Erosion Rates Depending on Slope and Exposition of Cropped Chestnut Soils

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Abstract The surface runoff erosion of dark and light chestnut soils (Kastanozems) in the Ile Alatau foothills in the Zhambyl/Karasai administrative area and in the western part of Chemolgan near Almaty/Kazakhstan was analysed for use in devising adaptive landscape agricultural systems. 1:25,000 scale maps were modelled by combining geo-information techniques, field work and laboratory analytics. Rain and snowmelt activity depending on exposure on southern and northern slopes of agricultural land was differentiated. Single parameters were measured as snowmelt erosion and water erosion; a runoff coefficient was then calculated to determine the level of soil erosion from the intensity of the erosion processes. The results reveal that dark and light chestnut soils on northern slopes are more resistant to water erosion than those on southern slopes. It was also found that soil erosion processes induced by erosive rain are more intensive than snowmelt erosion. For chestnut soils, water erosion rates ranged from 1.4 to 30.8 t/ha induced by rainfall and from 0.7 to 3.5 t/ha induced by snowmelt, depending on slope inclination and exposure. Greater erosion was detected on southern slopes. No clear differentiation was found when comparing the erosion rates of dark and light chestnut soils.

Keywords Soil erosion · Chestnut soils · Slope · Exposition

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1 Objectives

Only very few practical investigations into the soil erosion exposure of chestnut soils have been undertaken to date. In the foothills to the north of the Ile Alatau Mountains in Kazakhstan, no scientific studies have every been conducted to differentiate erosion rates caused by snowmelt and heavy rain. Little is known about the impact slope exposition has on soil erosion in this part of Central Asia, too. Chestnut soils (Kastanozems) are steppe soils defined by an accumulation of humus in semi-arid and arid environments, normally containing brown coloured upper horizons. These horizons have a high humus content and calcareous or gypseous fractions. The soil is developed mainly in loess materials, as described in the World Reference Base for Soil Resources; IUSS Working Group (2006). The same literature source mentions the key problem of wind and water erosion in Kastanozem soils, especially on fallow land, and the dominant land use of Kastanozem lands by extensive grazing when irrigation and arable land use is infeasible.

According to data obtained from research undertaken at the Institute of Soil Science (Pachikin and Erokhina 2011), approximately 60 % of the soil cover in Kazakhstan is affected by different degrees of soil degradation, differentiated by natural conditions and their soil usage. One of the causes of soil degradation is the extensive development of arable agriculture involving the conversion of steppes into arable land. Further causes are the strong impact of the mining industry and the wide network of former military test sites (from the USSR era). The battle against land degradation is of considerable importance in Kazakhstan. Approximately 43 % of the population (6.47 million) live in rural regions, the majority of whose livelihoods depend directly or indirectly on the agrarian sector and agrarian land use [data provided by Karazhanov et al. (1998)].

The peculiarity of the ecological/geographical situation in Kazakhstan is the generally low resistance of the natural environment to anthropogenic impacts. In data provided by Asanbaev (1998), fragile ecosystem types exist as deserts (45 %) and mountain landscapes (20 %) in the regions where the main pastures are located. Areas suitable for tillage agriculture are located in the chernozemic and dark chestnut soil zone. Chestnut soils are generally located in the dry steppe zone, light Kastanozems in desert steppes; brown Kastanozems in the semi-desert zone and grey-brown Kastanozems in the desert zone.

The research presented here is part of the ALAS (adaptive landscape agricultural systems) approach, based on the agro-ecological land evaluation methodology further developed by Kiryushin (2005). This assessment includes a comprehensive investigation of the territory's geomorphology, lithology, climate and hydrogeological conditions. Following the ideas developed by Kiryushin (2011) about classifications into ALASs and technologies (Editorial Board of Eurasian Soils Science 2011), scientific investigations into problems concerning the practical implementation of these systems have been initiated in several provinces of Russia, including at Kazakhstan Al-Farabi Kazakh National University in Almaty.

Iorgansky (2001) summarises that ALAS increases the production and environmental efficiency of crop production in several regions of Russia. This is achieved primarily by a better differentiation of the agro-ecological site conditions of the land.

In this regard, studies undertaken in Kazakhstan are devoted to the spatial analysis and preparation of landscape classification maps. The work presented here was performed in three stages: (1) territorial analysis of the test area, (2) differentiation and classification of landscapes using morphological characteristics and (3) development of agro-technology measurements for each type of landscape. The bio-physical and geographical analysis presented here was undertaken in the Almaty Oblast administrative region (Zhambyl/Karasai), located on the northern slope of the Ile Alatau, by using a geographical information system (GIS) and combining remote sensing data and field methods.

The aim of this paper is to investigate the impact water erosion processes caused by surface runoff have on dark and light chestnut soils in the foothills of the Ile Alatau Mountains, describing the role played by slope inclination and slope exposure. The analysis described in this paper therefore focuses on the following aspects:

1. Description of the soil characteristics of typical dark chestnut soil profiles,
2. Modelling of agricultural landscapes using GIS in terms of exposure and slope inclination, focusing on northern and southern slopes,
3. Text plot-based measurements for indicators of snowmelt water runoff intensity and their ratios, and indicators of soil erosion intensity depending on steepness and slope exposure for agricultural land,
4. Discussion about the field crop parameters that influence water erosion and water runoff as measures for adaptive landscape agricultural systems.

2 Materials and Methods

The research into dark and light chestnut soils in agricultural areas was undertaken at the foothills of Ile Alatau. The test site for **light chestnut soils** was located on the premises of the K. Mynbaev Kazakh Research Institute of Livestock and Fodder Production (43°13′20″N 76°40′56″E). In this field observatory, soil profiles were analysed on the southern and northern slopes. The sites were investigated using both the genetic-morphological structure as proxies and the field method. The average inclination of the slopes is around 5°. The humus horizon AB is 53 cm at slightly eroded sites; at sites featuring average erosion, this figure is still 38 cm.

The test site for **dark chestnut soil** profiles is located on arable land in "Sholak-Kargaly" village in western Chemolgan (43°22′39″N 76°37′12″E). Here, the humus horizon (AB) is up to 65 cm, and 55 cm with slightly eroded soils

(1–3°); with soils with average erosion (3–5°), the humus horizon is around 45 cm, and up to 35 cm with highly eroded soils (7° inclination and higher).

The erosive activity of surface runoff is measured at selected observation plots (with an area of 75 m^2) for each soil type. The experimental observation sites were established by applying three replications for the measurements of soil erosion intensity (g/l). These observations were made during the spring snowmelt and for heavy precipitation events. The field experiments were conducted in 2010 and 2011.

Table 1 shows the analytics of dark chestnut soils; averages are based on 13–23 replications. The texture is medium loamy and heavy. Due to long-term irrigation, some moving clay fraction is observed from the upper to the lower horizons. Micro-aggregation and water resistance of the macro-structure are relatively high.

The 1:25,000 scale map of the slope inclination was developed using GIS (Arc GIS 9.3 software) and additional functions of 3D visualisation and analysis of building surfaces. The thematic maps were based first on the digitisation of topographic data using analogous maps, which are later used to create a spatial

Table 1 Morphological and analytical characteristics of dark chestnut soils at the Ile Alatau foothills (n—number of soil profiles; max–maximum depth of soil horizon; min–minimum depth of soil horizon; x—average)

Parameters of soil properties	N	Genetic horizons	Parameter		
			Max	Min	X
Thickness of soil horizon, cm	23	A_1	10	6	9.6
		A_2	30	16	25.0
		B_k	60	40	50.3
		C_1	90	70	83.8
CO_2 carbonate, %	13	A_1	4.3	1.3	1.9
		A_2	6.8	1.8	1.9
		B_k	7.1	1.9	4.0
		C_1	8.5	2.6	4.5
Humus, %	17	A_1	4.2	2.0	3.2
		A_2	3.7	1.1	2.3
		B_k	3.6	0.4	1.4
		C_1	1.8	0.3	1.0
Absorbed calcium, mg-eq.	14	A_1	23.9	9.8	14.2
		A_2	16.0	6.2	12.1
		B_k	24.3	4.0	14.2
		C_1	10.7	1.9	5.8
Physical clay (< 0.01 mm), %	23	A_1	52.3	19.0	41.7
		A_2	55.4	23.5	42.7
		B_k	67.6	25.9	45.2
		C_1	62.2	34.9	46.2
Clay (< 0.001 mm), %	23	A_1	18.8	5.6	13.4
		A_2	21.3	3.3	12.1
		B_k	29.6	6.8	16.0
		C_1	29.9	9.8	16.8

model topography (slope maps, slope exposure). The work was performed by constructing a triangulated irregular network (TIN) model and then calculating the slope inclination using the 'Derive Slope' function for the contextual surface mode. Contour lines, roads, land uses, lakes, rivers, elevation points and additional information were added to the digital database for further analysis.

3 Results and Discussion

3.1 Light Chestnut Soils

Figure 1 shows the slope inclination of agricultural landscapes at the **light chestnut soil test site**, comprising 4,776 ha of land. Of this area, 1,893 ha (or 40 % of the territory) have slopes with an inclination of 1–3°; 2,219 ha (or 46 %) have 3–5° slopes; 523 ha (11 %) have 5–7° slopes, and only 141 ha (3 %) have slopes with an even steeper inclination.

The map provides the information required to assess the erosive activity of the landscape. The main factors that could influence the types of water erosion analysed are the physical properties of the soil (soil texture) to analyse the water household (infiltration and runoff). It is important to spatialise the distribution of the soil texture. Other important factors that can be gleaned from the test sites are the surface slope, the snowmelt runoff, the quantity and intensity of rainfall, the depth and extent of soil freezing, the type of land use, and the status of the surface soil, including information about plant residues and the micro-relief. Crops primarily cultivated at both investigation areas are spring barley, winter wheat and alfalfa. Table 2 summarises the observation results of surface runoff and intensity as an example of light chestnut soils.

Snowmelt runoff, storm water runoff and total runoff were categorised into different classes of slope inclination. Thus, the annual runoff of snowmelt and rain water varied depending on the steepness of the slopes with northern exposure from 21 to 67 mm, and erosion from 2 to 24 t/ha/yr. Figures for slopes with southern exposure varied from 24 to 74 mm and 3.9 to 33.9 t/ha, respectively. Higher volumes of runoff and eroded soils are observed on slopes with an inclination of 5–7° and in the class of slopes with an inclination of over 7° with southern exposure. This reflects the greater resistance to erosion of soils located on slopes with northern exposure, which is also confirmed by the lower intensity of erosion varying according to the slopes from 9.5 to 35.8 g/l in the runoff water analysis. The observed soil erosion intensity on the southern slopes is higher, measuring 16.2–45.8 g/l. The coefficient of runoff of snowmelt water was applied using a method developed by Surmach (1969) (Table 3).

Soil erosion at the test site occurs more rapidly after rainfall compared to snowmelt runoff. On the slopes with northern exposure, soil erosion affected by storm water runoff ranged from 1.4 to 20.9 t/ha; snowmelt runoff ranged from

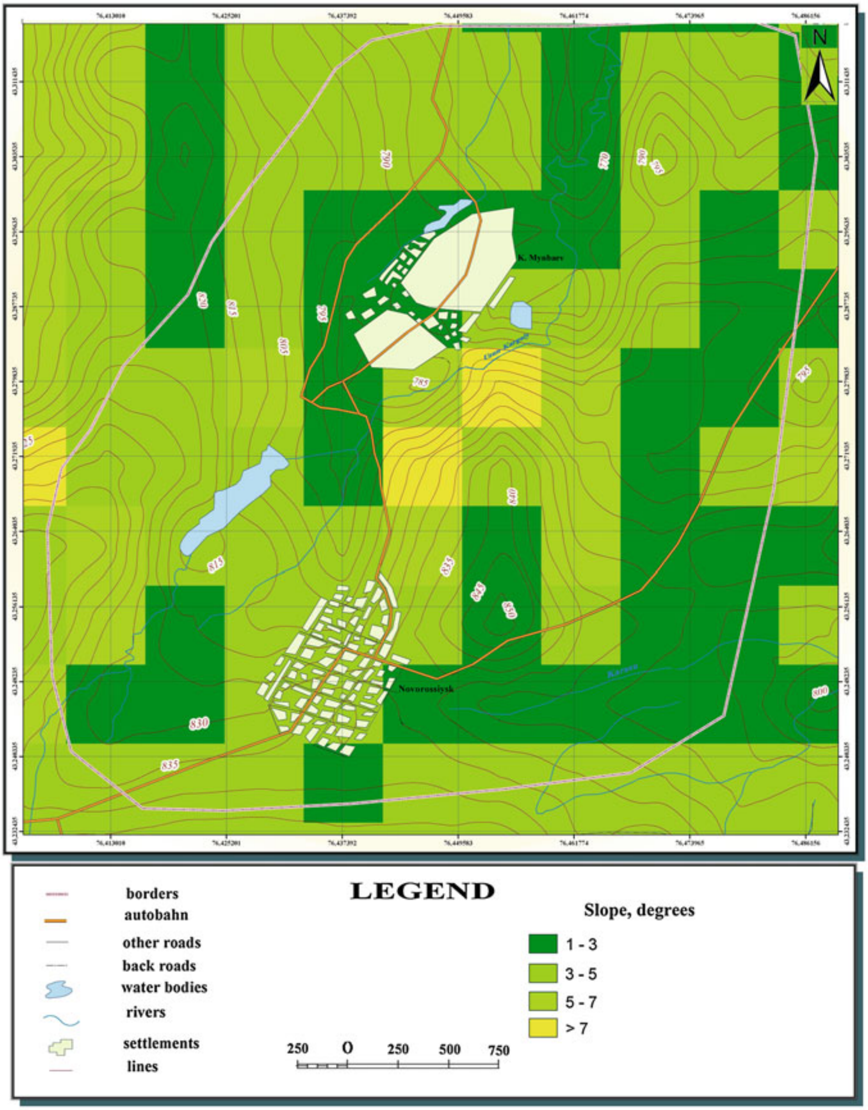

Fig. 1 Map of slope inclination at the light chestnut soil test area, test area K. Mynbaev Kazakh research institute of livestock and fodder production (Karasai/Almaty)

0.7 to 3.1 t/ha. When undertaking the agro-ecological assessment of land, it is also important to consider the soil's resistance to erosion. Resistance can be taken as a measure for assessing economic use, the field's potential crops and the local intensity of rainfall. For a typical rainfall event in May 2010, the results of surface runoff accounting for four elementary runoff test plots showed that the amount of

Table 2 Annual surface runoff and intensity of erosion in light chestnut soils, test area K. Mynbaev Kazakh Research Institute of Livestock and Fodder Production (Karasai/Almaty)

Parameter of erosion	Steepness of slope, degrees			
	1–3	3–5	5–7	>7
Northern exposure				
Snowmelt runoff, mm/year	13	16	20	26
Coefficient of runoff	0.12	0.16	0.20	0.2
Soil erosion, t/ha/year	0.6	0.8	1.9	3.1
Intensity of erosion, g/l	4.6	5.0	8.6	9.6
Storm water runoff, mm/year	8	15	28	41
Soil erosion, t/ha/year	1.4	3.6	11.8	20.9
Intensity of erosion, g/l	17.5	24.0	40.7	52.4
Runoff, mm/year	21	31	48	67
Soil erosion, t/ha/year	2.0	4.4	13.7	24.0
Intensity of erosion, g/l	9.5	14.2	28.5	35.8
Southern exposure				
Snowmelt runoff, mm/year	12	16	21	26
Coefficient of runoff	0.14	0.17	0.26	0.32
Soil erosion, t/ha/year	0.7	0.9	2.2	3.1
Intensity of erosion, g/l	5.8	6.4	10.5	12.9
Storm water runoff, mm/year	12	20	28	48
Soil erosion, t/ha/year	3.2	5.8	13.8	30.8
Intensity of erosion, g/l	26.6	29.0	49	59.2
Runoff, mm/year	24	36	49	74
Soil erosion, t/ha/year	3.9	6.7	16.0	33.9
Intensity of erosion, g/l	16.2	18.6	32.6	45.8

Table 3 Assessment of annual snowmelt runoff intensity

Runoff	Value of runoff, mm	Coefficient of runoff
None	0	0
Very little	Up to 7	Up to 0.05
Measurable	8–20	0.06–0.15
Clearly measurable	21–40	0.16–0.35
High	41–75	0.36–0.65
Very high	76–115	0.66–0.85
Extremely high	>115	>0.85

water runoff and soil erosion on steep slopes (7–8°) varied considerably, depending on which crops grew there (Table 4).

These figures suggest that the anti-erosion stability of light chestnut soils is determined largely by arable crops. It can be significantly regulated by performing crop rotation and planting particular crops. The cultivation of alfalfa and winter wheat in particular enhances anti-erosion stability. The lowest water runoff and soil erosion rates were observed on virgin soil covered by natural vegetation.

Table 4 Surface runoff on light chestnut soils

Date of registration	Steepness of slope degrees	Rainfall in mm	Average intensity of precipitation, mm/min	Indicators of erosion	Land				
					Fallow (uncropped)	Spring barley	Winter wheat	Alfalfa	Natural vegetation on virgin land
2.05.10	7–8	17	0.57	Runoff, m^3/ha %	27 18	23.1	15.1	37.2	10.0
				Soil erosion, t/ha	1.1	0.7	0.4	0.25	0.06
				Erosion, g/l	40.7	30.3	26.4	6.7	6.0

Perennial grasses cultivated on the croplands can also lead to a significant reduction in soil erosion. Storm water runoff measured here was higher than in fields in which winter wheat or spring barley were grown, but there was less soil erosion. The figures obtained are important for designing erosion control measures, for influencing the soil moisture regime and for improving the environmental situation in general.

3.2 Dark Chestnut Soils

Using comparable methods to those described for light chestnut soils, a 1:25,000 scale map was created for the agricultural landscapes of dark chestnut soils (4,361 ha) (Fig. 2). 285 ha (or 6.6 % of the land) belong to the class with a slope inclination of 1–3°; 775 ha (or 18 %) are in the 3–5° slope inclination class; 2,870 ha (66 %) have a slope inclination ranging from 5 to 7°, and 431 ha (9.4 %) of the land feature slopes with an inclination of over 7°.

Table 5 provides information about the surface runoff and intensity of erosion on dark chestnut soils. The quantitative measures of soil erosion with snowmelt and the spring rainfall event show that snowmelt varied significantly with slopes of varying steepness and exposure throughout the investigation, with soil erosion ranging from 3.6 to 31.1 t/ha.

Erosion processes are induced more intensely by early spring rain than by snowmelt; they are also more intense on slopes with southern exposure than on

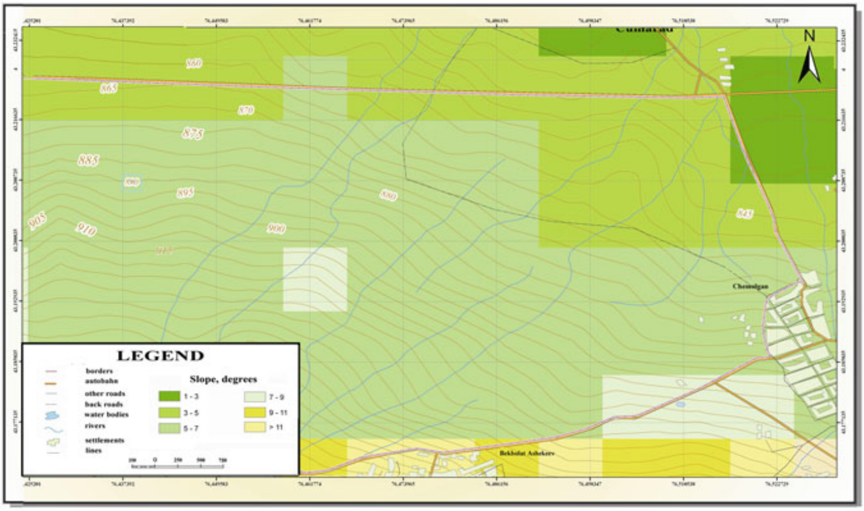

Fig. 2 Map of slope classes in the dark chestnut soil test area, Sholak-Kargaly (Zhambyl/ Almaty)

Table 5 Annual surface runoff and intensity of erosion on dark chestnut soils located in Sholak-Kargaly (Zhambyl/Almaty)

Indicators of erosion	Steepness of slope, degrees			
	1–3	3–5	5–7	>7
Northern exposure				
Snow water, mm/yr	99	96	91	86
Snowmelt runoff, mm/year	18	22	26	32
Coefficient of runoff	0.18	0.24	0.29	0.33
Soil erosion, t/ha/year	1.2	1.5	1.9	2.8
Intensity of erosion, g/l	6.5	6.8	7.3	8.7
Rain precipitation, mm/year	128	128	128	128
Storm water runoff, mm/year	14	28	38	45.9
Coefficient of runoff	0.11	0.22	0.33	0.34
Soil erosion, t/ha/year	2.4	4.9	12.3	23.4
Intensity of erosion, g/l	17.1	17.5	32.4	50.9
Runoff, mm	32	50	64	77.9
Soil erosion, t/ha	3.6	6.4	14.2	26.2
Southern exposure				
Snow water, mm/year	80	76	75	72
Snowmelt runoff, mm/year	20	22	24	28
Coefficient of runoff	0.25	0.29	0.32	0.39
Soil erosion, t/ha/year	1.5	1.7	2.4	3.5
Intensity of erosion, g/l	7.5	7.7	10.0	12.5
Rain precipitation, mm/year	128	128	128	128
Storm water runoff, mm/year	20	29	46	50
Coefficient of runoff	0.16	0.23	0.36	0.39
Soil erosion, t/ha/year	4.0	6.5	17.3	27.6
Intensity of erosion, g/l	20.0	22.4	37.6	55.2
Runoff, mm/year	40.0	51.0	70.0	78.0
Soil erosion, t/ha/year	5.5	8.2	19.7	31.1

those with northern exposure. Thus, the analysis of snowmelt and storm water soil erosion of northern slopes results in snowmelt ranging from 1.2 to 2.8 t/ha and storm water from 2.4 to 23.4 t/ha. For slopes with southern exposure, values range from 1.5 to 3.5 t/ha for snowmelt and from 4.0 to 27.6 t/ha for storm water erosion, respectively. The data indicate that soils on northern slopes are more resistant to erosion than those on slopes with southern exposure, which is also confirmed by the same parameters in Table 1.

The soil's resistance to erosion is primarily dependent on the type of agricultural land use and the crop grown. In this regard, as interpreted for light chestnut soils, cultivation on agricultural landscapes should focus on crops that have the potential to stabilise erosion resistance and to control surface water runoff at dark chestnut soil sites (Table 6).

According to Table 6, and taking into account the results of surface runoff at four elementary sites located on slopes with northern exposure and a 7–8° inclination, an average rainfall intensity of 0.57 mm/min was measured. The resulting

Table 6 Surface runoff on dark chestnut soil; Sholak-Kargaly (Zhambyl/Almaty)

Date of registration	The steepness of slope, degrees	Rainfall in mm	Average intensity of precipitation, mm/min	Indicators of erosion	Land		Cropland	
					Spring barley	Winter wheat	Alfalfa	Natural vegetation on virgin land
10.05.11	7–8	17	0.57	Runoff, m^3/ha %	37.5	25.2	48.9	14.7
					17.9	12.0	23.3	7.0
				Soil erosion, t/ha	1.8	0.65	0.34	0.07
				The intensity of erosion, g/l	48.0	25.7	7.0	4.76

flow of rainwater runoff varied strongly depending on the field crops grown. Runoff from spring barley, winter wheat and alfalfa ranged from 25.2 to 48.9 mm. With virgin soil, it was only 14.7 mm. Thanks to ploughing, the cultivation of alfalfa and winter wheat led to more effective erosion control, with soil erosion measuring 0.34 and 0.65 t/ha, respectively. The greatest erosion was detected for spring barley. However, the effectiveness of moisture accumulation on arable land is higher under winter wheat than under alfalfa, and runoff water was eventually almost twice as high. Erosion affects soil most under barley because the late, weak plant development results in the open soil cover of arable land during rainfall.

Compared with arable land, the lowest runoff water and soil erosion was observed on virgin soils covered with natural vegetation. The planning and implementation of measures to combat soil erosion should therefore be developed by farmers in cooperation with nomads and animal husbandry, depending on the crops cultivated on agricultural land. Parakshina et al. (2010) determined that erosion affects major parts of the territory of the Republic of Kazakhstan. Most of the irrigated land and the land used by rain-fed agriculture is located in the piedmont plains, and is endangered by water erosion, as investigations by Dzhanpeisov (1977), for example, clearly show.

4 Conclusion

A 1:25,000 scale map of agricultural landscape slope inclination was developed using GIS technology for dark and light chestnut soil test sites at the foothills of the Ile Alatau, located in the territory of Zhambyl/Karasai administrative area. Arc GIS 9.3 and built-in 3D Analyst were employed to create relief maps of slope inclination and slope exposure. Using experimental plots with different slope situations in the agricultural land, the surface water runoff from storm water and snowmelt and erosion intensity were characterised and typified by indicators for different slope classes (1–3, 3–5; 5–7; > 7). The loss of fertile soil particles by erosion is particularly problematic on the "warm" slopes with southern exposure, where erosion is much higher than that on slopes with northern exposure. This reflects a greater resistance to erosion of soils on slopes with northern exposure, which is also confirmed by the intensity of erosion rates when compared with southern exposed slopes, which are less resistant to erosion. There is the need for further investigations to verify erosion rates, e.g. (1) when applying a larger number of field observations, and (2) applying soil erosion modelling based on GIS systems, including the full range of factors that are known to affect soil erosion due to water. Verification of modelling should be tested on field-scale plots using measurements and modelling for characteristic drainage systems on the landscape scale.

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