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HUMUS RESERVE VARIATIONS WITH DIVERSE UTILIZATION OF ARABLE GRAY-BROWN SOIL IN THE ARID SUBTROPICAL ZONE OF AZERBAIJAN

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SUMMARY

The subsequent study aimed to determine the humus stock variations with diverse utilization of arable gray-brown soils in the arid subtropical zone. Based on the results, significant variations were prominent in humus stocks of gray-brown soils with diverse arable land uses under arid subtropical conditions. Climate change also considerably contributes to intensification of this process. Field and laboratory analyses revealed that the humus content in the topsoil ranges between 2.13% and 2.48%. The recording of lower humus levels appeared with cotton and maize crops, whereas relatively higher values were evident with alfalfa and winter wheat. The highest increase in humus content surfaced under alfalfa (0.26%), while the lowest increase was in the maize crop (0.05%). The input of plant residues varied, reaching 94 t/ha under alfalfa and 3.59 t/ha under vegetable crops (tomatoes). Over the last 15 years, mineralized humus under alfalfa reached 1.60 t/ha, while the lowest value (1.05 t/ha) emerged under vegetable crops. In the 0–30 cm soil layer, the humus stock balance was 28.58% for alfalfa and 2.60% for silage maize. Overall, a positive balance was notable with alfalfa, winter wheat, and grain maize, whereas a negative balance occurred for silage maize, cotton, and vegetable crops.

Keywords: Arid subtropics, gray-brown soils, humus loss, mineralization, humus balance

Key findings: Crop type was distinctively the main factor in the management of humus dynamics, with perennial crops (alfalfa and grasses) enhancing humus accumulation, while intensive crops (cotton, maize, and vegetables) contributed to its depletion. Overall, sustainable humus management requires the inclusion of perennial crops for improved residue return to the soil.

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INTRODUCTION

Soil global assessments highlighted that soil organic matter dynamics proved highly vulnerable to climate change and intensive land use in arid and semi-arid regions. Rising temperature and altered precipitation patterns further accelerated the mineralization of soil organic carbon, leading to a gradual depletion of humus stocks, particularly with continuous crop cultivation and insufficient organic inputs. However, the sustainable practices, such as crop rotation, inclusion of perennial crop species, and improved residue management, have shown evidence of enhancing carbon sequestration and stabilizing the soil structure.

According to the Food and Agriculture Organization (FAO, 2017), maintaining soil organic carbon is essential for ensuring long-term soil fertility and climate resilience under diverse climatic conditions. Similarly, Lal (2004, 2020) emphasized that balanced organic matter inputs and reduced soil degradation processes were remarkably crucial for sustainable productivity under dryland agroecosystems. Therefore, understanding the interaction between land use, residue dynamics, and current climate factors remains a critical research priority for the sustainable management of arable soils in the arid subtropical environment.

The directions of land use considerably affect soil processes in various ways, particularly in the context of recently observed contemporary climate change (Mammadov, 2015). Under arid subtropical desert conditions, the arable soil variations resulting from these impacts primarily influenced the humus content and its reserves (Babayev and Gurbanov, 2008; Babayev *et al.*, 2011; Ramazanova, 2017). The main objective of the presented study was to investigate the variations in the amount, composition, and stocks of humus in gray-brown (Kastanozems) soils under various arable land uses in the arid subtropical deserts of Azerbaijan.

Numerous factors significantly influencing humus content variations in the arable soils entailed studies over different years (Nadporozhskaya and Chertov, 2004; Mammadova *et al.*, 2022). In this regard, M.P.

Babayev studied the transformations that occurred in soil processes in arid subtropical deserts depending on irrigation and achieved significant results (Gurbanov and Ramazanova, 2000; Ramazanova, 2017). Furthermore, several researchers have investigated other characteristics of irrigated gray-brown soils (Babayev *et al.*, 2011; Babayev *et al.*, 2022).

It is a notable fact that humus amount and its reserves considerably influence the productivity of cultivated crops, their resistance to erosion, and overall soil fertility. Humus content significantly affects the quantity of water-stable aggregates, soil structure, and its susceptibility to erosion. Previous studies suggested that soil organic matter serves as a primary binding agent for the formation of water-stable macro-aggregates, thereby reducing the risk of soil crusting and surface runoff (Blanco-Canqui and Lal, 2004). Previous studies have established that humus content is a primary indicator of soil quality. However, understanding how different arable land uses impact these humus variations remains a vital challenge today.

Therefore, the investigation based on these issues is of great scientific and practical interest. We have endeavored to clarify the relationship between the utilization of nitrogen and biogenic substances by various crops from soils with different humus levels and the evaluation of their return to the soil in the form of residues. Likewise, this study assessed the variations in nutrient accumulation within the soil depending on arable land use.

MATERIALS AND METHODS

Since the cultivated annual and perennial crops possess a more homogenous vegetation cover than the natural vegetation, studying their productivity and the cycling of matter within these cropping systems is of critical importance under current climate change conditions. The conduct of this research transpired between 2019 and 2022 on gray-brown and brown soils in the arid subtropical landscapes of Azerbaijan. However, baseline data regarding humus content relied on research conducted in 2005.

Table 1. Coordinates and absolute altitudes of the research sites.

No.	Latitude (N)	Longitude (E)	Elevation (m)	Administrative district
1	39°23'19,19"N	48°21'31,83"E	80	Bilasuvär
2	40°20'17,21"N	46°50'59,82"E	918	Tartar
3	41°17'52,07"N	48°36'20,00"E	543	Guba
4	40°39'46,86"N	46°43'30,52"E	432	Goranboy
5	40°57'15,84"N	45°38'11,70"E	482	Tovuz
6	40°40'34,44"N	47°23'19,19"E	394	Goychay

Table 2. Humus content indicators in gray-brown and brown soils depending on arable land use.

No.	Land-use Category	Depth (cm)			
		0–25	25–50	50–75	75–100
1	Cotton (<i>G. hirsutum</i> L.)	2.18±0.02	1.62±0.01	0.96±0.02	0.76±0.01
	Alfalfa (<i>M. sativa</i> L.)	2.48±0.02	1.81±0.04	1.22±0.03	0.73±0.03
2	Cereal-grass crop rotation	2.36±0.03	1.76±0.08	1.15±0.03	0.86±0.02
	Winter wheat (<i>T. aestivum</i> L.)	2.12±0.02	1.61±0.06	1.12±0.03	0.84±0.02
3	Grain-vegetable rotation Winter wheat	2.39±0.02	1.68±0.04	1.16±0.02	0.82±0.02
	(<i>T. aestivum</i> L.)	2.51±0.03	1.83±0.05	1.18±0.03	0.81±0.03
4	Winter wheat (<i>T. aestivum</i> L.)	2.20±0.05	1.64±0.04	1.15±0.05	0.82±0.01
5	Maize cultivation (<i>Z. mays</i> L.)	2.13±0.04	1.56±0.02	1.05±0.01	0.79±0.03
6	Pasture land	2.96±0.03	2.48±0.02	0.86±0.01	0.60±0.01
		2.48±0.02			

Characteristics of the study area comprised a foothill relief, with altitudes primarily ranging from 300 to 600 meters above sea level (Table 1). The terrain consists of areas with relatively gentle slopes; nonetheless, the soil erosion risk was high, particularly during rainy periods. In irrigated soils, a persistent threat of irrigation-induced erosion existed. The soil-forming rocks were predominantly of sedimentary deluvial-proluvial origin. On the slopes of the Greater and Lesser Caucasus, calcareous clays, loess-like deposits, and sandstones were prevalent.

The climatic conditions of the region received an arid subtropical classification. The average annual temperature varied between 12.5 °C and 14.5 °C, annual precipitation ranged from 350 to 550 mm, and the humidity coefficient was 0.35-0.50. However, an increase in temperature and a decrease in precipitation levels have been evident in previous years. Consequently, the reduction in moisture necessitates soil irrigation, which subsequently influences soil processes and the mineralization rate of humus content.

Field research began following the methodological guidelines of Dospekhov

(1985). Composite soil samples totaled 36 as collected from the studied arable lands across research sites. Ensuring statistical reliability and analytical precision enabled all field samplings and subsequent laboratory analyses performed in triplicate (3 replicates). In the soil, the humus content determination happened under laboratory conditions using the Tyurin method (Shamrikova *et al.*, 2024).

RESULTS AND DISCUSSION

The long-term research revealed variations in humus content and reserves were prominent under irrigated conditions, both during the experimental period and over the last 15 years. Different results obtained were dependent on the crops cultivated in gray-brown soils of the arid steppe landscape. These variations were noticeable throughout the soil profile down to a depth of 100 cm (Table 2). In the 0–25 cm soil layer, the highest humus content recorded was in pasturelands (2.96%). In the soil with cotton-alfalfa crop rotation, the humus content was 2.48%, and in the soil under winter wheat, the said value was 2.51%,

Table 3. Variations in soil humus content (0–30 cm layer) during the experimental period (2019–2022).

No.	Agricultural orientation	Humus content (%)		Humus accumulation (%)
		Initial	Final	
1	Cotton cultivation (<i>G. hirsutum</i> L.)	2.18	2.18	0
	Alfalfa (<i>M. sativa</i> L.)	2.22	2.48	0.26
2	Cereal-grass crop rotation	2.16	2.36	0.20
	Winter wheat (<i>T. aestivum</i> L.)	2.12	2.13	0.01
3	Winter wheat (<i>T. aestivum</i> L.) Cereal-vegetable crop rotation	2.51	2.52	0.01
		2.39	2.45	0.06
4	Winter wheat (<i>T. aestivum</i> L.)	2.20	2.28	0.08
5	Maize cultivation (<i>Z. mays</i> L.)	2.13	2.08	-0.05
6	Pasture land	2.96	2.98	0.02

which remains low compared with other land uses. Similar patterns manifested in gray-brown soils of the arid subtropical steppe, where irrigation under cotton cultivation led to a decrease in humus content in the upper horizons, while it showed an increase in the lower layers of the soil profile (Babayev, 1984). This study finding was in agreement with Lal (2004), who reported that irrigation and intensive cultivation reduce organic matter in surface horizons while redistributing it to deeper soil layers.

The results revealed the lowest humus content was prevalent in areas under long-term winter wheat and maize cultivations, where values ranged between 2.12% and 2.13%. However, it was noteworthy that the humus content has not shown significant differences in these soils. In soil humus content, considerable variations were prominent throughout the study years. For soil humus, no increase appeared under cotton and maize crops. During the study period, the humus content in cotton-cultivated soils did not increase, while a decrease of 0.05% recorded in maize fields occurred (Table 3). However, the highest increase was remarkable under alfalfa cultivation, where the humus content rose by 0.26% during the study years, which is consistent with Drinkwater *et al.* (1998). They demonstrated that legume-based systems significantly enhanced soil organic matter compared to with cereal-based systems. These results were consistent with previous findings, which also reported a negligible increase in humus levels with

vegetable and maize cropping systems (Mammadova *et al.*, 2022).

In winter wheat-grass crop rotation, the increase in humus content was 0.20%. However, in other cropping systems, the amount of accumulated humus varied between 0.01% and 0.08%. From these observations, one can conclude that the highest humus content existed in alfalfa and perennial grass fields, receiving further support from Six *et al.* (2002). They stated that perennial grasses and legumes improve soil carbon stabilization compared with annual cropping systems. The lower increase observed in other crops has led to a gradual depletion of humus stocks. These results align with recent research demonstrating crop rotations involving perennial crops, like alfalfa and winter wheat, significantly enhance topsoil organic carbon (SOC) and nutrient accumulation compared with less diverse cropping systems in semi-arid environments (Li *et al.*, 2023).

The aforementioned results also allow for the determination of humus dynamics over the last 15 years. During this period, the study aimed to evaluate the accumulation of plant residues in the soil and the potential amount of humus formation (Table 4). Under irrigated conditions, the dry matter yield of alfalfa can reach 12.5 t/ha. Although the hay harvesting and removal ensued, a portion remains on the soil surface, with an average annual amount of 2.59 t/ha. With its dense root system, the average amount of root residues was 6.86 t/ha. Therefore, in total, 9.45 t/ha of organic residue accumulates in the soil annually, and

Table 4. Accumulation of plant residues in the soil and the potential amount of humus formation over the last 15 years.

Cultivated crops	Crop yield (t/ha)	Plant residue amount (t/ha)			Mean annual potential humus (t/ha)
		Root residues	Aboveground residues	Total	
Alfalfa	12.5	6.86	2.59	9.45	2.84
Winter wheat	3.25	4.36	1.78	6.14	1.24
Cotton	2.89	5.57	2.25	7.82	1.12
Silage maize	27.8	7.32	1.13	8.45	1.27
Grain maize	6.6	8.19	1.25	9.44	1.89
Vegetable (Tomato)	28.7	2.25	1.34	3.59	0.25

the potential humus formation has an estimate of 2.84%, highlighting the significant contribution of root-derived biomass to soil organic matter, as also reported by Bolinder *et al.* (2007).

The winter wheat average yield was 3.25 t/ha. This crop also contributes an annual average of 6.14 t/ha of plant residues to the soil, resulting in a potential humus formation of 1.24%. However, these indicators became significantly weaker for the cotton crop, which has an average annual yield of 2.89 t/ha. The total plant residues (root and surface residues combined) amount to 7.82 t/ha, with a potential humus formation of 1.12%. Since the cellulose prevails in cotton surface residues, the decomposition process appears considerably slower, which prevents the humus formation. Consequently, despite the high amount of surface residues, humus production remains low, reflecting the influence of residue composition on decomposition processes, as demonstrated by Jenkinson and Rayner (1977).

Maize cultivation served various purposes. In silage maize fields, the green biomass incurred harvesting and removal; therefore, the amount of surface residue entering the soil only had an average of 1.13 t/ha, with a total residue of 8.45 t/ha. Based on these residues, the potential humus formation was 1.27%, which was considerably higher than that of winter wheat. For grain maize, the plant residues were relatively higher, with root residues amounting to 8.19 t/ha, total residues amounting to 9.44 t/ha, and the resulting humus formation being 1.89%. This indicated the positive role of increased residue return in enhancing soil

organic matter, as highlighted by Wilhelm *et al.* (2004).

The experiments showed the lowest humus formation occurred in vegetable (tomato) fields, which is consistent with Zhang *et al.* (2012). They reported that intensive vegetable production systems often reduce soil organic matter due to low residue return and frequent soil disturbance. Despite relatively high productivity, the amount of plant residues remaining in the soil was significantly lower than other crops, totaling only 3.59 t/ha. Therefore, the potential humus formation had an estimate of only 0.25%. The above analysis clearly exhibited that the highest humus accumulation occurred under alfalfa, while the lowest was under vegetable crops. The results highlighted the indispensable role of alfalfa crops in increasing the soil humus content.

The soil organic matter (humus) losses during the cultivation of various crops during the experimental period (2019–2022) also underwent calculations (Table 5). The results revealed the alfalfa crop yield reached 12.5 t/ha, with a nitrogen requirement of 22 kg per ton of yield. This is consistent with Whitehead (2000), who highlighted that high biomass crops increase both nitrogen uptake and organic matter mineralization rates. However, the total nitrogen uptake for alfalfa crop was 266 kg/ha, in which 80 kg/ha being directly obtained from the soil. The amount of mineralized humus, as determined, occurred to be 1.60 t/ha.

For winter wheat, the nitrogen requirement was 25 kg per ton of grain. The total nitrogen uptake for the overall yield was 217 kg/ha, with 65 kg/ha sourced from the soil. Under winter wheat crops, the humus

Table 5. Loss of soil organic matter (humus) during the cultivation of various crops during the experimental period (2019–2022).

Cultivated crops	Crop yield (t/ha)	Nitrogen requirement per unit of yield (kg/t)	Total nitrogen uptake by crop yield (t/ha)		Mineralized humus (t/ha)
			Total	Including from the soil	
Alfalfa, dry hay biomass	12.5	22	266	80	1.60
Winter wheat grain	3.25	25	217	65	1.30
Cotton	2.89	28	102	51	1.20
Silage maize	27.8	30	173	86	1.22
Grain maize	6.6	22	145	72	1.45
Vegetable (Tomato)	28.7	21	81	40	1.05

Table 6. Potential humus balance in the 0–30 cm soil layer of the study areas over the last 15 years.

Cultivated crops	Humus loss (t/ha)	Humus increase (t/ha)			Humus balance
		Total humus increase (t/ha)	From plant residues	From manure application	
Alfalfa	28.12	46.7	42.6	4.1	+28.58
Winter wheat	14.36	23.0	19.5	3.5	+8.64
Cotton	26.32	25.2	18.0	6.2	-1.12
Silage maize	22.40	19.8	18.3	1.5	-2.60
Grain maize	23.20	22.25	21.75	1.5	+0.05
Vegetable (Tomato)	22.04	21.55	15.75	5.8	-0.49

mineralization occurs very slowly as compared with alfalfa, with an amount of mineralized humus equaling 1.30 t/ha. Under cotton crops, the mineralization further weakened. The nitrogen required to form one ton of cotton yield was higher than that of alfalfa and wheat crops, standing at 28 kg/t. The total nitrogen uptake for the cotton yield was 102 kg/ha, with half of which obtained from the soil. The amount of mineralized humus for cotton crops was 1.20 t/ha, reflecting the influence of crop type on nitrogen cycling and soil organic matter turnover, as noted by Brady and Weil (2016).

The silage maize yield reached 27.8 t/ha. Nitrogen consumption for maize crops was higher, with 30 kg of nitrogen required per ton of green biomass. The total nitrogen uptake was 173 kg/ha, of which 86 kg/ha was coming from the soil. The mineralized humus, upon calculation, was at 1.22 t/ha. In grain maize fields, humus mineralization was higher at 1.45 t/ha, although other indicators were lower than in silage maize. Vegetable (tomato) yields were high, reaching 28.7 t/ha. The nitrogen requirement for tomato yield

formation was 21 kg/t. Total nitrogen uptake amounted to 81 kg/ha, with 40 kg/ha directly obtained from the soil. In vegetables (tomatoes), the humus mineralization recorded was at 1.05 t/ha, indicating the differences in crop management and residue input significantly influence nitrogen dynamics and soil organic matter mineralization, as demonstrated by Smith *et al.* (2008).

During the study, determining the potential humus balance in the 0–30 cm soil layer over a 15-year period succeeded (Table 6). The results showed the highest humus formation occurred under alfalfa crops, with 28.58 t/ha of humus generated over 15 years. This figure has winter wheat (8.64 t/ha) following it, while the increase in grain maize fields was minimal. In contrast, the humus balance for other crops was negative. Specifically, the balance under the cotton crop was 1.12 t/ha, and for silage maize, it was 2.60 t/ha. In conclusion, alfalfa cultivation proved truly essential for preserving and maintaining soil humus levels, which is consistent with the findings of Lal (2004) and Six *et al.* (2002). They confirmed that

perennial legume systems are most effective in increasing long-term soil carbon stocks and maintaining soil fertility.

CONCLUSIONS

According to this study, in the gray-brown (cinnamon) soils of dry subtropics, the humus loss associated with climate variability was evident in cotton, maize, and vegetable fields. This was ascribable to the high humus requirements of these crops, combined with rising temperatures, which intensify the mineralization process. Conversely, the humus accumulation was more intensive under alfalfa and winter wheat. The results revealed the humus balance was positive under alfalfa, winter wheat, and grain maize. However, a negative balance for humus resulted in soils under cotton, silage maize, and vegetable crops. The results highlighted that it is essential to implement additional agrochemical and agrotechnical measures to preserve and maintain the soil's humus reserves.

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