the studied soils suggests that the chemical process acting at the bottom of the soil profile in the study area is bisiallitisation (Pedro, 1966). This process is favoured by the following morphoclimatic and hydrological conditions in this bioclimatic zone (Ngounou Gatcha et al., 2005): low rainfall, followed by dry periods that include evaporation, induce soil solutions concentrated in silica and basic cations, leading thus to the formation of smectite clays (Pedro, 1966; Nahon, 1991; Velde, 1995; Paquet and Clauer, 1997; Nguetkam, 2008). This predominance of smectite clays is confirmed by high values of CEC of clay, which range from 116.80 to 181.38 cmol(+).kg^{-1}. In addition to smectites, there are a few amounts of kaolinite, associated with traces of gibbsite. The presence of kaolinite suggests that monosiallitisation is a crystallochemical processes acting at the bottom of profile towards bisiallitisation. The neoformation of kaolinite is generated by the morphoclimatic and hydrological conditions prevailing in the studied area, but which remains dominated by the bisiallitisation process. The decrease in pH values and the Si/Al below 3 in the two upper horizons are consistent with the presence of kaolinite (Nguetkam, 2008). Similar coexistences of kaolinite and montmorillonite have been reported in the literature by many authors (Amouric and Olives, 1998; Meunier, 2003; Nguetkam, 2008). Traces of gibbsite are present in the studied soils. Generally, gibbsite has to be suspected as parent materials that weather to a coarse grained saprolite or C horizon allowing free downward drainage and which contain sufficient aluminium like granite and gneiss or other magmatic and metamorphic rocks (Driessen et al., 2001; Herrmann et al., 2007). This is consistent with the presence of gabbro with green amphibole, biotite and plagioclase. In addition, occurrence of traces of gibbsite might be due to high elevation in the studied area (Tsozué et al., 2011). Sepiolite is present in the studied soils. This fibrous mineral is generally neoformed (Singer, 1979). It is not stable in wet climates and their presence is favoured in soils under dry or semi-dry climates, where the alkaline, silica- and magnesium rich environment favours their formation (Singer, 1984). As palygorskite minerals, another fibrous mineral, sepiolite might also form from the transformation of montmorillonite through a dissolution-process already described by Jones and Galán (1988). The CIA is based on the progressive removal of soluble cations (e.g. Ca, Na, and K) from minerals during chemical weathering and reflects the proportion of primary and secondary minerals in the bulk sample (Ozaytekin and Uzun, 2012; Dengiz et al., 2013; Tunçay and Dengiz, 2016). Its values ranged between 50 and 60. This interval corresponds to little weathered soils (Ozaytekin and Uzun, 2012), in line with their classification in the dystric haplustepts subgroup. The MIA values ranging from 1.90 to 10.54%, also indicates incipient weathering. The studied soil profile is essentially autochthon, developed *in situ* with almost vertical lithodependance of the upper horizons. It is developed by the collapse of primary mineral structures from the bottom of the coarse saprolite, due to leaching as a result of hydrolysis process (bisiallitisation and monosiallitisation). This is accompanied by a progressive ferruginization of materials, confirmed by the presence under the microscope of goethitic brown veil that covers the remnants of weathered plagioclases shape at the base of the profile which is generalized in the loamy clay horizon. The progressive ferrugunization is also confirmed by the increase in iron contents from the bedrock to the humiferous surface horizon.

Conclusion

Soils resulting from weathering of gabbro rock in the high reliefs of Maroua region were investigated and classified as dystric haplustepts clayey isohyperthermic. Four main horizons were distinguished from the bedrock to the surface: a coarse saprolite, a fine saprolite, a loose loamy clayey horizon and a humiferous horizon. They were mainly composed of montmorillonite, associated to kaolinite, goethite and in lesser quantity quartz, feldspar, gibbsite, calcite, lepidocrocite and sepiolite. The studied soils were essentially autochthon, developed *in situ* with almost vertical lithodependance of the upper horizons. They were developed *in situ* by collapse of primary mineral structures from the bottom of the coarse saprolite, due to leaching as a result of bisiallitisation and monosiallitisation processes. This is accompanied by a progressive ferruginization, resulting in the presence under the microscope of goethitic brown veil that covered the remnants of weathered plagioclases shape at the base of the profile and which was generalized in the loamy clay horizon, confirmed by the increase in iron contents from the bedrock to the humiferous surface horizon.

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References

Amouric, M., Olives, J., 1998. Transformation mechanisms and interstratifications in conversion of smectite to kaolinite: an HRTEM study. *Clays and Clay Minerals* 46(5): 521-527.

Badía, D., Martí, C., Aznar, J. M., León, J., 2013. Influence of slope and parent rock on soil genesis and classifcation in semiarid mountainous environments. *Geoderma* 193-194: 13-21.

Bai, Y.Y., 2009. Distribution of Soil Temperature Regimes and Climate Change in the Mojave Desert Region. PhD Thesis. University of California Riverside, 137 p.

Bockheim, J.G., Gennadiyev, A.N., Hammer, R.D., Tandarich, J.P., 2005. Historical development of key concepts in pedology. *Geoderma* 124: 23-36.

Bray, R.H., Kurtz, L.T., 1945. Determination of total organic and available forms of phosphorus in soils. *Soil Science* 59 : 22-229.

Costantini, E.A.C., Priori, S., 2007. Pedogenesis of plinthite during early Pliocene in the Mediterranean environment. Case study of a buried paleosol at Podere Renieri, central Italy. *Catena* 71: 425-443.

De Martonne, E., 1926. Aréisme et Indice d'Aridité. *Comptes Rendus Académie des Sciences* 181: 1395-1398.

Dengiz, O. Sağlam, M., Özaytekin, H.H, Baskan, O., 2013. Weathering rates and some physico-chemical characteristics of soils developed on a calcic toposequences. *Carpathian Journal of Earth and Environmental Sciences* 8(2): 13-24.

Driessen, P., Deckers, J., Spaargaren, O., Nachtergaele, F., 2001. Lecture notes on the major soils of the world. Word Soil Resources Reports, 94. FAO, Rome, 334 p.

Gracheva, R., 2011. Formation of soil diversity in themountainous tropics and subtropics: rocks, time and erosion. *Geomorphology* 135: 224-231.

Herrmann, L., Anongrak, N., Zarei, M., Schuler, U., Spohrer, K., 2007. Factors and processes of gibbsite formation in Northern Thailand. *Catena* 71: 279-91.

Irfan, T.Y., 1996. Mineralogy, fabric properties and classification of weathered granites in Hong Kong. *Quaterly Journal of Engineering Geology and Hydrogeology* 29(1): 5-35.

Jones, B.F., Galán, E., 1988. Sepiolite and palygorskite. In: Bailey, S.W. (Ed.), Hydrous Phyllosilicates (Exclusive of Micas). Reviews in Mineralogy, vol. 19. Mineralogical Society of America, Washington, DC, pp. 631-674.

Lal, R., Stewart, B.A., 1990. Soil Degradation. New York, Springel-Verlag, 362 p.

Meunier A., 2003. Les argiles. Collection Géosciences, GB Science Publisher, 433p.

Nahon, D., 1991. Introduction to the Petrology of Soils and Chemical Weathering. John Wiley, New York, 313p.

Nesbitt, H.W., Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature* 279: 715-717.

Ngounou Ngatcha, B., Mudry, J., Sigha Nkamdjou, L., Njitchoua, R., Naah, E., 2005. Climate variability and impacts on an alluvial aquifer in a semi-arid climate, the Logone-Chari plain (South of Lake Chad). *International Association of Hydrological Sciences* 295: 94-100.

Nguetnkam, J.P., Kamga, R., Villiéras, F., Ekodeck, G.E., Yvon, J., 2008. Variable weathering response of granite in tropical zones. Example of two sequences studied in Cameroon (Central Africa). *Comptes Rendus Geoscience* 340(7) : 451-461.

Ozaytekin, H.H., Uzun, C., 2012. Comparison of weathering rates of the soils classified in Alfisol and Entisol order developed on limestone in the Taurus Mountains at East Mediterranean region. *Carpathian journal of Earth and Environmental Sciences* 7(1): 109-120.

Paquet, H., Clauer, N., 1997. Soils and sediments, Mineralogy and geochemistry, Springer-Verlag, Berlin, Heidelberg, 369 p.

Pédro, G., 1966. Essai sur la caractérisation géochimique des différents processus zonaux résultant de l'altération des roches superficielles (cycle alumino-silicique). *Comptes Rendus de l'Académie des Sciences* Série D 262: 1828-1831.

Pedro, G., 1982. The conditions of formation of secondary constituents. In: Bonneau M. and Souchier B. (eds), Constituents and properties of soils. Academic Press, London, pp. 63-81.

Pimentel, D., 1993. Word Soil Erosion and Conservation, Cambrdge, UK, Cambridge University Press, 349 p.

Pimentel, D., 2006. Soil erosion: a food and environmental threat, *Environmental, Development and Sustainnability* 8: 119-137.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science* 267: 1117-1123.

Pimentel, D., Kounang, N., 1998. Ecology of soil erosion in ecosystems. *Ecosystem* 1: 416-426.

Singer, A., 1979. Palygorskite in sediments: detrital, diagenetic or neoformed. A critical review. *Geologische Rundschau* 68: 996-1008.

Singer, A., 1984. Pedogenic palygorskite in the arid environment. In: Singer, A., Galán, E. (Ed.), Palygorskite-Sepiolite. Occurrences, Genesis and Uses. *Developments in Sedimentology* 37. Elsevier, Amsterdam, pp. 169-177.

Soil Survey Staff , 2010. Keys to Soil Taxonomy. United States Department of Agriculture, Natural Resources Conservation Service, Eleventh Edition, 338p.

Stoops, G., 2003. Guidelines for analysis and description of soil and regolith thin sections. Soil Society of America, INC., Madison, USA, 184p.

Tsozué, D., Bitom, D., Yongue-Fouateu, R., 2011. *In Situ* genesis of alumino ferruginous nodules in a soil profile developed on garnet rich micaschist in the high reliefs of South Cameroon Rainforest Zone (Central Africa). *The Open Geology Journal* 5: 56-66.

Tsozué, D., Haiwe, B. R., Louleo, J., Nghonda, J.P., 2014. Local initiatives of land rehabilitation in the Sudano-Sahelian region: Case of *Hardé* soils in the far North Region of Cameroon. *Open Journal of Soil Science* 4: 6-16.

Tsozué, D., Nghonda, J. P., Mekem, D.L., 2015. Impact of land management system on crop yields and soil fertility in Cameroon. *Solid Earth* 6: 1087-1101.

Tunçay, T., Dengiz, O., 2016. Chemical weathering rates and geochemical-mineralogical characteristics of soils developed on heterogeneous parent material and toposequence. *Carpathian Journal o Earth and Environmental Sciences* 11(2): 583-598.

USDA, 2004. Soil survey laboratory methods manual, Soil survey investigation report no. 42, Version 4.0. USDA-NCRS, Lincoln, NE, 700p.

Velde, B., 1995. Origin and mineralogy of clays. Clays and the environment. Springer-Verlag, New York, 334p.

Voicu, G., Bardoux, M., Jébrak, M., Voicu, D., 1996. Normative mineralogical calculations for tropical weathering profiles. *Geological Association of Canada and Mineral Association of Canadian Program with Abstract* 21: A-69.

Walkley, A., Black, I.A., 1934. Determination of organic matter in soil. *Soil Science* 37: 549-556.

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Distribution, typology and assessment of degraded soils Piedmont Plains Zhetysu Ridge, Kazakhstan

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Abstract

Identification of land degradation is essential to check the problem and to implement the remedial measures needed. The study area falls under parts of foothill plains Zhetysu Ridge, Kazakhstan, that is an arid region in climate. Recent data on the status of study area refer to the 80s of the last century, and the intensive use of them led to a significant anthropogenic transformation. This study was carried out in 2015-2016 as part of a project aimed to study features and causes of land degradation in foothill plains Zhetysu Ridge, Kazakhstan. Under the conditions of rainfed soil degradation manifests itself in the development of erosion processes, agro depletion of soils, reducing the productivity of agriculture. The use of land for irrigation often accompanied by secondary salinization. In this regard, at present there is need to assess current state of the soil, with the identification of changes in their properties as a result of the impact of various anthropogenic factors and creation of new electronic soil maps and applied the powerful capabilities of advanced remote sensing (RS) and geographic information system (GIS) techniques to identify the geomorphological units and degradation risk assessment. Satellite imagery in addition to the field and laboratory studies to identify salinity-induced soil degradation was adopted in this study. Morphological, chemical and physical characteristics of soils in degraded sites in foothill plains Zhetysu Ridge, Kazakhstan, were depicted. The main results of a thorough evaluation of soil degradation in foothill plains Zhetysu Ridge, Kazakhstan, are presented. The data revealed that extent of salinity-induced degradation was generally related to some physical properties of soil, uncontrolled livestock grazing and previous soil management practices. These results are useful as the basis for designing soil conservation and restoration programs, as a base line for evaluating the performance of conservation programs and for assessing the impact of other soil-related activities (e.g. agriculture and livestock rising).

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Introduction

The second half of the XX century characterized by a maximum gain of anthropogenic impacts in pedosphere. According to international organizations arable-suitable of the Earth Fund is only about 3-3.5 billion ha, of which nearly 2 billion more or less susceptible to degradation as a result of which the development is lost annually about 7 million ha of arable land (Gabbasova and Habirov, 2010). In the agricultural turnover of Kazakhstan is located 222.5 million ha, of which 33.7 million ha (10.8%) of arable land, 187.0 million ha of pastures (84.8%) and grasslands (2.3%), 1.8 million ha of reserve and perennial

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plants (2; 0.1%) (Figure 1) (Medeu and Akiyanova, 2011; Kozybayeva, 2014). The percentage of land Structure as follows: agricultural land - 35.1%, the settlements - 8.8%, land used in industry transport communications defense and other non-agricultural purposes - 1%, protected areas, recreational, historical and cultural lands - 1.8%, lands of forest fund - 8.9%, lands of water fund- 1.6%, reserve lands - 42.8% (Figure 2) (Medeu and Akiyanova, 2011).

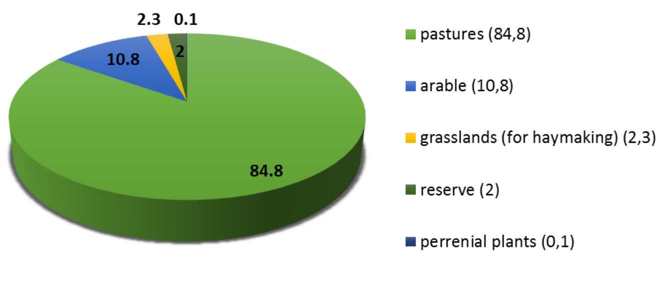

Figure 1. Agricultural lands structure (%)

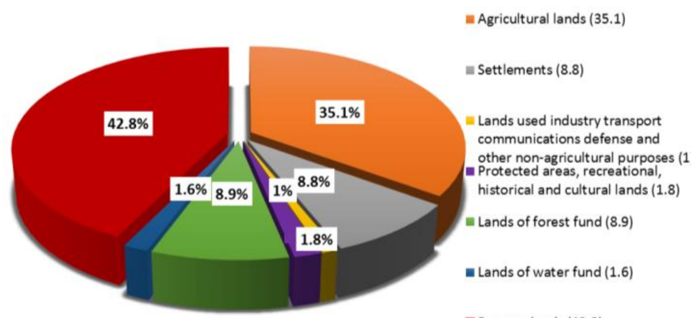

Figure 2. Landuse structure (%)

Already today about 60% of the soil cover of Kazakhstan applies in varying degrees to the degraded, depending on the characteristics of natural conditions and the national economic use. Current estimates of degraded and agricultural land distributed as follows: according to the Agency of Land Resources (2011), the area of land subject to water erosion, is 4988.9 thousand ha, and the area of land subject to wind erosion, is 25,493.1 thousand ha, Figures 3, 4 (Medeu and Akiyanova, 2011).

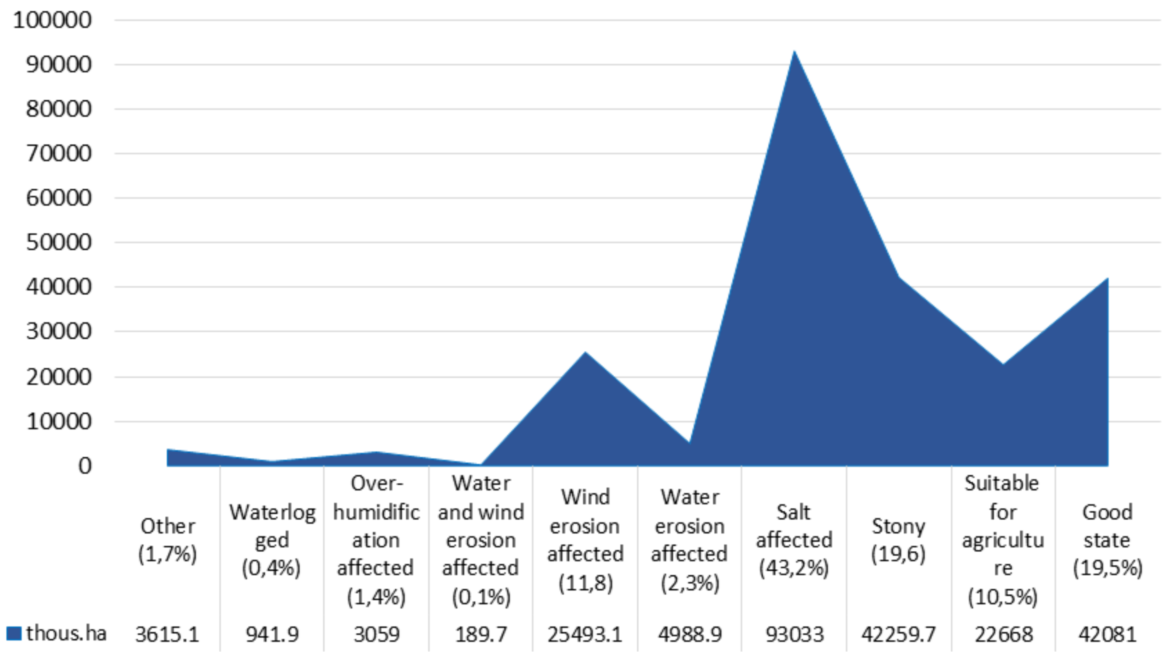

Figure 3. Current state of agricultural lands degradation

For formation of highly adaptive land management, in addition to improving the economic land resources management mechanisms, it is necessary to take measures to improve the quality status of the land based on landscape ecological approach. In this regard special relevance acquired by questions of carrying out soil and geographical researches in the territory of Almaty region for the fair presentation of Kazakhstan's soil resources, conservation and reproduction of soil fertility, control the environmental state of the soil and forecasting trends of its transformation.

These problems can not be solved without a reliable systematic information, including data on the spatial distribution of soil and data about the basic properties of soils (morphological, chemical, physicochemical, physical). Under conditions of transition agricultural to paid land use there is a need to improve the forms and land resource management practices, which is impossible without the development of information support (Dusembekov, 1997). To conduct development related to the solution of practical problems of land administration, we must have a reliable and qualitative data on the characteristics of the soils of the region, the structure of soil and its transformation associated with the effect of natural and anthropogenic factors. The main purpose of this study - to give comprehensive qualitative and quantitative assessment of the current state of agricultural land piedmont plains Zhetysu ridge and to develop schemes of rational land use the study area.

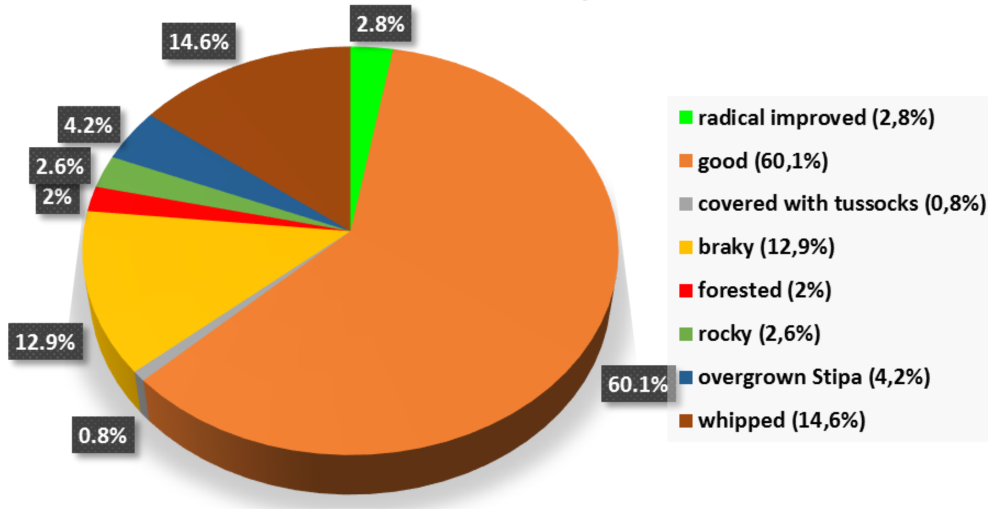

Figure 4. Current state of pastures

For the implementation, we set several goals: i) Explore the current state of soils irrigated areas piedmont plains Zhetysu Range: basic chemical, physicochemical and morphological properties of virgin and used in agricultural soils (30 incisions); ii) Develop criteria and parameters of soil degradation; iii) electronic versions of maps of soil degradation of the key area in scale of 1: 100,000.

Latest data on the state of land resources of the region belong to the 80s of the last century, and the intensive use of them led to a significant anthropogenic transformation. In the context of rainfed soil degradation manifested in the development of erosion processes, agro depletion of soils, reducing the productivity of agriculture. The use of land for irrigation often accompanied by secondary salinization. Unregulated grazing leads to rangeland degradation. In this regard, at present there is a need to assess the current state of the soil, with the identification of changes in their properties, because of the impact of various anthropogenic factors and the creation of new electronic soil maps and applications with modern technology.

Material and Methods

The study area is located in the zonal and related intrazo-functional soil piedmont plains of Kazakhstan of Zhetysusky ridge, 135 km to the east of the railway station Mulaly (line Semey-Almaty) and 155 km north-east of Taldykorgan (Figure 5). Its geographic lies between 078º11'E - 079º55E longitude and 45º16'N - 45º 24'N latitude. The altitude range of the study area is 1000-1500 m.a.s.l.

An integrated approach for evaluating current state of agricultural land and soil degradation foothill plains Zhetysu Ridge as adopted in this study, through the combined analysis of satellite imagery, supported by field work and previous work in the region.

The basic concept of defining the methods of obtaining the actual material and its processing is a genetic approach (Sokolov, 2004; Isachenko, 1980). The basis of investigation put the comparative geographical method (Korsunov et al., 2002).

Landsat ETM+ image and digital elevation model (DEM) were used in ENVI 4.7 software to produce the physiographic map of the studied area. Thirty soil profiles representing the different physiographic units were developed in the studied area. A detailed morphological description of soil profiles was carried out according to Rozanov (2004). The studied soil profiles were taken from comparative options as arable land and virgin soil to ensure the accuracy and validity of the field diagnostics of soils, soil mapping and morphological characteristics of the main properties of the soil.

The use of instrumental methods associated with laboratory analytical studies of samples, which carried by conventional methods (Arinushkina, 1962; Alexandrova et al., 1986).

Figure 5. Location map of the study area

Preparation of a preliminary layout the test portion the soil map (1: 100 000) was carried out using conventional mapping techniques (Soil Survey, 1959), as well as with the use of GIS technologies and remote sensing data (Korsunov et al., 2002; Yashin et al., 2000). The basic method of processing space data is indirectly indicational decryption (Smirnov, 2005; Kravtsova, 2005), which is based on establishing a relationship with the soil components of the landscape, to get the best display on satellite images in the first place with vegetation and topography. In conducting research on the topic were used in deciphering large-scale multispectral satellite images such as «Landsat», with the involvement of GoogleMap and BingMap. Work on the preparation of the soil map, was conducted in MapInfo Professional environment.

Preparation of the soil map was conducted as follows:

1. Pre-cameral work with space photographic materials - visual decryption, edge detection, saturation of their data as possible of past years of research.

As a result, pre-prepared the soil map layout. On that basis, outlines key areas, covering a total diversity of soil cover in representative locations for the development of methods of deciphering, and a detailed study in the field.

2. Field research conducted routing way to clarify the content of the selected contours, boundaries of soil zones, the establishment of deciphering features soil.

In the course of field works, preliminary cards are specified and supplemented.

3. Extrapolation of final deciphering.

For a reliable assessment of the degree of transformation of morphogenetic properties of soils characterized by the territory of the paired sections were laid (virgin land - arable land), occurring in the same conditions for terrain. The studies were conducted on dark brown, light-brown soils, ordinary gray soils of the northern, meadow-gray soils.

Results and Discussion

In the process of work structure of soil database has been designed and prepared the tables in Microsoft Excel format for data entry. Collected, structured and entered into the database of soil data existing materials in their morphological, physical and chemical properties of zonal and intrazonal soils associated within the selected portion for 30 profiles. Used materials (Nikolaeva, 1969; Pachikin, 1991) obtained in the process of implementation of the program with the 1981-1985 years.

In 2015 was held 30 soil profiles for which morphological descriptions were made, selected and analyzed soil samples to determine their physical and chemical properties. The resulting material also incorporated in the soil database. The principal causes of soil degradation are few changes. Zaydelman brings them to the action of the five factors - hydrological, erosion, chemical, radiological, mechanical (Zaydelman, 2000). Karmanov and Bulgakov (1998) identified three main categories of soil degradation: physical or mechanical, biological, and biochemical and specific forms of their manifestation (erosion, dehumidification, condensation and formation of merge, increased acidity or alkalinity, alkalinity, secondary salinization and waterlogging) characterized as a kind of degradation (Karmanov and Bulgakov, 1998).

The main causes of soil degradation in all regions of Kazakhstan caused by three main factors: 1. the extensive development of agricultural production; 2. resource-intensive development of the industry; 3. the wide network of the former (in the Soviet period) military test sites (Kozybayeva, 2014). Because of these effects can develop various types and kinds of soil degradation. Type of soil degradation within the type characterized mainly by the deterioration of the specific properties of soils in the first stage (subsequently primary change of one will inevitably lead to transformation of all complex of properties of the soil). Alternatively, it is caused by distinctions in the factors of degradation causing identical reaction (for example, the different reasons cause remoistening, redrainage, etc.) or responses depend on a type of the same influence (for example, at pollution), etc. Table 1 (Gabbasova and Habirov, 2010).

Table 1. The typological taxonomy of soil degradation

Type of degradation	Degradation Factors *	The types and forms of degradation
Pollution	1 Exploration, production, transportation and processing of minerals; 2. Industrial, agricultural and household emissions and waste; 3.Technogenic catastrophes; 4. Combustion of fuel.	1. Hydrocarbonic (oil crude and commodity, oil products, oil slimes); 2. Highly mineralized oil-field sewage; 3. Heavy metals; 4. Radiation; 5. Biological; 6.Gas-gene heathlands.
Salinization	1. Drainage of solonchak marsh soils; 2. Emergency floods of technogenic brines; 3. Violation of the mode of an irrigation.	1. Superficial; 2. Deep-profile; 3. Full-height; 4. Sulphatic; 5. Chloride; 6. Soda.
Alkalinity and solodization	Developed under appropriate conditions after technogenic salination instigated sodium containing substances.	1. Continuous; 2. Uneven; 3. Focal.
Pyrogenesis	1. The fires on the drained bogs; 2. Wildfires; 3. Combustion of straw and eddish.	1. With full loss of peat; 2. With partial loss of peat; 3. With the disturbed humus accumulative horizon.
landscape	1. Mining; 2. Construction of dikes and dams; 3. Karst (natural and technogenic).	1. Formation of embankments (waste heaps, dumps, etc.); 2. Formation of dredging (pits, ditches, trenches, funnels, etc.).

* Degradation factor - the reason, the motive force of the process (phenomenon) degradation, defining its character or individual features.

Assessment of the current status of soil

Factors soil anthropogenic transformation

Studies to evaluate the current state of soil of Zhetysusky ridge Sarkand area revealed that the ecosystem within the territory and characterized by soil cover in particular largely transformed under the influence of anthropogenic factors. The most intensive disturbances of natural soil and vegetation cover confined to foothill plains, where favorable climatic conditions and availability of sufficient water resources led to the intensive use of land in agricultural production. The types and extent of anthropogenic degradation of soil depend not only on the impact of a degradation factor, but largely determined by the genetic characteristics of the soils and lithology-geomorphological conditions of their occurrence.

When the soil irrigated agriculture, regardless of the typical belonging are undergoing a profound transformation, caused, in addition to mechanical and chemical effects associated with agro-technical measures for handling of arable land, a change in water regime with no washing on the washing. For irrigated lands as compared to virgin analogues characterized less differentiated by color and mechanical composition densified stretched profile with humus horizon. Loss of humus in the arable horizon can reach 50-60%, especially in the first years of irrigation (Erokhina et al., 2004; Suleymenov, 2000). In the subsurface horizon, on the other hand, there is a relative increase in humus content.

With long-term irrigation of soils in the lower, (subsurface) of the profile occurs weighting texture, mainly due to the silt fraction. The texture of the arable horizon can vary significantly even within the same field due to the appearance of irrigation erosion, causing an increase in sand fraction washable area as well dusty and muddy - in accumulative. Changing the water regime leads to a shift deeper into the carbonate-illuvial horizon and washed out from the profile of water-soluble salts. Transformation of soil because of irrigation can have both negative and positive and depends on the duration of irrigation, irrigation water quality, the system used by agricultural activities and the type of land use. For example, soil gardens properties similar to virgin or analogs they observed significant improvement in the overall performance of fertility. With prolonged light gray soils irrigation with rational watering noted of humus enrichment, increasing absorption capacity, biological activity, improving micro aggregation. Significant areas of soils of foothill plains also used for rainfed agriculture. The annual distribution of rainfall with winter-spring maximum creates the opportunity for the successful cultivation are cereals, fodder and industrial crops.

Anthropogenic transformation of arable soil, in addition to purely mechanical disorders of the structure surface horizons and subsoil compaction horizon, related primarily to the decrease in humus content, caused by flushing and blowing humus composed of silt, humus mineralization and removal of nutrients with the harvest of crops. Accordingly, the physical properties deteriorate, exchange capacity decreases, micro- and macro elements content etc. (Rubinshteyn, 1985; Rubinshteyn and Tazabekov, 1988).

The development of rainfed agriculture in a steeply sloping- undulating piedmont plains leads to increased erosion. Noticeable symptoms of surface flushing not only observed at the surface slopes not exceeding 3-5^{o} (Fedorin, 1977). Whereas the total area of arable rainfed foothill plains only 60% placed on the slopes with a slope and about 32% occupied by the slopes in 5-8^{o} and over 8^{o} - more than 8% rainfed arable land. In the medium and strongly eroded soils almost half, the number of water-stable aggregates decreased by 20% reduces humus horizon. Surface horizons become layered-foliated addition and porous, and in the illuvial horizon B is a characteristic brown colour. Pasture degradation of soil takes place because of overloading the cattle lands. Overgrazing primarily manifested in violation of vegetative cover, sometimes until its destruction, accompanied by deterioration of physical, chemical and physico-chemical and biological properties of soils.

Under the conditions of weakly dissected topography piedmont plains of water erosion is almost not developed, but the sparseness of vegetation, high wind activity, insufficient soil moisture at immoderate grazing create preconditions for the development of deflation processes. It was found that even one-time run cattle destroys the surface layer of soil, and sprayed material is easily taken out even at a wind speed of 4-5 m / sec. Studies show that intensive grazing is causing losses of up to 30% of humus content, 20-50% of the elements of plant nutrition, and 10% of the absorption capacity. In addition, surface layers of an increase amount of water-soluble salts and carbonates (Muhametkarimov and Smailov, 2001).

Soil degradation because of anthropogenic impact is manifested in form of linear (road network communication lines, canals, pipelines, etc.) and local (residential-industrial zones, quarries, etc.) violations.

It characterized as a rule, the complete destruction of the soil cover with the destruction of the original micro- and nano-relief and the formation positive technogenic topography (embankments, shafts) and negative (excavation, trench) forms. Which accompanied by a technogenic turbation (horizontal stratification loss, mixing substrates of different horizons) denudation (formation of soils with an incomplete or truncated profile) and buried soils extracted to the surface bedrock.

Residential and industrial land degradation associated with total destruction of the natural land cover and areas besides the placement of residential buildings and infrastructure captures the band width of 300-500 m around the settlements, which is a multi-faceted area of anthropogenic impact (transport, livestock, dirt and debris etc.) to form a fully converted from baseline soils of anthropogenic soils, mostly devoid of vegetation. Road digression of soil is an inevitable part of any kind of human impact. Lack of profiled surfaced roads, and they are often unsatisfactory condition leads to the formation of a dense network of dirt roads, which at year-round operation become impassable, and beside them a new form. As one of the main causes of the degradation of the physical properties of soils as a result traffic loads in favor of soil repacking, which is perhaps the most dangerous factor of vegetation degradation.

At consolidation of soils the cloddy low-porous structure is formed, the smallest moisture capacity, coefficient of a filtration and moisture pro-water content decreases (Ivanov, 1989). Even at insignificant biases of a surface leads to the accelerated development of processes of a water erosion. On light-textured soils, destruction of vegetation and disturbance of the structural condition of surface horizons leads to the formation of hearths deflation. Technogenic soil disturbance at their apparent locality can occupy large areas. It was found, that the laid asphalt and pipeline routes disturbed land area, excluding the indirect impact on the soil and vegetation cover reaches 2.3-2.5 km^2 is 100 km, to the existing dirt roads - 0.8 km^2. The zone of indirect influence technological disturbances associated with the change of water and salt regime, the composition of the vegetation surrounding areas, captures an area of 2-3 times more (Asanbayev, 1998; Marynich, 1999).

Determining the extent of degradation of soil test site

For a reliable assessment of the degree of transformation of the territory characterized by the morphogenetic properties of soil were laid paired soil profiles in different versions (virgin - irrigated arable land, virgin land - arable land under rainfed), occurring in the same conditions. As you can see in Figure 6 sections and soil profiles, were carried out on dark brown, light-brown soils, ordinary gray soils of the northern and light, meadow gray soils.

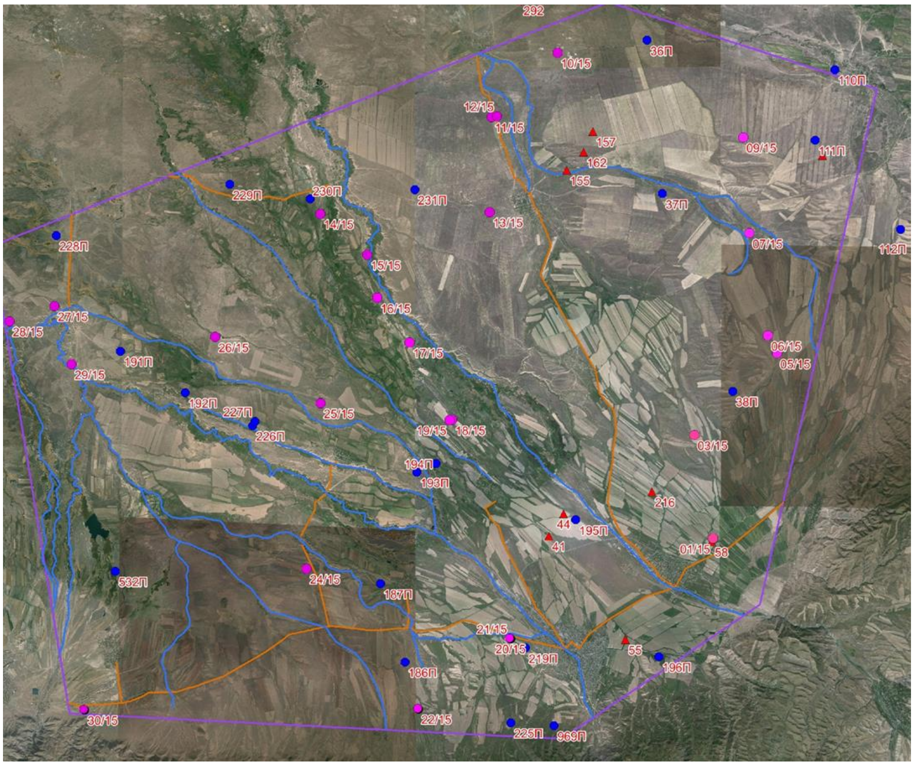

Figure 6. Scheme of arrangement of soil profiles on the test site

The main morphological parameters that indicate the changes in the processes of soil formation are: the humus horizon (A + B) and the depth of the upper boundary of the visually defined carbonates.

Changing these morphological parameters arable soils compared to virgin analogues shown in Figure 7.

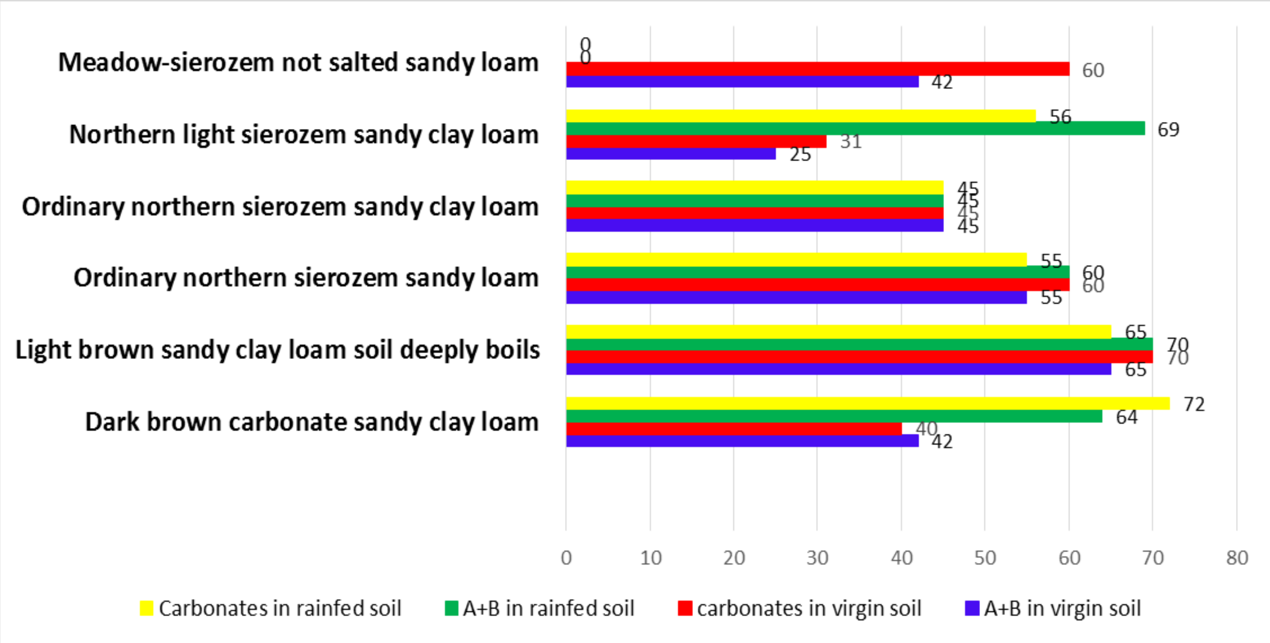

Figure 7. Changing the thickness of the humus horizon and depth of carbonates of arable soils in comparison with virgin counterparts.

As we see the boundary of on the profile of A + B, the deepest in the irrigated light brown sandy clay loam soil deeply boils, as virgin northern light sierozem sandy clay loam profile that is much poor.

According with the regulations of the Republic of Kazakhstan on protection of land resources (Environmental Requirements, 2005) and taking into account regional peculiarities of formation of soil study area identified the following criteria for determining the extent of arable land degradation, which you can see in Table 2.

Table 2. Criteria for determining extent of soil degradation

Indicators	very weak	weak	medium	raised	high
Reducing the power of the soil profile (A + B)% of original	<3	03-25	26-50	51-75	>75
Reducing stocks of humus in the soil profile (A + B)% of original	<10	10-20	21-40	41-80	>80
Reduction of clay on physical size,% of the original	<5	5-15	16-25	26-32	>32
Area of bare parent rock (C) or bedrock (B)% of total area	0-2	3-5	6-10	11-25	>25
Changing the pH of soil environment,% of average	<10	10-15	16-20	21-25	>25
The projected coverage of pasture vegetation,% of the zone.	>90	71-90	51-70	11-50	<10
The increase in exchangeable sodium content (in% of the cation exchange capacity):					
- soils containing <1% sodium	<1	1-3	3-7	7-10	>10
- for the other soil	<5	5-10	10-15	15-20	>20

Map of degradation of soils of a test site

The degradation of the soil map of the test site, which is given in Figure 8, have been prepared on the basis of the soil map (Pachikin, 2016), the degree of soil degradation was determined by the results of the analytical examination of samples, taking into account the factors and criteria for soil degradation.

Despite the advancement in the measurement of land degradation in Le et al. (2014), its definition as a long-term decline in the NDVI still entails some issues, since confounding factors changing over time, such as land use, influence the NDVI. Kazakhstan underwent a considerable transition in agricultural land use in the post-Soviet era, marked by a sharp decline in total rainfed grain area from 25 million ha in 1983 to 14 million ha in 2003, particularly in the country's northern part (De Beurs and Henebry, 2004). Today, the area is largely covered by abandoned cropland returning to original land cover types prevalent before their conversion to cultivation (Schierhorn et al., 2013), mainly grassland. Although soil itself might have recovered some of its lost carbon due to abandonment (ibid.), cultivated land may elicit a higher NDVI value than abandoned land with sparser vegetation, leading to an overestimation of inherent soil degradation processes (Klein et al., 2012). Within the framework of solving the research tasks developed soil structure unified database based on scientifically sound methodology for assessing the current state of the soil. Cumulative to date soil information characterized by low availability, incompatible and often unreliable and incomplete. The study of natural resources, including soil, using modern computer technology has received in recent years widespread. However, for the Almaty region there is no single soil database tailored agro resource building land.

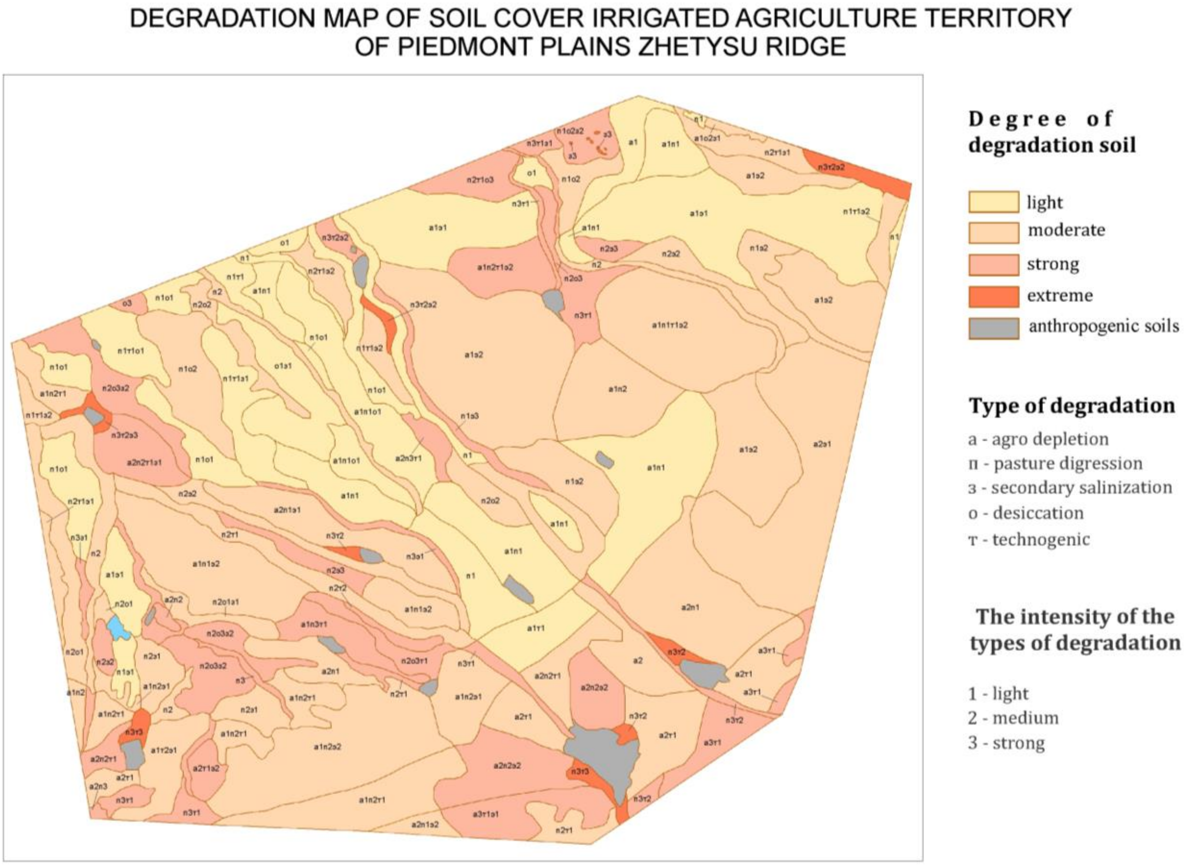

Figure 8. Map of degradation of soil test site

Conclusion

As a result, soil investigations Zhetysu ridge, obtained new data on soil properties and composed a large-scale (1: 100 000) soil degradation maps using GIS technologies and remote sensing data. One of the most important tasks of development of Kazakhstan is to implement measures aimed at the preservation and reproduction of soil fertility because land degradation and desertification leads to a permanent reduction of the impact of material resources invested in agricultural production, undermining food and economic security of the Republic, worsens the living conditions of the population has a negative effect on health and demographic situation. The results of these studies are the basis for making decisions related to land use and environmental - of sustainable development of the territory schemes, regulatory and legal acts on the protection of soils, determining the measures to restore the natural landscape, the regulatory intensity of grazing pressure, the rational use of land.

In accordance with the purpose of the study the following results were obtained: i) Based on existing materials and materials research 2015 (30 sections) designed and engineered soil data base on the territory of of the key area (150 ha.) Within the irrigated areas piedmont plain Zhetysusskogo ridge; ii) Developed parameters, types and criteria for soil degradation; iii) Compiled applied map of degradation soil of test site on a scale of 1: 100,000.

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References

Agency of Land Resources, 2011. Report on state land in Kazakhstan in 2011. Available at [Access date: 28.07.2016]: http://2011-2014.ecodoklad.kz/

Aleksandrova, L.N., Naydenova, O.A., 1986. Laboratorno-prakticheskie zanyatiya po pochvovedeniyu [Laboratory and practical classes of soil science]. – L.: Agropromizdat, – 295 pp. [in Russian]

Arinushkina, E.V., 1962. Rukovodstvo po himicheskomu analizu pochv [Guidelines for Chemical analysis of soil]. – M.: MGU, 491 pp. [in Russian]

Asanbayev, I.K., 1998. Antropogennyye izmeneniya pochv i ikh ekologicheskiye posledstviya [Anthropogenic changes in soils and their environmental consequences]. Almaty: ylym. 180 pp. [in Russian]

De Beurs, K.M., Henebry, G.M. 2004. Land surface phenology, climatic variation, and institutional change: analyzing agricultural land cover change in Kazakhstan. *Remote Sensing of Environment* 89(4): 497-509.

Dyusenbekov, Z., 1997. Problemyi zemelnyih otnosheniy i mehanizmyi perehoda k platnomu zemlepolzovaniyu [Issues of land relations and mechanisms of transition to the paid land use]. Mezhdunarodnyiy selskohozyaystvennyiy zhurnal [International Journal of Agriculture] (Vol. 6. pp. 11-14). Moscow. [in Russian]

Environmental requirements, 2005. Ekologicheskiye trebovaniya v oblasti okhrany i ispolzovaniya zemelnykh resursov (v tom chisle zemel selskokhozyaystvennogo naznacheniya) [Environmental requirements in the field of land protection and use (including agricultural land)]. RND Okhrana zemelnykh resursov. MKh RK. Astana. 2005. [in Russian]

Erokhina, O.G., Nasyirov, R.M., Pachikin, K.M., Yakunin, G.N., 2004. Transformatsiya pochv podgornyih ravnin Zailiyskogo Alatau v rezultate orosheniya [Transformation of Soil piedmont plains Trans-Ili Alatau as a result of irrigation]. Aktualnyie problemyi pochvovedeniya [Actual Problems of Soil Science] (k 50-letiyu osvoeniya tselinnyih i zalezhnyih zemel). Almaty: Tetis, pp. 78-92. [in Russian]

Fedorin, Yu.V., 1977. Zemelnyie resursyi predgornyih ravnin Kazahstana [Land foothill plains of Kazakhstan]. – Alma-Ata: Kaynar, 187 p. [in Russian]

Gabbasova, I.M., Habirov, I.K., 2010. Rasprostranenie, tipologiya i otsenka sostoyaniya degradirovannyih pochv respubliki Bashkortostan [The spread, typology and assessment of degraded soils of Bashkortostan] Vestnik BGAU/Vestnik BSAU, 22, 5-13. [in Russian]

Isachenko, A.G., 1980. Metodyi prikladnyih landshaftnyih issledovaniy [Methods Applied Landscape Research]. L.: Nauka, 222 p. [in Russian]

Ivanov, B.N., 1989. Vliyanie hodovoy sistemyi avtomobilya na fizicheskie svoystva pochv pod lesom [Effect of suspension system of the car on the physical properties of soils under forest]. *Pochvovedenie* [Soil science]. 7, 47-54. [in Russian]

Karmanov, I.I., Bulgakov, D.S., 1998. Degradatsiya pochv: predlozheniya po sovershenstvovaniyu terminov i opredeleniy [Soil degradation: proposals on improvement of terms and definitions]. Kn.: Antropogennaya degradatsiya pochvennogo pokrova i meryi ee preduprezhdeniya [Anthropogenic degradation of the soil and its prevention measures]. (Vol. 1, pp. 5-7). Rosselhozakademiya, DOP pri RAN, Soil science institute after named V.V.Dokuchaev. M. [in Russian]

Klein, I., Gessner, U., Kuenzer, C., 2012. Regional land cover mapping and change detection in Central Asia using MODIS time-series. *Applied Geography* 35(1-2): 219–234.

Korsunov, V.M., Kraseha, E.N., Raldin, B.B., 2002. Metodologiya pochvennyih ekologo-geograficheskih issledovaniy i kartografii pochv [Methodology of soil ecological and geographical studies and soil mapping]. – Ulan-Ude: BNTs SO RAN, 2002. 232 p. [in Russian]

Kozyibaeva, F.E., 2014. Pochvyi Kazahstana. Problemyi i puti ih resheniya [Soils of Kazakhstan. Problems and solutions]. *Delovoy Kazahstan [Business Kazakhstan],* 25(422). p. 5. [in Russian]

Kravtsova, V.I., 2005. Kosmicheskie metodyi issledovaniya pochv [Space methods of soil research]. M.: Aspekt-Press, 180 p. [in Russian]

Le, Q. B., Nkonya, E., Mirzabaev, A., 2014. Biomass Productivity-Based Mapping of Global Land Degradation Hotspots. ZEF-Discussion Papers on Development Policy No. 193. University of Bonn.

Marynich, O.V., 1999. Transformatsiya stepnoy rastitelnosti pri dorozhnoy digressii [The transformation of steppe vegetation at the road digression]. Transformatsiya prirodnykh ekosistem i ikh komponentov pri opustynivanii [The transformation of natural ecosystems and their components with desertification]. Almaty: Naurzum. pp. 55-61. [in Russian]

Medeu, A., Akiyanova, F., 2011. LADA Regional Training for Asian Countries 10-18th April 2011 in Beijing institute of geography land degradation status and desertification assessment in Kazakhstan Almaty, 2011 [in Russian]

Muhametkarimov, K.M., Smailov, K.Sh., 2001. Izmenenie fiziko-himicheskih svoystv pochvyi pri razlichnyih rezhimah vyipasa na estestvennom pastbische [Changing the physical and chemical properties of the soil at various modes of grazing on natural pasture]. Nauchnyie osnovyi vosproizvodstva plodorodiya, ohranyi i ratsionalnogo ispolzovaniya pochv Kazahstana [Scientific bases of reproduction of fertility, protection and rational use of soil in Kazakhstan]. Almaty: Tetis, pp. 228-231. [in Russian]

Nikolayeva, V., 1969. Pochvy Sarkandskogo raiona Taldy-Kurganskoi oblasti i ikh agroproizvodstvennaya gruppirovka: otchet o NIR (zaklyuchitelnyy) [Soils Sarkand area Taldykorgan area and agricultural industrial grouping: research report (final)]. «Institut pochvovedeniya»: ruk. Nikolayeva V. (Vol. 44, pp. 250). Alma-Ata. [in Russian]

Pachikin, K.M., Erokhina, O.G., Altynbekova, N.A., Omirzakova, A.N., Kusainova, M.D., Nasyrov, R.M.,Adamin, G.K., Lukbanova, R.S., 2016. Interim statement of the Programme 212: "Evaluation of the current state of agricultural land in South-East Kazakhstan (for example, foothills the plains ridge Zhetysu) Registration number: 0115 RK02030, Inventory number: 0215RK02371. 66 p. [in Russian]

Pachikin, K.M., 1991. Pochvy i pochvennyi pokrov Severnogo Sklona Dzhungarskogo Alatau [Soils and soil cover of the North Slope of Jungar Alatau]: dis. kan. bio. nauk: 03.00.27/ Institut pochvovedeniya. – Alma-Ata. 264 p. [in Russian]

Rozanov, B.G., 2004. Morfologiya pochv [Soil Morphology]. – M.: Akademicheskiy proekt, 432 p. [in Russian]

Rubinshteyn, M.I., 1988. Bogarnyie pochvyi predgornyih ravnin Tyan-Shanya [Rainfed soil foothill plains of Tien Shan]. Alma-Ata: Nauka, 136 p. [in Russian]

Rubinshteyn, M.I., Tazabekov, T.T., 1985. Antropogennyie izmeneniya gumusa v pahotnyih pochvah Kazahstana [Anthropogenic changes of humus in arable soils of Kazakhstan]. Dostizheniya Dokuchaevskogo pochvovedeniya v Kazahstane [Achievements of the Dokuchaev Soil Science in Kazakhstan]. Alma-Ata: Nauka, pp. 33-43. [in Russian]

Schierhorn, F., Müller, D., Beringer, T., Prishchepov, A. V., Kuemmerle, T., Balmann, A., 2013. Post-Soviet cropland abandonment and carbon sequestration in European Russia, Ukraine, and Belarus. *Global Biogeochemical Cycles* 27(4): 1175–1185.

Smirnov, L.E., 2005. Aerokosmicheskie metodyi geograficheskih issledovaniy [Aerospace methods of geographical research]. – SPb.: Sankt-Peterburgskiy Universitet, 348 p. [in Russian]

Soil Survey, 1959. Pochvennaya s'emka [Soil survey]. M.: Izd-vo AN SSSR. 346 p. [in Russian]

Sokolov, I.A., 2004. Teoreticheskie problemyi geneticheskogo pochvovedeniya [Theoretical problems of genetic soil science]. - Novosibirsk: Gumanitarnyie tehnologii, 288 p. [in Russian]

Suleymenov, B.U., 2000. Povyishenie plodorodiya oroshaemyih serozemov Yuzhnogo Kazahstana [Increased fertility of irrigated sierozems South Kazakhstan]. Almaty: Sanat, 194 p. [in Russian]

Yashin, I.M., Shishov, L.L., Raskatov, V.A., 2000. Pochvenno-ekologicheskie issledovaniya v landshaftah [Soil and environmental studies in landscapes]. – M.: MSHA, 558 p. [in Russian]

Zaydelman, F.R., 1992. Estestvennoe i antropogennoe pereuvlazhnenie pochv [Natural and anthropogenic wetland soils]. SPb.: Gidrometizdat, 288 p. [in Russian]