Research Article

Interactions of Soil Order and Land Use Management on Soil Properties in the Kukart Watershed, Kyrgyzstan

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Surveys of soil properties related to soil functioning for many regions of Kyrgyzstan are limited. This study established ranges of chemical (soil organic matter (SOM), pH and total N (TN)), physical (soil texture), and biochemical (six enzyme activities of C, N, P, and S cycling) characteristics for nine profiles from the Kukart watershed of Jalal-Abad region in Kyrgyzstan. These profiles represent different soil orders (Inceptisols, Alfisols, and Mollisols) and land uses (cultivated, nut-fruit forests, and pasture). The Sierozem (Inceptisols) soils had the highest pH and contained the lowest SOM and TN contents compared to the Brown, Black-brown, and Meadow-steppe soils (Alfisols and Mollisols). Enzymatic activities within surface horizons (0–18 cm) typically decreased in the following order: forest > pasture > cultivated. Enzyme activity trends due to land use were present regardless of elevation, climate, and soil types although subtle differences among soil types within land use were observed. The significant reductions in measured soil enzyme activities involved in C, N, P, and S nutrient transformations under cultivation compared to pasture and forest ecosystems and lower values under Inceptisols can serve as soil quality indicators for land use decisions in the watershed.

1. Introduction

Expected changes in global climate, land uses, population distribution, and water availability create challenges to meet societal needs for ecosystem services that agricultural, forestry, and pasture lands provide. In order to make sound decisions regarding land use, knowledge of specific properties related to soil functioning under different land use scenarios are necessary. Dynamic properties such as enzyme activities and soil organic matter (SOM) are sensitive to land management practices and can provide valuable information about important soil processes such as nutrient cycling,

decomposition and formation of SOM, and overall productivity potential. Enzymatic potential in soils is influenced by inherent soil properties such as soil texture, type of clay, and drainage class that were established as soil formed as well as dynamic properties such as SOM, pH, and nutrient holding capacity. Among the various enzymes present in soil, assessment of the activities of hydrolases involved in C, N, P, and S cycling can provide information about soil fertility [1, 2] as well as the metabolic potential of soil [3, 4]. Previous studies with soils from various regions have shown that enzyme activities are sensitive to soil changes due to tillage [5, 6], cropping systems [7–9], and land use [10–12].

Surveys of soil properties related to soil functioning for many regions of Kyrgyzstan are limited. Kyrgyzstan is a mountainous country located in the north-eastern part of Central Asia. Altitudes range from 500 to 5000 m above sea level creating diverse ecological landscapes. The land area of the Kyrgyzstan represents 191,800 km² with approximately 5.0% under forest, 7.0% under arable and permanent crops, and 49% are pastures [13]. Many forested regions within this country contain the original genetic sources of many domesticated fruit and nut trees that are cultivated widely in temperate countries. For example, Kara-Alma and Arslanbob in the Jalal-Abad Province are home to some of the largest walnut forests, where trees occur in extensive, nearly pure stands at 1,000–2,000 m altitude [14]. In this country, there are soil studies that date to >40 years ago about SOM [15], the activities of urea and phosphatases [16] and microbial classification using culture methods [17], however, few current soil evaluations exist. Information about soil properties for this region will increase the knowledge base regarding how typical land uses in the region impact the functionality of the soil ecosystem. The objective of this study, therefore, was to evaluate selected chemical (SOM, pH, and total N), physical (soil texture), and biochemical (enzyme activities involved in C, N, P, and S cycling) characteristics for different soil profiles from the Kukart watershed of the Jalal-Abad region of Kyrgyzstan representing three land uses: cultivated, nut-fruit forests, and pasture.

2. Material and Methods

2.1. Geographic Characterization of the Kukart Watershed.

The Kukart watershed is located in the Jalal-Abad region of Kyrgyzstan. This region is characterized by a diverse ecological setting (elevation ranging from 500 to 2000 m, fluctuating weather patterns and soil types), which supports multiple land use options important for the region's economy (i.e., agricultural, grazing lands, nut-fruit forests, etc.). A total of nine soil profiles were sampled from three contrasting land uses within the Kukart watershed (1370 km²), spanning an elevation gradient from 732 m to 1942 m (Table 1 and Figure 1). The Kukart watershed is bordered by latitudes 41°08'10.18"N and 40°53'59.2"N to the north and south, respectively, and longitudes 72°55'06.99"E and 73°34'35.30"E to the west and east, respectively. It is located on the western and southwestern slopes of the Fergana and Chatkal ridges of the southwestern Tien-Shan mountain range.

The Kukart watershed is characterized by a continental subtropical climate. In the foothills, the average daily temperature in July is 28°C. In January daily averages are as low as −14°C (Jalal-Abad Meteorological Station). Conditions are much colder at high elevations, where the average daily temperature for July is 5°C and in January is −28°C (Jergetal Meteorological Station). The majority of the annual precipitation falls during winter and spring with little precipitation occurring during summer months. Average annual precipitation is between 100 and 500 mm in the

FIGURE 1: Map showing the Kukart watershed region near Jalal-Abad, Kyrgyzstan where nine soil profiles were characterized for chemical and physical properties and enzymatic activities. See Table 1 for site location details. Briefly, one forested sites is located in Suzak and the other two are in Kara-Alma and indicated on the map as Su₁, KA₁, and KA₂, respectively. The pasture sites are located in Kyzyl-Senir (KSr), Kalmak Kyrchyn (KK₁), and Kyzyl-Suu (KSu). The cultivated sites are located in Suzak (Su₂), Taigara (Tai), and Kalmak-Kyrchyn (KK₂).

foothills and from 500 to 1,000 mm in the mountains (above 1,000 m).

The geology of the Kukart watershed is dominated by deposits from the middle and upper Paleozoic period, which was described in detail by Roichenko [18]. In this watershed, clay and clay-siliceous shales and small-grained sandstones are dominant and are up to 150 m thick. Thick dark greenish-gray clay and clay-siliceous, chlorite shales, containing layers of sandstone, diabase, and dolomite limestone were found in the upper part. Main facies types of Devonian deposits for Kukart watershed are effervescent (i.e., carbonates present).

2.2. Soil and Flora Characteristics of Each Land Use Group.

For each of the three land use groups, three soil profiles were characterized (Table 1). The first land use group was forests (nut or nut-fruits) with a profile sampled under a pistachio (*Pistacia vera* L.) plantation located at 850 m elevation and two profiles sampled under native walnut-fruit forests located at 1580 m and 1800 m elevation, respectively, (Figures 2(a)–2(c)). Soils from the two walnut-fruit forests were Black-brown or Brown soils (both Mollisols) while the pistachio plantation was sampled from a Sierozem (Inceptisol). The native walnut (*Juglans regia* L.) fruit forests also contained Kirghiz apple (*Malus kirghisorum* Theodet. Fed.), Niedzwetzky apple (*Malus niedzwetzkyana* Dick.), almond

TABLE 1: General geographic description and soil classification from each land use site within the Kukart watershed, Kyrgyzstan.

Land use	Site name	Dominant vegetation ^a	Elevation (m)	Latitude/longitude	Aspect	Slope (degrees)	Soil classification system	
							USA	Russia
Forest	Suzak (Su ₁)	Pistachio	853	40°55'42.63"N 72°53'33.10"E	Northern	20	Inceptisol	Sierozem
	Kara-Alma (KA ₁)	Walnut	1580	41°12'30.49"N 73°20'57.12"E	Northern	43	Mollisol	Brown
	Kara-Alma (KA ₂)	Walnut	1801	41°12'54.66"N 73°23'00.05"E	Northern	28	Mollisol	Black-brown
Pasture	Kyzyl-Senir (KSr)	Mixed	930	41°02'41.35"N 73°01'05.86"E	Western	12	Inceptisol	Dark sierozem
	Kalmak Kyrchyn (KK ₁)	Mixed	1634	41°07'04.28"N 73°30'04.27"E	Northeast	45	Alfisol	Brown
	Kyzyl-Suu (KSu)	Mixed	1942	41°08'16.89"N 73°34'47.13"E	Northeast	45	Mollisol	Meadow-steppe
Cultivated	Suzak (Su ₂)	Cotton	732	40°54'58.41"N 72°56'15.16"E	N/A	0.3	Inceptisol	Sierozem
	Taigara (Tai)	Maize	833	40°59'04.65"N 73°00'10.50"E	N/A	0.3	Inceptisol	Sierozem
	Kalmak-Kyrchyn (KK ₂)	Sunflower	1615	41°07'06.54"N 73°29'58.11"E	Northeast	0.5	Alfisol	Brown

^aDetails regarding vegetation types are provided in material and methods.

(*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 understory is dominated by *Impatiens parviflora*, *Viola isopetala*, *Geum urbanum*, and *Brachypodium silvaticum*.

A second land use group represented grassland sites commonly used as open pasture areas primarily for cattle, but horses and sheep can also be present on the landscape (Figures 2(d)-2(e)). An elevation gradient was identified where three profiles were characterized and sampled: a Dark Sierozem (Inceptisol) profile at 930 m elevation, a Brown soil (Alfisol) at 1630 m, and a Meadow-steppe (Mollisol) profile at 1940 m (Table 1). The flora along this gradient contained a wide diversity of grass species including: *Artemisia vulgaris*, *Trifolium pratense*, *Poa pratensis*, *Thalictrum minus*, *Origanum vulgare*, *Rumex paulsenianus*, *Achillea biebersteini*, *Plantago lanceolata*, *Taraxacum alpinum*, *Vicia angustifolia*, *Eremurus fuscus*, *Euphorbia alata*, *Exochorda tianschanica*, and *Inula macrophylla*.

A third land use group represented long-term cultivated sites either under maize (*Zea mays*), cotton (*Gossypium hirsutum*), or sunflower (*Helianthus annuus*) for at least three consecutive years prior to sampling (Table 1; Figure 2(f)). The cotton and maize sites (furrow irrigated) were classified as Sierozems (Inceptisols) and located in the foothills at an elevation of 732 m and 833 m, respectively. The sunflower site under a Brown soil (Alfisol) was not irrigated and was at an elevation of 1615 m.

2.3. Soil Sampling and Analyses. The soil samples were collected by genetic horizons within each profile, air dried, passed through a 2-mm sieve, and stored in cloth bags

for subsequent analyses. Soil texture was determined by a rapid method as described by Kettler et al. [19]. Soil pH was measured from a 1:2 (soil:water) mixture using a combination glass electrode. Soil organic matter was determined by the weight loss on ignition method. Briefly, soil samples were oven-dried at 105°C overnight, cooled in a desiccator, and weighed. The samples were then ignited at 400°C for hours in a muffle furnace. After ignition, samples were transferred to a desiccator until it cooled and again weighed. The loss on ignition (LOI) was calculated using the following formula:

$$\text{LOI} = [(W_1 - W_2)/W_1] \times 100, \quad (1)$$

where W_1 = oven-dry soil weight (g) dried at 105°C and W_2 = soil weight after ignition at 400°C. SOM was then estimated according to the equation: %SOM = (%LOI × 0.7) – 0.23 as recommended in the Cornell Soil Health Assessment Training Manual [20]. Total N was determined by dry combustion using a Carlo Erba 1500 NA (Milan, Italy).

The enzyme activities, β -glucosidase, β -glucosaminidase, acid and alkaline phosphomonoesterase, phosphodiesterase, and arylsulfatase, were assayed using 0.5 g of air-dried soil with the appropriate assay conditions (i.e., incubated for 1 h at 37°C at their optimal pH and substrate final concentration) as described by Tabatabai [21]. β -glucosaminidase activity was determined similarly as described by Parham and Deng [22]. The enzyme activities were assayed in duplicate with one control, to which substrate was added after incubation (product of all reactions is PN = *p*-nitrophenol). A summary of the assay conditions, reactions, and role of these enzymes in soil metabolic functioning is provided in Table 2.

TABLE 2: Conditions for assay of soil enzyme activities and their role in soil biogeochemical functioning.

Class/EC number	Recommended name	Role in soil function	Reaction	Assay conditions Substrate	Optimum pH
C cycling					
3.2.1.21	β -Glucosidase	Cellulose degradation, produces glucose needed by plants and microorganisms	Glucoside-R + H ₂ O → Glucose + R-OH	<i>p</i> -Nitrophenyl- β -D-glucopyranoside (10 mM)	6
C and N cycling					
3.2.1.30	β -Glucosaminidase	Chitin degradation, produces amino sugars, one of the major sources of mineralizable N	R-N-acetyl- β -D-glucosaminide → R-OH + N-acetyl- β -D-glucosaminide	<i>p</i> -Nitrophenyl-N-acetyl- β -D-glucosaminide (10 mM)	5.5
P cycling					
3.1.3.2	Acid Phosphatase	Produces plant available phosphates, predominant in acid soils	RNa ₂ PO ₄ + H ₂ O → R-OH + Na ₂ HPO ₄	<i>p</i> -Nitrophenyl-phosphate (10 mM)	6.5
3.1.3.1	Alkaline Phosphatase	Produces plant available phosphates, predominant in alkaline soils	RNa ₂ PO ₄ + H ₂ O → R-OH + Na ₂ HPO ₄	<i>p</i> -Nitrophenyl-phosphate (10 mM)	6.5
3.1.4.1	Phosphodiesterase	Produced from plants, animals, and microorganisms	RNa ₂ 2PO ₄ + H ₂ O → RNa ₂ PO ₄ + R-OH	bis- <i>p</i> -nitrophenyl phosphate (10 mM)	8
S cycling					
3.1.6.1	Arylsulfatase	Produces plant available sulfates	Phenol sulfate + H ₂ O → phenol + sulfate	<i>p</i> -Nitrophenyl-sulfate (10 mM)	5.8

2.4. Data Calculations. As a survey, our purpose was to establish ranges of commonly used soil properties important for nutrient cycling and productivity among the three land use groups (pasture, forest, and cultivated) within the Kukart watershed. Enzymes were grouped into C-cycling and P- and S-cycling groups using three-dimensional plots to determine if patterns among land use groups existed. In order to compare surface soils (0–15 cm), the top two soil depths were summed for the three forest sites and two of the three pasture sites. The remaining sites were already sampled at this depth (except for one of the cultivated sites where the first soil horizon was taken from 0 to 34 cm depth).

3. Results and Discussion

3.1. Soil Physical and Chemical Characterization of the Nine Soil Profiles. The texture within the top 57 cm of soil depth from the Kukart watershed was generally in the loam family (i.e., silt loams, silty clay loam, clay loams, etc.) and ranged in clay content from 6% to 39% (Table 3). In general, soil chemical properties were influenced by soil order. The Sierozem (Inceptisols) soils had the highest pH values and contained the lowest SOM and TN contents compared to the Brown (Alfisols), Black-brown, and Meadow-steppe soils (Mollisols). Soil pH values from Brown (Alfisols), Black-brown and Meadow-steppe soils (Mollisols) ranged from 7.0 to 7.7 and values of the Sierozems (Inceptisols) ranged from 7.9 to 8.2 within the first two soil depths.

The two Brown and Black-brown (Mollisol) profiles from the nut-fruit forested sites (KA₁ and KA₂) contained higher SOM levels (i.e., 12–16% from the Oe and 9–12% from the A1 horizons) compared to all other profiles (<7.6% in the A horizons), including the other forest profile, which was a Sierozem (Inceptisol) under pistachio (Su₁). Additionally, these two forested sites had higher levels of SOM at depth compared to the other land use sites. For example, SOM was 2.65% within 48 cm depth at the KA₁ site and 5.51% within 57 cm depth at the KA₂ site. The levels of SOM found at greater than 1 m depth were comparable to the surface horizons of the cultivated Sierozems indicating the importance of vegetation-land use interactions in supporting SOM formation and stabilization [23]. Compared to other soil orders using the USDA system, the Inceptisols (Sierozems) of this watershed experience less precipitation and higher temperatures due to their geography (foothill position on the leeward side of the mountain range; 732–930 m). Among the Sierozems, the lowest SOM level was found in the cultivated cotton site, which is likely attributed to constraints on further soil development related to management interactions. Tillage, irrigation events, and quantity and quality of crop residues influences the balance between decomposition and accumulation of SOM. Of the cultivated sites studied, cotton produces lower residues compared to corn or sunflower [24].

3.2. Soil Enzyme Activities as Affected by Land Use and Soil Order. All enzyme activities generally decreased with increasing depth for the nine profiles (Table 4). Within the

TABLE 3: Selected properties of the Kukart watershed sites from Kyrgyzstan.

Land use	Site name	Horizon	Depth (cm)	Soil pH	Organic matter %	Total N %	Clay	Silt	Sand	Texture Class
Forest	Suzak (SU ₁)	A1	0–2	7.9	3.55	0.46	18.7	64.4	16.9	Silt loam
		A2	2–14	8.3	0.96	0.08	12.2	67.9	19.9	Silt loam
		Bw	14–52	8.2	0.74	0.08	11.8	67.9	20.3	Silt loam
		BC	52–105	8.2	0.42	0.05	8.7	70.1	21.2	Silt loam
		C	105–165	8.3	0.22	0.04	7.9	68.6	23.5	Silt loam
	Kara-Alma (KA ₁)	Oe	0–2	7.7	12.07	0.91	37.6	39.7	22.7	Clay loam
		A1	2–13	7.5	9.21	0.72	26.2	49.0	24.8	Loam
		A2	13–48	7.9	2.65	0.19	19.3	57.4	23.3	Silt loam
		BC	48–120	8.1	0.88	0.08	14.6	56.7	28.7	Silt loam
		C	120–165	8.1	0.82	0.07	16.2	59.0	24.8	Silt loam
	Kara-Alma (KA ₂)	Oe	0–4	7.3	16.13	1.88	38.6	35.9	25.5	Clay loam
		A1	4–18	7.0	12.5	0.84	29.5	54.8	15.7	Silty clay loam
		A2	18–57	7.2	5.51	0.38	5.9	74.0	20.2	Silt loam
		AB	57–91	7.1	2.06	0.13	2.4	70.6	27.0	Silt loam
		BC	91–130	7.2	1.37	0.14	2.0	67.5	30.5	Silt loam
Pasture	Kyzyl-Senir (KSr)	C	130–185	7.3	1.23	0.08	2.3	67.1	30.6	Silt loam
		A1	0–3	7.9	2.13	0.15	15.7	69.5	14.8	Silt loam
		A2	3–13	8.1	1.49	0.12	12.8	71.5	15.7	Silt loam
		Bw	13–44	8.3	0.60	0.10	6.4	78.4	15.2	Silt loam
		BC	44–86	8.3	0.23	0.04	4.1	82.2	13.7	Silt
	Kalmak Kyrchyn (KK ₁)	C	86–170	8.5	0.21	0.04	3.7	80.7	15.6	Silt
		A1	0–3	6.9	1.30	0.09	25.7	45.1	29.2	Loam
		A2	3–17	7.2	0.40	0.10	16.4	47.8	35.7	Loam
		A3	17–38	7.3	0.38	0.04	18.6	49.5	31.9	Loam
		2Ab	38–63	7.3	0.81	0.05	20.2	51.8	28.1	Silt loam
	Kyzyl-Suu (KSu)	2Bt1	63–91	7.6	1.15	0.09	17.8	58.4	23.9	Silt loam
		2Bt2	91–120	7.3	0.36	0.13	23.2	47.8	29.0	Loam
		2BCb	120–140	7.4	0.30	0.02	16.3	49.1	29.0	Silt loam
		2C	140–180	7.6	0.18	0.01	20.0	61.3	18.8	Silt loam
		A	0–15	7.4	7.59	0.68	31.1	54.5	14.4	Silty clay loam
	Bw (BC)	C	15–28	7.3	4.14	0.42	26.6	57.1	16.3	Silt loam
			28–50	7.4	2.79	0.22	23.8	53.9	22.3	Silt loam

TABLE 3: Continued.

Land use	Site name	Horizon	Depth (cm)	Soil pH	Organic matter %	Total N %	Clay	Texture (%) Silt	Sand	Texture Class
Cultivated	Suzak (Su ₂)	Ap	0–14	8.0	0.79	0.07	30.9	47.5	21.6	Clay loam
		A	14–30	8.2	0.64	0.06	33.0	45.6	21.3	Clay loam
		Bw	30–50	7.9	0.52	0.14	34.4	46.1	19.5	Silty clay loam
	Taigara (Tai)	Ap	0–34	8.2	1.13	0.11	32.8	47.8	19.4	Silty clay loam
		Bw (BC)	34–59	8.1	0.92	0.1	17.9	53.9	28.3	Silt loam
		C	59–98	8.2	0.62	0.08	34.3	41.2	24.6	Clay loam
	Kalmak-Kyrchyn (KK ₂)	Ap	0–14	7.3	3.72	0.3	32.3	45.2	22.5	Clay loam
		A	14–30	7.6	2.34	0.19	33.6	43.8	22.6	Clay loam
		Bt	30–50	7.4	1.32	0.1	36.6	39.6	23.9	Clay loam

TABLE 4: Enzyme activities (mg PN kg⁻¹ soil h⁻¹) for the Kukart watershed sites of Kyrgyzstan^a.

Land use	Site name	Depth (cm)	C cycling β -Gluc	C&N cycling β -Glucm	Acid phos	P cycling Alk phos	Phosphod	S cycling Aryl
Forest	Suzak (SU ₁)	0–2	809.5	51.0	286.4	1021.5	560.9	115.4
		2–14	38.3	8.8	22.9	67.3	17.6	5.3
		14–52	16.0	10.6	17.9	59.0	33.7	8.7
		52–105	7.6	7.5	12.0	36.0	26.0	8.1
		105–165	5.3	5.6	2.8	6.6	8.0	1.7
	Kara-Alma (KA ₁)	0–2	807.6	189.9	397.4	1441.5	746.2	498.9
		2–13	1137.5	87.6	422.3	1033.0	742.1	393.3
		13–48	135.1	14.7	114.7	244.6	222.1	114.3
		48–120	27.1	4.0	29.8	76.5	43.8	33.5
		120–165	19.3	2.1	26.0	57.5	85.2	19.6
	Kara-Alma (KA ₂)	0–4	1235.9	298.5	712.7	1809.8	714.2	439.2
		4–18	546.9	106.0	897.7	757.8	754.5	493.4
		18–57	74.6	7.3	272.5	283.9	225.9	158.3
		57–91	17.8	10.9	59.8	27.7	41.7	15.3
		91–130	14.7	1.7	27.7	18.7	11.9	4.8
		130–185	11.1	14.4	18.0	8.1	15.4	2.2
Pasture	Kyzyl-Senir (KSr)	0–2	428.7	43.3	176.2	594.3	303.6	81.3
		2–13	209.3	34.5	81.8	285.5	177.7	34.9
		13–44	25.7	11.2	21.0	72.7	53.4	18.4
		44–86	7.4	6.2	2.4	20.5	11.5	3.5
		86–170	2.0	2.9	1.3	9.6	5.3	2.4
	Kalmak Kyrchyn (KK ₁)	0–3	323.6	45.7	146.8	276.0	258.9	77.1
		3–17	25.4	7.7	24.3	54.6	40.1	9.8
		17–38	16.4	6.8	24.9	32.2	21.0	11.7
		38–63	33.9	9.2	35.5	79.2	49.1	21.4
		63–91	64.6	13.7	70.9	109.0	79.1	48.5
		91–120	11.1	6.9	21.1	29.9	16.4	6.5
		120–140	3.8	4.5	19.6	34.3	16.2	7.9
	Kyzyl-Suu (KSu)	140–180	1.4	3.7	10.6	2.0	2.7	1.4
		0–15	513.6	58.2	978.3	431.3	467.4	381.2
		15–28	77.5	25.6	371.7	340.9	212.7	160.8
		28–50	24.5	8.6	134.0	174.0	107.9	56.6
Cultivated	Suzak (Su ₂)	0–14	69.8	11.9	228.9	162.1	83.4	23.4
		14–30	22.8	5.8	42.7	84.5	53.9	14.0
		30–50	3.3	4.2	31.5	80.4	67.7	9.1
	Taigara (Tai)	0–34	79.7	9.8	63.5	166.4	107.5	28.2
		34–59	29.6	11.8	37.5	83.8	55.2	14.7
		59–98	12.8	6.4	12.0	68.6	32.7	11.5
	Kalmak-Kyrchyn (KK ₂)	0–14	202.2	30.6	141.1	337.6	214.6	101.0
		14–30	60.9	18.8	135.9	212.5	127.8	85.3
		30–50	18.0	6.7	36.3	104.6	46.3	23.1

^a PN: *p*-nitrophenol; β -Gluc: β -glucosidase; β -Glucm: β -glucosaminidase; Acid phos: acid phosphatase; Alk phos: alkaline phosphatase; Phosphod: phosphodiesterase; Aryl: arylsulfatase.

forest sites, the pistachio forest (Su₁) showed a substantial decrease from the 0–2 cm depth to the 2–14 cm in all enzymes compared to differences in similar depths for the two forest sites under nut-fruit forests (KA₁ and KA₂). This observation is likely related to the lack of an O horizon in the

Sierozem (Inceptisol) of the Su₁ site and further influenced by potential differences in litter chemistry and climate shifts between the low (Su₁) and high (KA₁ and KA₂) elevation sites. The decrease of enzyme activities with depth can be mainly attributed to the mitigation of biological activity

FIGURE 2: Representative landscape and soil profile pictures of the Kukart watershed including forest sites (a–c), pasture (d–e), and cultivated (f) land use. The forest sites included Pistachio plantation located at the Suzak (Su_1) site under a Sierozem (a) and two Walnut-fruit forests under a Brown soil (b) and a Black-brown soil (c) located at the Kara-Alma sites, KA_1 and KA_2 , respectively. Two of the pasture sites are shown under a Brown soil (d) in Kalmak Kyrchyn (KK_1) and a Meadow-steppe soil (e) in Kyzyl-Suu (KSu). The Maize cultivated profile at Taigara (Tai) under Sierozem is shown (f). Details regarding the sites are described in Table 1.

down the profile [25]. The decrease of enzyme activities and microbial biomass with soil depth has been noted in other studies [26, 27].

Enzymatic activities among land use groups within surface horizons (0–18 cm) typically decreased in the following order: forest > pasture > cultivated. Generally, enzyme activities are correlated to SOM content because litter plays a key role as a precursor for enzyme synthesis and in enzyme physical stabilization [21] but litter quality is also important. In general, forested sites, which tend to have higher lignin content, C:N ratios, and lignin:N ratios, resulted in greater accumulation of SOM in comparison to pasture or cultivated lands [28]. The SOM does not tend to accumulate in cultivated sites because harvest removes biomass and tillage of the remaining residues accelerates breakdown of SOM.

The ranges of enzyme activities (e.g., alkaline phosphatase and β -glucosidase) found in the soil surface of the nine profiles from the Kukart watershed in Kyrgyzstan were much higher than values reported for other forest and grasslands, but similar to cultivated land in a review for soils across the world [29]. Soil β -glucosidase activity ranged from 848 to 1945 $\text{mg PN kg}^{-1} \text{ soil h}^{-1}$ in the forest (adding up both first depths to ~ 15 cm), 349 to 635 $\text{mg PN kg}^{-1} \text{ soil h}^{-1}$ in the pasture (adding up both soil depths to ~ 15 cm),

and 69.8 to 202 $\text{mg PN kg}^{-1} \text{ soil h}^{-1}$ (0–14 or to 34 cm) in the cultivated sites (Table 4). The ranges detected for this enzyme activity, which is important in C cycling, may suggest very distinct soil C substrates availability among these land uses. The forest sites showed more than two times higher values of this enzyme activity compared to the pasture sites and between 9 and 12 times higher compared to the cultivated sites. β -glucosaminidase activity is an enzyme involved in both C and N cycling and has been shown to be highly correlated with N mineralization [22]. Ranges for this enzyme followed a similar pattern as those shown for β -glucosidase: forest sites ranged from 59.7 to 405 (0–14 cm), pasture from 53.4 to 77.8 (0–17 cm), and cultivated sites ranged from 9.8 to 30.6 (0–34 cm) $\text{mg PN kg}^{-1} \text{ soil h}^{-1}$. In general, forested sites tend to support increased fungal biomass and more complex C sources (chitin) compared with pasture and cultivated profiles, which may explain the higher levels of β -glucosaminidase found in the forested sites compared with the other land uses. Although the Brown and Black-brown surface soils (0–18 cm) under forest had higher β -glucosaminidase and β -glucosidase activities than those under the pistachio forest (Su_1) in a Sierozem (0–14 cm), the pistachio Sierozem had higher levels of these enzymes than the two pastures under Brown and Meadow-steppe soils

FIGURE 3: Three-dimensional plots showing three enzyme activities at a time under forest (blue), pasture (green), and cultivated (red). Soils were grouped according to taxonomy and are distinguished by squares (soils under Black-brown and Meadow-steppe or Mollisols), circles represent Brown soil (Alfisols) and triangles represent Sierozems (Inceptisols). The first two depths were summed for forest sites (Su₁, KA₁, and KA₂) and for two of the pasture sites (KSr, KK₁). The third pasture site is abbreviated KSu. The cultivated sites are abbreviated (Su₂, Tai, and KK₂). Details regarding the sites are described in Table 1.

(KK₁ and KSu). This indicates that land use and more likely, substrate quality of decomposing residues within each land use are strong drivers of metabolic potential rather than soil type or SOM content alone. Among the P and S cycling enzyme patterns, only phosphodiesterase activity showed a clear distinction between the three land uses. The activity of this enzyme ranged from 579 to 1488, 299 to 481, and 83.4 to 215 mg PN kg⁻¹ soil h⁻¹ for the forest, pasture, and cultivated sites, respectively.

Enzyme activity trends due to land use were present regardless of elevation, climate, and soil types although more subtle differences among soil types within a land use were observed. For example, among the forest sites, the Inceptisol site (Su₁, Sierozem) had the lowest enzyme activities and SOM values and these values were comparable to the Inceptisol pasture site (KSr, Sierozem) (Figure 3). However, Inceptisols under cultivation showed the lowest levels of enzyme activities among this group of soils evaluated. A study by Acosta-Martínez et al., [30] in a tropical watershed found that the management practice influenced the forest and pasture land uses tended to increase the enzyme activities in the Inceptisols compared to the other soil orders. The authors suggested that nutrient cycling as monitored by enzyme activities in Inceptisols under agriculture could be increased with adoption of conservation practices to levels comparable to other soil orders under pasture or forest. In general, Mollisols by definition contain greater SOM content than Inceptisols, which is related to processes that

occurred during soil formation. Although SOM was strongly correlated with enzyme activity ($r > 0.85$), we did not find significant correlations between enzyme activities and inherent soil properties such as pH or clay content as has been shown in other studies [26, 31].

4. Conclusion

This study provided the first soil survey on the characterization of key soil chemical, physical, and biochemical properties of nine soil profiles in the Kukart watershed, Kyrgyzstan. Our results demonstrated the important interactive forces between inherent soil properties (e.g., pH and texture) and land management on dynamic soil properties (SOM and enzyme activities) important for soil quality and ecosystem functioning. The significant reductions in measured soil enzyme activities involved in C, N, P, and S nutrient transformations under cultivation compared to pasture and forest ecosystems and lower values under Inceptisols can serve as soil quality indicators for land use decisions in the watershed. This study serves as a baseline for further soil classification efforts within the Kukart watershed and similar watersheds within Kyrgyzstan.

Disclosure

The use of trade, firm, or corporation names in this publication is for the information and convenience of the

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