Soils of nut-fruit forests in southern Kyrgyzstan – important ecosystems worthy of protection

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Abstract

The walnut forests of the Jalal-Abad region are located primarily in the northern slopes of the Fergana and Chatkal mountain ranges of the Tien Shan. The role of these organically evolved forest ecosystems changed from a pure food source to an important natural gene pool functioning as source of many domesticated fruit and nut trees that are widely cultivated in countries of the temperate zone. Natural walnut forests are characterised by an enormous biodiversity of the plant communities promoting the formation of highly fertile soils. The dominant soil type is brown soil. On seven different sites, several soil characteristics were investigated on soil profiles until 150 cm soil depth. The soil samples were investigated for macro and micro nutrient contents, humus content and its composition, as well as bulk density. The humus content of the top soils ranged from 2.4 to 18.5 % (soil organic matter). Up to 25.4 mg/100 g nitrogen, 4.9 mg/100 g phosphorus, and 54.6 mg/100 g potassium in plant available form were determined. Noticeable high contents of calcium (670 to 6,239 mg/100 g) and magnesium (up to 1,179 mg/100 g) were also determined indicating a good base saturation of these soils. Both nutrients are involved in the formation of stable mineral and organic-mineral soil aggregates which should maintain an increased water erosion resistance of these soils. Since an intensive progress of soil erosion by human impacts is to observe in the nut-fruit forest belt of Kyrgyzstan, in particular the enhancement of soil fertility and its subsequent maintenance are of utmost importance..

Keywords: *Kyrgyzstan, mountains, nut-fruit forests, agrochemical soil properties, humus content, soil erosion*

Zusammenfassung

Die Böden der Nusswälder in Süd-Kirgisien – schützenswerte Ökosysteme von besonderer Bedeutung

Die Nusswälder der Jalal-Abad-Region erstrecken sich vorrangig auf den Nordhängen des Fergana- und des Chatkal-Gebirges im Tien Shan. Die Funktion der historisch gewachsenen Waldökosysteme hat sich geändert: dienten sie früher vorrangig der Nahrungsbeschaffung, haben sie heute besondere Bedeutung als natürlicher Ursprung zahlreicher Obst- und Nusssorten, die in vielen Ländern der gemäßigten Klimazone kultiviert werden. Diese Waldökosysteme zeichnen sich durch Artenreichtum aus, die Vielfältigkeit der Pflanzenwelt trägt zur Bildung von sehr fruchtbaren Böden bei. Braunerden sind die vorherrschende Bodenart. An siebem Standorten wurden an Bodenprofilen bis zu einer Tiefe von 150 cm Nährstoffe, Humusgehalt und -zusammensetzung sowie die Lagerungsdichte bestimmt. Der Humusgehalt im Oberboden lag zwischen 2,4 bis 18,5 % (organische Bodensubstanz). An pflanzenverfügbaren Nährstoffen wurden bis zu 25,4 mg/100 g Stickstoff, 4,9 mg/100 g Phosphor und 54,6 mg/100 g Kalium gemessen. Die Böden waren gut basengesättigt, sehr hohe Kalzium (670 bis 6.239 mg/100 g) – und Magnesiumgehalte (bis zu 1.179 mg/100 g) wurden nachgewiesen. Beide Elemente sind an der Entstehung von stabilen organo-mineralischen Bodenaggregaten beteiligt und tragen damit zur Erosionsminderung bei. In den untersuchten Regionen sind zunehmend Bodenverluste durch menschliche Einflüsse zu beobachten, deshalb sind Maßnahmen zur nachhaltigen Verbesserung der Bodenfruchtbarkeit und deren nachfolgende Erhaltung von größter Bedeutung.

Schlüsselwörter: *Kirgistan, Gebirge, Nuss-Frucht-Wälder, agrochemische Bodeneigenschaften, Humusgehalt, Bodenerosion*

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1 Introduction

Kyrgyzstan is a mountainous country located in the center of the Turan, the Central Asian and the Kazakhstan soil and climate region. The nature of Kyrgyzstan represents a high-altitude mountainous ecosystem. The overwhelming majority of the territory is located at an altitude of 500 to 5,000 meters above sea level (m a.s.l.). In the Kyrgyzstan report prepared by the Scientific Information Centre Aral of the Sustainable Development Commission IFAS (2003), the grouping of soil types was described as follows: gray soil, gray brown and chestnut colored soils, and chernozem are predominant in inter mountainous hollows. Naked and gray desert steppe soils and chestnut steppe soils are to find in the outside part of the mountains. Gray, gray brown, gray dark brown, chestnut-hued and brown soils are typical for the mountainous slopes which are situated at 1,000 to 2,500 m a.s.l. Black soils, brown soils, black-brown nut tree forest soils, black fir tree forest soils, and dark colored juniper forest soils are spread throughout the steppe-forest part of the mountains (2,100 to 3,200 m a.s.l.). Steppe and meadow (plain) soil are characteristic for the Subalpic Mountains (3,100 to 4,500 m a.s.l.). Turfy half peat-bog and turfy tundra-like peat bog soils are the main soil types located in the alpine area. Meadow, meadow bogged, bogged, and peat bogged soil are typical for the inside zoning area (IFAS, 2003).

The Jalal-Abad region covers 33,647 km^2 in the southwest part of Kyrgyzstan. It is a land of mountain lakes, walnut forests and natural mineral springs. Kyrgyzstan is one of the most sparsely wooded countries in Asia. Only 6.97 % of the Kyrgyz soil surface is covered by forests (Grisa et al., 2008). Unique forests of walnut (*Juglans regia* L.) and other fruit-bearing tree species grow in the southern part of Kyrgyzstan.

Natural walnut woods grow on the lower slopes of the Fergana and Chatkal ridges of the Kyrgyzstan Tien Shan range at elevations of 1,500 to 2,200 m a.s.l. On two isolated large massifs (Arslanbop-Kokart and Hodja-Atynckyi), they extend over an area of about 630,000 ha. These forests are recognized by the UNESCO as a world natural heritage site, collaboratively supported by German scientists (Zhukov, 2004), Kyrgyz scientists and foresters, and the Volkswagen Project. The Kyrgyz Republic has ratified the Convention on the Protection of World Cultural and Natural Heritage in 1996.

In the past, these forests served as a food source for primitive human communities, it is assumed that they are one of the centers of origin of cultural fruit plants (Roichenko, 1954). Beer et al. (2008) investigated the vegetation history of the walnut forests in Central Asia. Their results suggest that in most of the regions *Juglans regia* stands were growing since more than 1,000 years. Therefore, it is widely recognized to guard these relic forest ecosystems against further depletion, and to restore their natural resources as a significant gene pool in the century.

The walnut-fruit forests are characterized by a considerable biodiversity. These forests are the source of many domesticated fruit and nut trees that are cultivated widely in countries of the temperate zone. The flora is composed of 5,000 species, including 180 tree species, many endemic to this area. The walnut (*Juglans regia* L.) is the dominant species, other including species are Kyrgyz apple (*Malus kirghisorum* Theodet. Fed.), Niedzwetzky apple (*Malus niedzweckiana* Dick.), pistachio (*Pistacia vera* L.), almond (*Amygdalus communis* L.), plum (*Prunus domestica* L.), cherry plum (*Prunus divaricata* L.), Turkestanic hawthorn (*Crataegus turkestanica* A. Pojarn), Turkestanic maple (*Acer turkestanicum* Pach.), and white poplar (*Populus alba* L.). The fauna of the natural forests in the Jalal-Abad region includes 160 species of birds and 34 species of mammals (such as deer, bear, lynx, wolves, foxes, badgers, even snow leopards) (Aiupov and Junusov, 2011).

The conditions beneath the walnut forest canopies promote improved soil properties. Specifically, a characteristic indicator for the black-brown soil is the high humus content that composes up to 10 to18 % in the upper part of the humus horizon, and 3 to 4 % in the lower part. The high humus content in black-brown soils is attributed to the continuous organic matter input from the forest litter. According to Roichenko (1960), walnut forest soils annually receive more than 7 tons of above-ground organic matter per hectare: about 4 t/ha leaf litter and more than 3 t/ha dried grass.

Former investigations of forest soils in the Jalal-Abad region where abstracted by large regions. But, as mentioned above, the main massifs of walnut forests are spread throughout the Jalal-Abad region. Therefore, the primary object of this research project was to study the soil properties of the Kara-Alma and Arslanbop natural nut-fruit forests more detailed and to document their changes in consequence of anthropogenic impacts. In recent years, for instance, increasing mudflow processes are to be observed in the foothill areas. Such erosion processes are decisively damaging the sensitive nut-fruit forest ecosystem. Therefore, it is necessary to maintain the upper soil layer of these forest massifs in a stable, adequate fertility status to inhibit further soil degradation within the slopes. In the present study, humus content, macro- and micro-elements, and bulk density of different soil layers until 150 cm depth were evaluated. These selected chemical and physical soil properties are decisive for the soil fertility; maintenance of optimum soil conditions contributes to the conservation and rehabilitation of forest ecosystems.

2 Material and methods

2.1 Study area

2.1.1 Soils

In the frame of this project, the principal soil types naturally occurring in the nut-fruit forest region of Southern Kyrgyzstan were analyzed. These natural woodlands are located between 40°5´ to 42°0´N and 71°45´ to 73°40´E on the western and south western slopes of the Fergana and Chatkal ridges of the south western Tien Shan.

Considering the soil on the vertical zonation, there are sierozem and the mountain dark sierozem soils, the brown soils, and the mountain-forest black-brown soils. Mountain dark sierozem soils are to find in the foothills and adyrs, in a belt of pistachio forests at an elevation of 800 to 1,000 m a.s.l. Mountain brown soils are located in the belt of apple tree and nut-fruit woods at heights of 1,000 to 2,000 m a.s.l. (Figure 1). Mountain black-brown soils under nut-fruit and apple forests extend to an elevation of 1,000 to 2,200 m a.s.l. (Figure1).

Figure 1
Nut-fruit forests in the Jalal-Abad region and characteristic soil profiles: brown soil, Charbak (left) and black brown soil, Aral (right), Kyrgyzstan, 2007

An overview on the characteristics of the different sampling areas is given in Table 1.

2.1.2 Climate

The Jalal-Abad region of Kyrgyzstan is characterized by a pronounced continental subtropical climate. The summer period is hot and dry, during the cold winter months the temperatures fall down below the freezing point. Maximum precipitation falls in winter and spring. Depending on the altitude, temperature conditions can be divided into four altitudinal climatic zones: high (3,100 to 3,800 m a.s.l.), middle-mountain (2,200 to 3,100 m a.s.l.), foothill (1,500 to 1,800 m and 2,000 to 2,400 m a.s.l.) and mountain plain (600 to 800 and 1,200 to 1,500 m a.s.l.). The average climate data are shown in Figure 2 and 3. The annual courses of temperature and precipitation are calculated for 9 years from data of the Jergetal Meteorological Station of the Jalal-Abad region which is located at 1,205 m a.s.l. The average January temperature is -4.0 °C, and the average July temperature is +23.2 °C. At an elevation of 1,000 to 2,000 m a.s.l., the annual precipitation amounts 700 to1,000 mm. At an elevation of 1,000 to 2,200 m a.s.l. the amount of precipitation exceeds 1,000 mm per year. The climatic conditions with high precipitation and a moderately cold winter period are beneficial for a sustainable development of natural nut-fruit forests. The upper soil layer of these forest ecosystems is intensively rooted by the different trees and undergrowth species. Therefore, in these areas, the number of erosive mudflow processes and landslides is relatively low.

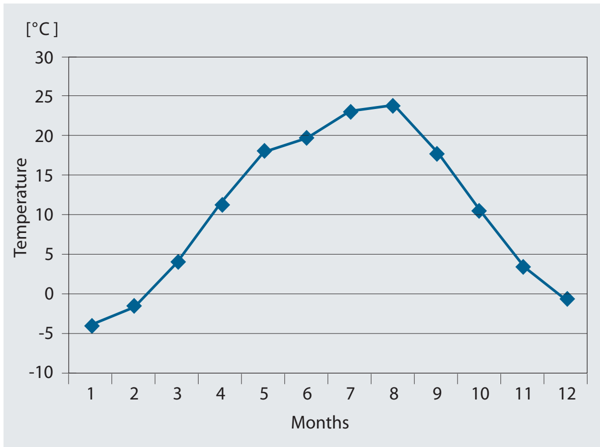

Figure 2
Monthly average of temperature in the nut-fruit forest area, Jalal-Abad region, Kyrgyzstan (mean values, 2000 to 2008)

Table 1
General characteristics of the study areas

Sampling site	Exposition	Slope gradient [°]	Average altitude [m a.s.l.]*	Soil type	Main tree species
Zindan	southern slope	12	1,830	black brown	walnut, Kyrgyz apple, plum, cherry plum, white poplar
Aral	south-east slope	20	1,750	dark brown	
Charbak	south-west slope	15	1,290	brown	
Balykty-Sai	southern slope	24	1,550	brown	
Kara-Alma forest enterprise	northern slope	28	1,580	brown soil	
Suzak forest area	northern slope	20	853	sierozem	pistachio
Suzak arable land	north-east slope	0.3	732	sierozem	cotton

* meters above sea level

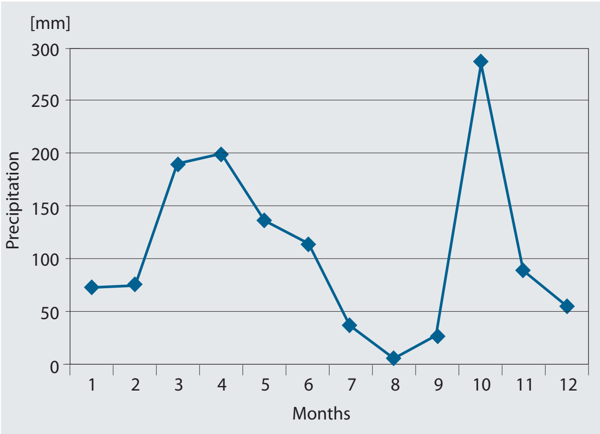

Figure 3
Annual rainfall distribution in the nut-fruit forest area, Jalal-Abad region, Kyrgyzstan (mean values, 2000 to 2008)

2.2 Sampling

In June 2007, the first set of soil samples were collected from each of the Kara-Alma and the Arslanbop ecosystems (Zindan, Aral, Charbak, and Balykty-Sai) (Table 1). The soil samples were taken in 10 cm increments until soil depths of 130 or 150 cm, respectively. In 2009, a second set of soil samples for determination of humus fractions was taken from two forest sites (Suzak, Kara-Alma) as well as an arable site (Suzak) (Table 1). The several soil horizons were characterized at prepared soil profiles (Figure 4), the soil samples were air dried, sieved (mesh size 2 mm), finely ground, and stored in closed bags until chemical analysis.

Figure 4
Preparation of a soil profile for soil layer characterization and soil sampling, nut-fruit forest, Kara-Alma, 2007

Based on the bilateral scientific cooperation between Kyrgyzstan and Germany from 2008 to 2012, the soil analyses were conducted in both countries. Readily soluble nitrogen, plant available phosphorus and potassium, total humus content, pH value, and bulk density were determined at the Institute of Nut and Fruit Growing, Science Academy of the Kyrgyz Republic in Jalal-Abad. Total macro and micro nutrients as well as humus fractions were analyzed at the German Institute for Crop and Soil Science, Julius Kühn-Institute, Federal Research Centre for Cultivated Plants in Braunschweig.

2.3 Soil analyses

2.3.1 Total carbon and nitrogen content

The total carbon (C_t) and nitrogen (N_t) contents were analyzed in air-dried, sieved soil samples after dry combustion in the presence of oxygen (elementary analysis) by a Vario MAX CN Analyzer system.

2.3.2 Plant available nitrogen

The readily soluble nitrogen (NO_3) was analyzed by the Turin and Kononova method (Radov et al., 1971). Each 20 g of prepared soil were suspended in 100 ml H_2SO_4 for 16 hours. After filtration, a 0.1 g Fe and a 0.8 g Zn were added, then the filtrate was heated to 100°C. After cooling, 5 ml H_2SO_4 were added to the solution. That followed, the solution was evaporated until appearance of dark-hued SO_2 fumes. To the residual liquid, 2.5 ml $K_2Cr_2O_7$ (10 %) were added, then the mixture was boiled until its color changed to green. After addition of 20 ml NaOH (50 %), the extracted ammonia was stripped by reheating, and transferred into 0.02 N H_2SO_4, using Congo red as indicator. The available nitrogen was afterwards estimated assuming that 1 ml of 0.02 N H_2SO_4 corresponds to 0.28 mg N.

2.3.3 Plant available potassium and phosphorus

Plant available potassium (K) and phosphorus (P) were extracted in Machigin solution (Radov et al., 1971). Each 10 g of prepared soil were suspended in 200 ml of 1 % NH_4CO_3 solution by shaking for about five minutes. The suspension was stored for 24 hours shaking every six hours, and then filtered through a dense fluted filter paper. The K content of the filtrate was directly measured by flame-photometry. For the P analysis, the filtrate was decolorized by diluted H_2SO_4, and 0.5 N $KMnO_4$ solutions. After boiling for two minutes, 1 ml of 10 % glucose was added, the solution was cooled down, and then neutralized by 10 % Na_2CO_3 solution in the presence of an indicator. 50 ml of colorless mixture were spiked with 2 ml of molybdenum reagent solution, and 0.5 of ml stannous chloride. The P content was measured calorimetrically.

2.3.4 Total nutrient content

The total content of calcium (Ca), magnesium (Mg), sulphur (S), manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) were determined by mass spectrometry after aqua regia digestion of the soil samples. For nutrient extraction each 5 g of homogenized, air dried soil were mixed with 25 ml of the extractant in round-bottom flasks, and stored in a fume cupboard for twelve hours. Then, the suspension was boiled under reflux for two hours. After cooling, the reflux was rinsed by 30 ml of double distilled water into the reaction vessel.

Afterwards, the solution was transferred into 100 ml volumetric flasks, filled up to 100 ml with double distilled water, then filtered into 100 ml PE-bottles using fluted filter papers.

2.3.5 Humus content

The total humus content (SOM) was determined corresponding to the Turin method (Arinushkina, 1980). The organic matter was oxidized using a mixture of 0.4 N $K_2Cr_2O_7$ and H_2SO_4 (1:1, vv), and back-titrated with Mora salt ($FeSO_4$). Based on the measured content of readily oxidizable organic carbon the amount of total organic carbon was calculated.

2.3.6 Humus quality

From a forest sierozem site, an arable sierozem site (Suzak area), and a forest brown soil site (Kara-Alma area), respectively, selected soil samples were investigated on their humic and fulvic acid contents. The agrochemical properties of these soils are comparable with that of the soils used for the other investigations.

The humic and fulvic acid contents were determined in air-dried, sieved soil samples accordingly to Faithfull (2002). After separation of fulvic and humic acids from the insoluble humins by 0.5 M NaOH, and following centrifugation, the humic acids were precipitated by adjusting the pH value of the supernatant to 2.0 with 6 M HCl, and once more centrifugation. Afterwards, the fulvic acid content was photometrical measured in the supernatant. The content of humic acid was gravimetrical determined after re-drying and incineration of the residue.

2.3.7 Soil reaction

The pH-value was potentiometrically detected in water in a proportion of 1:2.5 (Arinushkina, 1980).

2.3.8 Bulk density

The soil bulk density was determined by the Kachinski method (Plushin and Vernikovskaia, 1974) on core sample sections (5 cm diameter) corresponding to the several soil horizons.

3 Results and discussions

An overview on the nutrient state, the total humus content as well as the soil reaction of the investigated soils is given in Table 2. The highest humus contents were found in the upper layer (0 to 20 cm) of the Zidan forest soils. The humus-rich layers reached till soil depths of 80 cm. Although, the humus content gradually decreases by soil profile depth, because of the high total humus content in these soils 0.7 up to 3.1 % humus were still found at 100 cm depth.

To a depth of 100 cm, the N, P, and K contents tend to be higher than that of the other investigated forest sites. In the top horizons of the soils, an accumulation of mobile P and K compounds were observed. The nutrient quantity gradually decreases with depth at all sites with the highest amounts in the A horizons. Below 100 cm depth very low N, P, and K contents were measured.

Table 2

Soil nutrient state, total humus content, and soil reaction of the sampling sites, given for selected soil layers, Kyrgyz nut-fruit forests, 2007

sampling site	soil depth	plant available nutrients			humus content	pH
		NO_3-N*	P	K		
	[cm]	[mg/100g]			[%]	
Zindan	0 - 10	25.4	4.9	54.6	18.5	7.6
	10 - 20	22.7	3.8	38.9	11.4	7.5
	20 - 40	21.8	2.5	37.8	9.5	7.5
	40 - 100	16.1	1.0	23.1	3.1	7.6
	100 - 130	4.1	0.5	8.6	0.6	8.4
Aral	0 - 10	20.6	3.1	40.8	10.3	8.6
	10 - 20	19.7	1.5	31.4	6.2	8.7
	20 - 40	16.3	1.2	26.8	4.4	8.6
	40 - 100	9.2	0.5	13.2	1.8	8.8
	100 - 150	2.2	0.4	8.3	0.6	8.8
Charbak	0 - 10	14.6	3.1	41.2	5.7	8.6
	10 - 20	11.7	1.5	31.9	3.4	8.7
	20 - 40	9.9	1.2	26.6	2.0	8.6
	40 - 100	6.8	0.5	13.4	0.8	8.8
	100 - 150	2.1	0.3	7.4	0.5	8.8
Balykty-Sai	0 - 10	10.2	3.8	44.1	4.8	8.7
	10 - 20	10.0	3.0	24.8	2.4	8.7
	20 - 40	8.2	1.8	17.8	1.7	8.9
	40 - 100	2.9	0.8	13.2	0.7	9.1
	100 - 130	1.2	0.4	11.3	0.3	9.1

* Readily soluble nitrogen analyzed by the Turin and Kononova method

The vertical nutrient allocation within the soil profile indicates the suitable drainage conditions of these forest soils. The nutrient distribution pattern is closely correlated with the humus content in the soil profile (Table 2). Concerning the aspect of an annual precipitation up to1,100 mm, it can be assumed that nutrient losses by leaching are only minimal in these Central Asia districts due to the strong bonding ability of the organic substances in the different soil layers. Gajić et al. (2010) analyzed long term effects of land use changes on SOM content and aggregate stability of Serbian noncarbonate silty-clay Fluvisols. In the top soil of native forests, SOM contents of 7.7 % (0 to 10 cm), 3.3 % (10 to 20 cm), and 2 % (20 to 30 cm) were determined. In comparison, the SOM contents of corresponding soil layers of arable land were decreased up to 41 % .In collaboration with the rich plant biodiversity, the beneficial climate regime of the studied region promotes the development of high fertile mountain forest black-brown soils. The litter layer under the canopy of the walnut-fruit forests mainly consists of a loose plant felt with a depth till 5 cm. According to Karabaev (1993), an annual average amount of 4.6 t/ha forest fall is to estimate. Its main part is foliage, yearly up to 3.7 t/ha of decomposed leaves contribute to the sustainable formation of an upper soil layer with high content of organic matter. However, due to intensive decomposition processes affected by weather and soil organisms, the N and P contents of this layer are 1.5 to 2 times less than that of the original plant material (e.g. leaves) (Karabaev, 1993). In addition, continuous decomposition processes in the rooting zone significantly contribute to the improvement of soil fertility. Along with the soil stabilization by organisms, accumulated sesquioxides (especially metal oxygen compounds like Fe, Mn, or Mg oxides), and silica play an important role in the formation of water-stable soil structures. According to Matveev and Karabaev (1986), around 18.5 % of the total humus content are to found in wood felt of these soils, and about 12.8 % in the humus accumulative horizon. The organic substances consist to a large part (64.3 %) of hydrolyzed humus compounds.

But also, the soil texture has a determining function for water and nutrient bonding (Schroeder and Blum, 1992). Furthermore, the dense plant cover of the undergrowth which is characteristic for these nut-fruit forests in conjunction with the closed forest canopies being distinguished by high interception of rainfall has an important reducing influence on nutrient losses.

According to Mamytov et al. (1971), in the brown soils up to 46 % of the humic acids are newly formed by decomposition processes. The same also applies for fulvic acids, about 41 % of the total amount result from recent rotting processes. The amounts of newly formed humic and fulvic acids in the observed soils depend not only on the large annual supply of organic material by litter fall and rooting (55.5 t/ha), particularly the hydrothermal conditions of the middle mountains belt effect the chemical composition of the SOM.

Studies carried out by Roichenko (1970) using the method of Kononova and Belchikova (1961) showed that in the humus compartment of typical mountain brown forest soils humic acids are predominant, the fraction of fulvic acids is comparatively low. Similar results were obtained by Glazovskaya (1953) for brown soils, located in the Bostandyk's district in the western Tien Shan, and by Andzhaparidze (1964) for mountain-forest brown soils of Georgia. Apparently, the formation of humic compounds is strongly dependent on the amount of decomposable organic raw material in the upper soil horizons.

According to Geissler (1999), chernozems are very fertile soils due to their composition of humic substances. These soils are affected by high humic acid contents; the contents of fulvic acids are relatively low. In soils, the humic acids act as natural ion exchangers which absorb alkaline nitrogen compounds, and release the plant available nitrogen again by substitution of metallic cations (Geissler, 1999; Schroeder and Blum, 1992).

For the Kyrgyz soils included in the present study, land use management effects on the proportion of humic acids and fulvic acids, but also on the absolute quantity of these humus fractions could be shown (Table 3).

Table 3

Total nitrogen content (N_t), total carbon content (C_t), humic and fulvic acid contents in the A and B horizons of selected Kyrgyz areas; forest: Suzak, Kara-Alma, arable land: Suzak, 2009

sampling site (soil type)	soil depth [cm]	N_t [%]	C_t [%]	humic acids [mg/100g]	fulvic acids [mg/100g]	humic acids/ fulvic acids
Suzak forest area (sierozem)	0 - 14	0.10	2.29	160	67	2.4
	14 - 30	0.08	2.07	86	45	1.9
	30 - 50	0.07	2.21	76	31	2.4
Suzak arable land (sierozem)	0 - 14	0.07	2.66	65	29	2.2
	14 - 30	0.06	2.52	70	20	3.5
	30 - 50	0.15	2.54	74	22	3.4
Kara-Alma forest enterprise (brown soil)	0 - 14	0.31	3.08	662	158	5.2
	14 - 30	0.24	2.36	439	110	4.0
	30 - 50	0.12	2.18	78	131	0.6

Comparing the both different land use management systems in the Suzak area, in forest soils the total N content decreased with depth, in arable land the highest N content was detected in the 30 to 50 cm layer, which could be attributed to nutrient leaching by precipitation. Maximum total C contents were observed in the upper 14 cm of all investigated sites. Rusanov et al. (2012) compared properties of chernozem soils originating from forest massifs and steppe zone, respectively, of the Ural region. Decreasing humus reserves with increasing distances from the forests were found depending on land use management and the composition of the plant cover. Also the fractional-group composition of the SOM was changed; the humic acid/fulvic acid ratio became larger. Also for Mediterranean forest soils, Traversa et al. (2011) observed changing chemical and spectroscopic properties of humic acids depending on the composition of the plant cover and the resulting parent litters. Comparing the soil carbon and nitrogen cycle under different climate and soil scenarios, Battle-Aguilar et al. (2011) found higher C and N levels in forest soils than in agricultural soils as a result of the higher litter decomposition. Moreover, the SOM turnover runs less seasonal depending in soils of forest stands. Due to their different physical properties, seasonal climate-induced frequency changes in water saturation were alleviated, with matching changes in C and N contents.

The brown soil of the forest in the Kara-Alma region was characterized by a large proportion of humic acids in the upper 30 cm with a comparatively wide humic/fulvic acids ratio.

The fulvic acids were predominating in deeper soil layer (30 to 50 cm). Obviously, fulvic acids tend to migrate down the soil profile outweighing the number of humic acids in the lower soil horizons (Table 3). On Suzak arable land, only minor differences in humic and fulvic acid quantities were measured in the several soil layers. The humic acids slightly decrease with depth, therefore a wider humic/fulvic acids ratio were found below a soil depth of 14 cm. On the Suzak forest sierozem, by contrast, in all soil layers nearly similar humic/fulvic acid ratios were found. Studies comparing the SOM contents in soils of sites under different land use confirm these results. In soils of forest sites increased lignin contents, higher C/N ratios, and lignin/N ratios were determined, resulting in enhanced accumulation of SOM in comparison to pastures or arable land (Lavahun et al., 1996; Melillo et al., 1989). The Ca bonding of large portions of humic acids in combination with high humidity of forest soils was described by Łabaz et al. (2011) as important cause for SOM stabilization. Based on the results of an eight-year field experiment to study the long-term effects of litter quality and quantity on pH and nutrient content of a forest soil in North Hungary, Toth et al. (2011) underlined the close connection between litter production and soil fertility. Decreasing inputs of organic matter induced by unsustainable forest management or climatic change would lead to obvious soil degradation caused by reduced Mg and Ca inputs and acidification.

In the current study, the total nutrient state was determined for soils of the Zindan, Aral, Charbak, and Balykty-Sai forest sites. The sampling was carried out until soil depths of 150 cm, 130 cm, and 80 cm, respectively, depending on the soil body.

The nutrient contents given in Figure 5 were calculated as averages of separately analyzed 10 cm-soil sections. Within the investigated soil horizons, the Mg and S contents were comparatively equalized. At all forest sites, in contrast, the Ca contents showed distinct differentiations; the Ca contents were considerably increased in deeper soil layers in consequence of soil genesis.

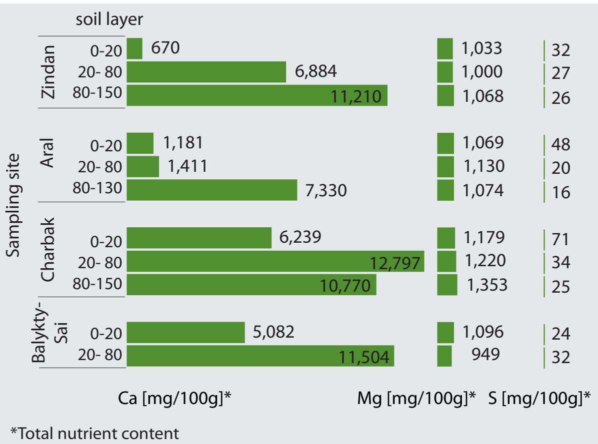

Figure 5
Distribution of macro nutrients (Ca, Mg, and S) within the soil profile of selected Kyrgyz nut-fruit forest sites (averages of 10 cm-soil sections, sampling in 2007)

The result is a good base saturation of the investigated soils. Calcium and magnesium are involved in the formation of mineral and organic-mineral water-stable structural aggregates and also increase the erosion resistance of the upper soil layer. The content of several micro nutrients (Mn, Fe, Cu, and Zn), and its allocation within the soil horizons are presented in Table 4.

Table 4
Micro nutrient contents (Mn, Fe, Cu, Zn) in the soil profile of selected Kyrgyz nut-fruit forest sites (averages of 10 cm-soil sections, sampling in 2007)

sampling site	soil depth [cm]	Mn	Fe [mg/100g]*	Cu	Zn
Zindan	0 - 20	78	3,701	3.3	8.5
	20 - 80	61	3,149	3.0	7.0
	80 - 150	53	2,657	2.5	6.1
Aral	0 - 20	73	3,276	3.5	8.8
	20 - 80	83	3,799	4.0	9.2
	80 - 130	83	3,464	3.9	7.2
Charbak	0 - 20	60	2,648	3.0	7.9
	20 - 80	50	2,453	2.4	5.8
	80 - 130	54	2,645	2.5	6.2
Balykty-Sai	0 - 20	76	3,625	3.5	8.3
	20 - 80**	53	2,727	2.6	6.3

*Total micro nutrient content
**Samples of 80 to 130 cm were lost

There was a slight increase of Zn fixed in the upper layer of the studied soils; Mn and Cu were also enriched in the upper soil layers where organic matter is accumulated (Table 4). It is well documented that there is a significant positive correlation between organic matter and the plant availability of micronutrient cations (Heredia et al., 2002), since metal ions associated with low molecular weight humic substances will released to the soil solution by microbial decomposition (Dabin, 1971; van Wambeke, 1995).

While organic matter is one of the major soil substances which are responsible for metal retention processes due to its surface characteristics (Sutherland et al., 2000), it can be assumed, that the high amounts of iron detected in these fertile mountain-forest soils (Table 4) considerably contribute to erosion prevention. This element creates strong organo-mineral compounds with humic substances (Tipping, 1981). In general, the concentrations of the macro and micro nutrients determined in the investigated soils are within the range of commonly found soil nutrient levels (Finck, 2007; Müller, 1980). The Ca, Mg, and especially the Fe concentrations ranged around the upper limit, whereas the Zn and Mn concentrations were comparatively low (Figure 5, Table 4).

The studied soils could serve as standard model of fertility for other soils of the Fergana valley. High humus content

(Table 2) and a good structured soil profile (Table 5) contribute to optimum physical properties, which are accompanied by porosity, high water permeability and moisture capacity.

In the belt of nut-fruit forests, the landscape geomorphology is the main factor that causes intensive erosion and determines its course: the altitude of the erosion sensitive sites (up to 3,000 m a.s.l.), steep slopes, and extreme cuts by river valleys, ravines and canyons. Induced by the prevailing climatic conditions large soil surfaces are exposed to high precipitation. In combination with the relief, surface destruction and soil erosion occurs mainly on the slopes. Their intensity is directly dependent on the slopes' shape, steepness, length, and aspect. This was shown for the studied area by Samusenko and Kojekov (1989). The process of soil degradation is more intense on the southern slopes of the Balykty-Sai and Kara-Alma forest ecosystems than on the northern and western slopes of the same tracts.

Greater stability against soil erosion and nutrient leaching is found on the north, northwest and west slopes where increased forest litter enriches soil organic content and the climatic conditions are humid. Due to less favourable temperature regimes, the process of decomposition is weakened. On the southern, less humid, but sunnier slopes, the litter production by the forest canopies and the undergrowth is reduced by the lower annual precipitation in these areas. Together with encouraging temperature conditions, the decomposition processes are more accelerated, the risk of soil structure damages is increased, and consequently the soils of the southern slopes are less erosion resistant (Samusenko and Kojekov, 1989).

Besides the above-mentioned parameters conditioned by geographic and climatic facts, vegetation forms and canopy closeness are crucial for the erosion susceptibility of the Kyrgyz mountain regions. Where the slope areas are covered by nut-fruit stands the risk of water erosion by surface runoff will be reduced due to the higher water permeability of these forest soils, and concomitant sediment inputs into the subsurface water bodies will be abated (Sakbaeva et al., 2009).

Certainly, the walnut forest ecosystems are always influenced by another important impact: the forest use by the humans living in these regions should not be underestimated. Just in the Jalal-Abad district alone, five forest stands with increasing exploitation by the human population were identified by Novikov (2006). Research studies have shown that haphazard exploitation, overgrazing, firewood harvesting, and unjustified felling of walnut-fruit stands caused irreversible damages to these sensitive ecosystems. The natural self-seeding ability will be suppressed, the soil and water protective functions will be lowered, and the micro-climatic and hydrological conditions will change. Hence, a progressive degradation of walnut-fruit forests is to expect with a sharp decrease in their productivity. The current area of these walnut-fruit forests is 47,000 hectares, large areas of which are in critical state (Müller and Sorg, 2001). Unregulated grazing is a main factor contributing to the development of soil erosion. On the slopes, livestock trails are formed by excessive used pastures. Often the trails cut across the hills in all directions, de-stroying vegetation and forming well-showed travel prisms. It is known that these prisms are most susceptible to erosion especially on weakly vegetated, steep slopes (Avazov, 2008). Up to 50 to 60 % of the soil is washed away on these hillsides. The upper humus horizon is eroded first, followed by the underlying more friable horizons.

Studies of Härdtle et al. (2005) under stationary and laboratory conditions have identified the differences between eroded and non-eroded soils. Eroded dark brown soils are deprived of a 15 to 20 cm layer of humus horizon. Non-eroded soils contain 11 to 13 % humus in the upper horizon, eroded soils 1 to 2 %. The carbonate content (8 to 12 %) and the alkalinity of eroded soils are significantly increased. Slightly acidic soils are even more likely to sustain varied forest vegetation than alkaline soils (Härdtle et al., 2005).

The current study showed that long-term erosive processes result in considerable changes of bulk density up to 30 cm soil depth (Table 5). A tendency to soil compaction was also observed in the deeper soil horizons (below 30 cm), both for the dark brown soil in Aral and for the black-brown soil in Zindan. But, the detected differences between eroded and non eroded soils were only marginal for these soil layers. Studies of soils in the Serbian Kolubara Valley indicated comparable results: differences of bulk density by land use changing were only significantly verifiable for the upper 20 cm of the soils (Gajić et al., 2010).

Table 5

Bulk density [g/cm^3] of eroded and non eroded mountain wood brown soils of Kyrgyz nut-fruit forests, profile depth 0 to 150 cm (sampling in 2007)

profile depth	bulk density [g/cm^3]			
	dark brown soil (Aral)		black-brown soil (Zindan)	
[cm]	non eroded	eroded	non eroded	eroded
0 - 5	0.82	1.24	0.78	1.20
5 - 10	1.01	1.27	0.96	1.25
10 - 20	1.06	1.38	1.00	1.36
20 - 30	1.15	1.39	1.07	1.35
30 - 40	1.24	1.41	1.28	1.38
40 - 50	1.36	1.45	1.35	1.39
50 - 60	1.39	1.47	1.38	1.38
60 - 70	1.37	1.45	1.38	1.39
70 - 80	1.36	1.41	1.39	1.39
80 - 90	1.36	1.35	1.37	1.36
90 - 100	1.37	1.36	1.35	1.36
100 - 110	1.32	1.33	1.35	1.35
110 - 120	1.33	1.35	1.34	1.37
120 - 130	1.38	1.39	1.36	1.37
130 - 140	1.39	1.40	1.37	1.39
140 - 150	1.39	1.41	1.35	1.42

The bulk density determined in the upper layers of non-eroded black-brown soil indicates a loose structure until a depth of 20 to 30 cm which differs significantly from the markedly compacted top soil of the eroded dark brown soil. The physical characteristics of soils have high ecological significance, since they largely determine the metabolic processes between the soils and the other components of the ecosystem. Investigative studies (Mamytov, 1982; Liverovskii, 1987; Karabaev, 2000) have shown, that soil properties are largely defined by their resistance to erosion (humus content, the presence and volume of forest litter, carbonate content, volume weight, etc.) and deteriorate with increasing degrees of erosion.

5 Conclusions

The establishment of further nut plantations in more regions of the natural nut-fruit forest belt of Kyrgyzstan would surely enhance soil fertility and biodiversity while protecting the environment of this district. In particular, expansion should favour highly fertile mountain black-brown soils where adequate precipitation will allow the cultivation of nut plantations without additional irrigation. This approach does not contradict the requirements of a world natural heritage area, particularly if seeds from old-growth native nut trees would be used and the development of a broad spectrum of native plant species would be carefully maintained. Considering the current European wholesale price of cleaned nuts (0.90 to 1.48 Euro/kg) and kernels (2.13 to 5.49 Euro/kg) such land use management would encourage the economic development of this region (Bourne, 2012). Native nuts harvested in the Kyrgyz natural nut-fruit forest regions, are an ecologically pure food product and a valuable raw material for the pharmaceutical industry. In these habitat systems, soils are reliably protected from erosion incidents and unfavourable human impact, respectively. The fertility of black-brown soils will be restored over the years (Bourne, 2012). Highly fertile soils are the outcome providing productive nut-fruit forests, which are the basis to exhaust the high ecological, economic, and recreational potential of the whole region.

Based on this knowledge, both in the mountain brown soils belt, and in the dark sierozem soils belt of the south-western Tien Shan, industrial nut-fruit plantations should be also established. In these regions the natural chemical and physical soil properties provide optimal conditions for growing walnuts when adequate moisture is supplied. Therefore, the simultaneous implementation of drip irrigation systems is necessary for a profitable establishment of such ecologically valuable nut-fruit forest stands. In the long term, the yearly amount of organic plant residues produced by litter fall and undergrowth will contribute to an increasing humus quantity in the top soil (Karabaev, 1993).

The extension of irrigated nut-fruit plantations could be a helpful method to protect more erosion sensitive areas currently not used as farm land against soil degradation and soil losses. Eligible regions are mainly located in the foothills of the Fergana and Chujsky hollows. In conclusion, the improvement and maintenance of soil quality will enhance the life quality of the residents if the established forest stands will be sustainable managed in consideration of economically effective and ecologically responsible aspects.

Acknowledgments

This study was jointly funded by the German Academic Exchange Service (DAAD, Germany).

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