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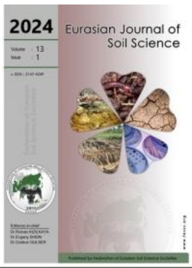

Soil fertility status, productivity challenges, and solutions in rice farming landscapes of Azerbaijan

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Abstract

Rice, a fundamental staple globally, plays a pivotal role in addressing food security and nutrition. This study explores the intricate interplay between soil characteristics, productivity challenges, and solutions in Azerbaijan's rice farming landscapes, acknowledging the agricultural importance of rice and its contribution to human nutrition. This study aims to assess the physical and chemical properties of soil samples from Azerbaijan's rice cultivation areas, with a focus on nutrient content and the identification of elements limiting productivity and plant nutrition. By synthesizing these perspectives, the study enriches the understanding of the complex relationship between soil fertility class and rice productivity, offering insights for sustainable rice farming. Soil samples were collected from representative rice fields across Azerbaijan and analyzed for various parameters, including soil texture, pH, electrical conductivity, organic matter, and nutrient content. The soil sampling and preparation process maintained the integrity of collected samples, providing a reliable basis for scientific analysis. The results reveal diverse soil properties, with clayey texture prevailing. Soil acidity, salinity, and nutrient deficiencies pose challenges, emphasizing the need for corrective measures. The majority of soils exhibit unsuitable pH levels and elevated sodium content, necessitating interventions such as soil acidification and sodicity remediation. Soil salinity issues highlight the importance of drainage and leaching practices. Low organic matter and nutrient deficiencies, particularly zinc and manganese, underscore the need for targeted interventions, including foliar applications. Overall, Azerbaijan's rice-cultivated areas face challenges related to soil fertility, salinity, and nutrient deficiencies, impacting productivity. Corrective measures, such as soil reclamation, proper fertilization, and foliar applications, are crucial for enhancing crop yields. The study contributes valuable insights for local practices and the broader global pursuit of sustainable rice farming, emphasizing the importance of tailored strategies in addressing specific regional challenges.

Keywords: Rice, Soil, Fertility, Salinity, Azerbaijan, Sustainability.

Introduction

Rice stands as a cornerstone in global agriculture, serving as a vital food source for a substantial portion of the world's population. Its significance extends beyond mere sustenance, playing a critical role in addressing food security and nutritional needs (Fukagawa and Ziska, 2019; Mohidem et al., 2022; Maftukhah et al., 2022). As we delve into the nuances of soil characteristics, productivity challenges, and solutions within the rice farming landscapes of Azerbaijan, it becomes imperative to recognize the agricultural importance of the rice plant and its indispensable role in human nutrition. Globally, rice boasts an average yield of approximately 4.5 tons per hectare, with Turkey exceeding this average at an impressive 8.5 tons per hectare. However, the unique rice

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farming landscape of Azerbaijan presents distinct challenges, reflected in an average yield of 3 tons per hectare—a notable disparity compared to global and regional averages. This yield discrepancy prompts a comprehensive investigation into the multifaceted factors contributing to the suboptimal performance of rice production within the Azerbaijani context. From crop selection to soil preparation, and from disease and pest management to deficiencies in fertilization practices, our study focuses on the intricate interplay of these elements in the fields where rice is cultivated in Azerbaijan.

Looking beyond the borders of Azerbaijan, insights from soil science significantly contribute to our understanding of the intricate relationship between soil characteristics and rice productivity. Simultaneously, an exploration of soil physico-chemical properties underscores the necessity for precise measurements to ensure higher rice production, as exemplified in regions such as Turkey and Japan. The critical role of soil physico-chemical properties in the growth, yield, quality, and market competitiveness of crops is evident, and their degradation leads to decreased soil fertility, nutrients, and overall productivity (Bueno and Ladha, 2009; Gathala et al., 2011; Timsina and Connor, 2001; Fan et al., 2008). In the context of sustainable agro-ecosystems, the enhancement of soil chemical properties can be achieved through fertilization, cropping adjustment, and other farm managerial practices (Gathala et al., 2011; Ladha et al., 2000; 2003). Researchers have extensively studied the variability and impact of soil chemical properties on rice yield. Juhos et al (2016) explored yield determinants by constructing a soil quality index from more than ten chemical and physical indicators on a 225 ha farmland in East Hungary. Similarly, Obade and Lal (2016) tested four methods to construct a soil quality index, identifying properties determining soil physico-chemical and crop yield in private fields of Ohio, US. In Japan, despite rice still being the largest crop, its contribution to gross agriculture output decreased from 27.8% in 1990 to 18.0% in 2016 (Ladha et al., 2003). Under acreage reduction policies, the total planted area of rice decreased by 24% in the past two decades (Mousavi et al., 2009). Compared to other crops, rice yield is more influenced by soil fertility. Therefore, precise measurement of soil properties and their impact on yield is crucial in Japan, where significant soil nutrients are drained by the rich or deposited in dammed rivers (Ladha et al., 2000). A substantial body of literature has focused on the soil chemical properties of paddy fields in Japan. Katayanagi et al (2009) conducted a nationwide analysis of 986 plots, adopting individual indicators such as pH and total carbon. To estimate the effect of soil chemical properties, Matsumoto et al (1995) included the content of available arsenic, phosphorus, and acid ammonium oxalate extractable iron and aluminum. Additionally, Mori et al (2011) represented soil chemical properties by pH, cation exchange capacity, and oxidation-reduction potential. Li et al (2003) assessed the determinacy of soil chemical properties on rice yield, using on-farm data from individual paddy fields.

In this study, we aim to determine the physical and chemical properties of soil samples from Azerbaijan's rice cultivation areas, assessing nutrient content, and identifying soil characteristics and nutrient elements that may limit productivity and plant nutrition in rice farming. Synthesizing these perspectives, our study enriches our understanding of the complex interplay between soil fertility class and rice productivity. By shedding light on challenges specific to Azerbaijan, we aspire not only to enhance local practices but also to contribute valuable insights for the broader global pursuit of sustainable rice farming.

Material and Methods

Soil Sampling

In accordance with the 2022 data, rice cultivation is carried out on a total of 3.129,3 hectares in Azerbaijan. The rice cultivation areas in the country are distributed as follows: 1.225,3 hectares in the Lenkeran-Astara economic region (including Astara, Lenkeran, and Masalli districts), 1.820 hectares in the Central Aran economic region (including Agdash, Goychay, Ujar, Yevlakh, and Zardab districts), and 84 hectares in the Shirvan-Salyan economic region (Salyan district). Therefore, a total of 17 soil samples were collected from rice fields, representing the rice cultivation areas in Azerbaijan: 6 samples from the Lenkeran-Astara economic region, 7 samples from the Central Aran economic region, and 4 samples from the Shirvan-Salyan economic region. The soil samples were collected from the 0-20 cm depth at the conclusion of rice harvesting, specifically from rice fields characterized by monoculture rice farming practices, where rice plants are cultivated annually. The locations from which soil samples were obtained are illustrated in Figure 1. Upon collection, soil samples were carefully taken from each rice field, ensuring representation across the entire area. The collected soil samples were subjected to thorough removal of stones and plant residues on the soil surface. Subsequently, the soil samples were transported to the laboratory for further analysis. In the laboratory, the soil samples were processed under controlled conditions. They were first air-dried in a cool and shaded environment to prevent alterations in their chemical composition due to excessive heat or sunlight. Once dried, the soil samples were finely ground after removing any remaining moisture. The grinding process facilitated homogenization and ensured that the soil samples were uniform for subsequent analyses. The sieving of the soil samples through a 2 mm mesh was then conducted to achieve a consistent particle size for optimal analytical results. The prepared soil samples, now in a homogeneous and fine-grained state, were deemed analytically ready and were utilized for subsequent investigations. The entire soil sampling and preparation process aimed to maintain the integrity of the collected samples and provide a reliable basis for the scientific analysis of the soil characteristics in the designated rice fields.

Figure 1. Collection of Soil Samples from Rice-Cultivated Lands in Azerbaijan

Climate

The annual precipitation and temperature averages of Azerbaijan, along with the Köppen-Geiger classification map (Figure 2), are provided herein. The temperature patterns across Azerbaijan exhibit regularity, influenced by the characteristics of incoming air masses, regional topography, and proximity to the Caspian Sea. The Caspian Sea plays a pivotal role in modulating temperatures in coastal areas situated approximately 20 kilometers away, causing a decrease in summer temperatures and an increase in winter temperatures. Simultaneously, it acts as a mitigating factor against the impact of hot and arid air masses originating from Central Asia. The average annual temperature maintains a range of 14–15°C in regions such as the Kur-Araz Lowland, coastal areas south of the Apsheron Peninsula, and the Lenkoran Lowland. Temperature decreases are observed with proximity to mountainous terrain, with averages of 4–5°C at an altitude of 2,000 meters and 1–2°C at 3,000 meters. Notably, the absolute minimum temperature of −33°C and the absolute maximum temperature of 46°C were recorded in Julfa and Ordubad, respectively. Azerbaijan experiences varying precipitation levels across its regions, with the maximum annual precipitation occurring in Lankaran (ranging from 1,600 to 1,800 mm) and the minimum in the Absheron Peninsula (ranging from 200 to 350 mm). This geographical diversity in precipitation underscores the nuanced climatic conditions within Azerbaijan.

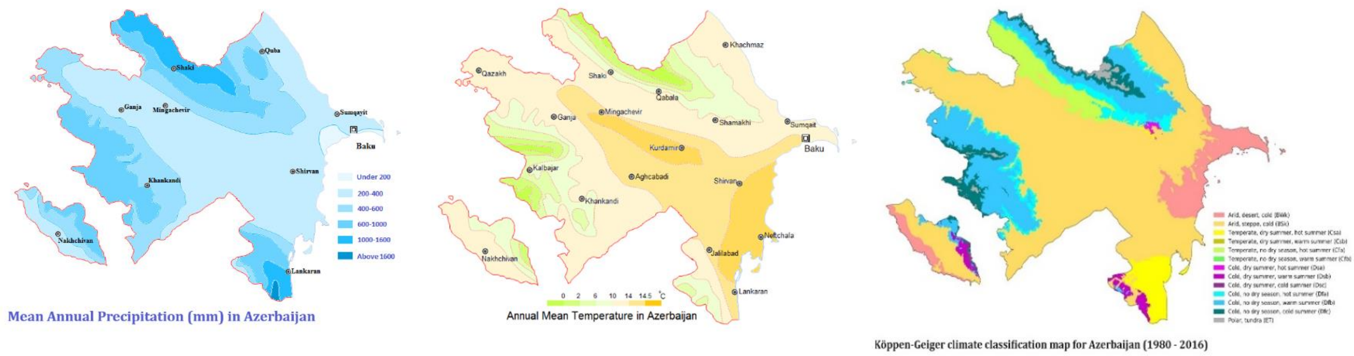

Figure 2. Climatic Overview of Azerbaijan: Precipitation, Temperature, and Köppen-Geiger Classification map

Soil Analyses

In the conducted soil analyses, various parameters were determined using established scientific methods. The soil texture was determined by the hydrometer method as described by Bouyoucos (1962). The pH and Electrical Conductivity (EC) were measured in a 1:1 (w/v) soil-to-distilled water suspension using a pH meter and EC meter, following the procedures outlined by Peech (1965) and Bower and Wilcox (1965). Organic matter content was assessed through wet oxidation with $K_2Cr_2O_7$, following the method proposed by Walkley and Black (1934). Calcium carbonate ($CaCO_3$) content was determined volumetrically using the Scheibler calimeter, as per the protocol detailed in Rowell (2010). Total nitrogen was quantified using the Kjeldahl method, following the procedures outlined by Bremner (1965). Olsen method with 0.5 M $NaHCO_3$ extraction was employed for the determination of available phosphorus, in accordance with the method introduced by Olsen and Dean (1965). Exchangeable potassium (K) and sodium (Na) were measured using Flame photometry after 1N NH_4OAc extraction, as described by Pratt (1965). Exchangeable calcium (Ca) and magnesium (Mg) were determined by EDTA titration following 1N NH_4OAc extraction, as per the procedures outlined by Heald (1965). Additionally, available iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) were determined in triplicate using the DTPA extraction method, followed by analysis with Atomic Absorption Spectrophotometry, as detailed by Lindsay and Norvell (1978).

Computation of Soil Fertility Index (SFI)

Over the years, there are many different soil testing procedures or methods that provide the most reliable prediction of crop yield response to evaluate soil fertility status. Soil fertility status can be evaluated directly or indirectly. Direct evaluations are carried out in the field, greenhouses or laboratory by means of experiments carried out under given climatic and management conditions. Indirect evaluations consist basically in developing and applying models of varying complexity. One of the most suitable models is SFI model. SFI was calculated to qualitative soil fertility classes by means of parametric approach using fifteen parameters for each soil sample point. To develop this model and determine threshold level of each SFI class, some literature such as Lindsay and Norvell (1978), Moran et al. (2000), Arshad and Martin (2002), Lu et al. (2002), Borůvka et al. (2005), Hazelton and Murphy (2007) were used. The fifteen parameters (diagnostic factors) are commonly implemented in physical and chemical characteristics of soil and designated with letters from A to P (Table 1). Each parameter or factor is evaluated ranging between 10 and 100. The least favour value of factor rating is 10 and the most beneficial value of factor rating is 100 for plant growth. In other words, the limiting nature of each SFI classes is taken into account by its effect in reducing productivity.

Table 1. Factor rating each soil parameters

	Diagnostic Factors	Units	Factor rating 100	80	50	20	10
			Available macronutrients				
A	N_{total}	g kg^{-1}	>3,2	1,7-3,2	0,9-1,7	0,45-0,9	<0,45
B	$P_{av.}$	mg kg^{-1}	>80	25-80	8-25	2,5-8	<2,5
C	$K_{exc.}$	me 100g^{-1}	0,28-0,74	0,74-2,56	0,23-0,28	>2,56	<0,13
D	$Ca_{exc.}$	me 100g^{-1}	17,5-50	5,75-17,5	1,19-5,75	>50	<1,19
E	$Na_{exc.}$	me 100g^{-1}	<0,20	0,21-0,30	0,31-0,70	0,71-2,00	>2,00
F	$Mg_{exc.}$	me 100g^{-1}	1,33-4,00	4,00-12,5	0,42-1,33	>12,5	<0,42
			Available micronutrients				
G	$Mn_{av.}$	mg kg^{-1}	14-50	4-14	50-170	>170	<4
H	$Zn_{av.}$	mg kg^{-1}	0,7-2,4	2,4-8,0	0,2-0,7	>8,0	<0,2
I	$Fe_{av.}$	mg kg^{-1}	2,0-4,5	1,0-2,0	0,2-1,0	>4,5	<0,2
J	$Cu_{av.}$	mg kg^{-1}	>0,2				<0,2
			Soil physico-chemical properties				
K	$CaCO_3$	g kg^{-1}	50-150	10-50	150-250	>250	<10
L	EC	dSm^{-1}	<2	2-4	4-6	6-8	>8
M	pH	1:1, w/v	6,5-7,5	7,5-8,5	5,5-6,5	4,5-5,5	>8,5 and <4,5
N	SOM	g kg^{-1}	>30	20-30	10-20	5-10	<5
O	Texture		CL, SCL, SiCL	vfSL, L, SiL, Si, <50%C	>50%C, SC, SiC	SL, fSL	S, LS

N_{total} : Total nitrogen; $P_{av.}$: Available phosphorus; $K_{exc.}$: Exchangeable potassium; $Ca_{exc.}$: Exchangeable calcium; $Mg_{exc.}$: Exchangeable magnesium; $Mn_{av.}$: Available manganese; $Zn_{av.}$: Available zinc; $Fe_{av.}$: Available iron; $Cu_{av.}$: Available copper; EC: Electrical conductivity, SOM: Soil organic matter, CL: Clay Loam; SCL: Sandy Clay Loam; vfSL: very fine Sandy Loam; L: Loam; C: Clay, SL: Sandy Loam, fSL: fine Sandy Loam; S: Sand, LS: Loamy Sand, SiCL Silty Clay Loam; SiL; Silty Loam, Si: Silty, SC: Sandy Clay, SiC: Silty Clay

SFI is calculated and using the value of factor rating for each factor as follows (Equation 1);

SFI= Soil Fertility Index

$$SFI = \left[R_{max} x \sqrt{\frac{A}{100} x \frac{B}{100} x.......} \right] x100 \quad (1)$$

$$R_{max} = \text{Maximum ratio, } \frac{(A + B + ...+O)}{15}$$

A, B... Rating value for each diagnostic factors

SFI of each soil sample point can be classified according to classes indicated in Table 2.

Table 2. Classes and values of soil fertility index.

Class	Description	Soil Fertility Index
S1	Good fertility	>80
S2	Moderate fertility	80-50
S3	Marginal fertility	50-20
N	Poor fertility	<20

Results and Discussion

The physicochemical properties, nutrient contents, and productivity classes of soils collected from rice cultivation areas in Azerbaijan are presented in Tables 3, 4, 5, and 6. According to the obtained results, soil texture exhibits a wide variability ranging from Sandy Clay Loam (SaCL) texture to heavy clay (C) texture, although soil texture is generally clayey. The soil texture plays a crucial role in influencing the movement and availability of air and water in soil, root growth, water and nutrient uptake, and overall plant growth. Typically, Azerbaijan paddy soils are characterized by a high clay content, which is the predominant component of mineral soil due to its exceptionally high specific surface area. This property allows clayey soils to effectively retain nutrients and water (Hamoud et al., 2019). It can be asserted that a significant majority (>88%) of rice-cultivated areas in Azerbaijan have suitable soil texture and clay content.

Table 3. The coordinates where soil samples were taken and the particle size distribution and bulk density status of the soil

Lab No	Sampling points	Coordinates		Partical size distribution			
				Sand, %	Silt, %	Clay, %	Class
1	Lenkeran-Astara economic region	38.6322740 N	48.8646310 E	50,69	15,91	33,41	SaCL
2		38.4605490 N	48.8385470 E	12,94	36,55	50,51	C
3		38.6339410 N	48.8409200 E	10,51	29,66	59,83	C
4		38.9879560 N	48.7193950 E	18,23	37,16	44,61	C
5		38.6318770 N	48.8654710 E	45,83	15,25	38,91	SaC
6		38.6328720 N	48.8646280 E	4,86	34,20	60,94	C
7	Central Aran economic region	40.2591950 N	47.6314250 E	7,66	42,50	49,84	SiC
8		40.2559770 N	47.6289990 E	11,55	78,58	9,87	SiL
9		40.5438710 N	47.2880790 E	6,76	7,69	85,55	C
10		40.5664400 N	47.3426590 E	8,43	31,40	60,17	C
11		40.2532890 N	47.5357300 E	17,28	37,33	45,38	C
12		40.5070390 N	47.6789500 E	4,83	15,00	80,17	C
13		40.4983230 N	47.6842900 E	7,54	30,53	61,93	C
14	Shirvan-Salyan economic region	39.9033420 N	40.0782160 E	2,68	40,68	56,64	SiC
15		39.8355970 N	49.0250100 E	13,37	20,82	65,81	C
16		39.9027510 N	49.0793570 E	4,90	16,02	79,07	C
17		39.9016200 N	49.0666840 E	4,04	29,15	66,81	C
			Min.	*2,68*	*7,69*	*9,87*	
			Max.	*50,69*	*78,58*	*85,55*	
			Mean	*13,65*	*30,50*	*55,85*	

Approximately 82% of rice soils in Azerbaijan exhibit an alkaline reaction (pH > 7.3). The elevated pH levels in the soils may stem from high lime or sodium content. When evaluated based on lime content (Table 4), the soils are generally classified as calcareous (5-15%) and highly calcareous (>15%). Furthermore, about 94% of the soils have a high exchangeable sodium content (>0.7 me Na $100g^{-1}$), indicating sodicity in approximately 35% of these soils based on the Exchangeable Sodium Percentage (ESP) value (>10%), and a risk of sodicity (5-10%) in 14% of the soils (Table 5). Both the high soil pH and elevated sodium content are unsuitable for rice cultivation. The optimal pH level for rice cultivation is around 6 (Abdul Halim et al., 2018). Therefore, corrective measures are essential, such as applying soil acidifying materials (e.g., powdered or liquid sulfur compounds) in soils without sodium-related issues to lower soil pH. For soils with high ESP, remediation methods involving the removal of sodium from the soil, such as applying gypsum ($CaSO_4$) to the soil and leaching sodium from the soil, are necessary. The electrical conductivity (salinity) of the soils exhibits a wide range, ranging from 0.40 to 14.41 dSm^{-1}, with some rice fields indicating a significant salinity issue. In 70% of the sampled points, the salinity level is deemed unsuitable for rice cultivation. Moreover, approximately 70% of the sampled areas exhibit a severe salinity problem (>4 dSm^{-1}). For rice cultivation, electrical conductivity values below 0.90 dSm^{-1} are recommended (USDA, 2001), highlighting the unsuitability of the soil in the sampled locations for rice crops. In fields with salinity issues, after the implementation of drainage systems, it is crucial to leach the soil to remove excess salts. In 65% of the collected soil samples, the organic matter content is low (<1.70%), 24% exhibit a moderate level (1.70% – 3.00%), and 12% are considered sufficient (>3%). In fields with insufficient organic matter, enhancing soil organic matter content to the 3% level, using composts with low salt content derived from plant and animal sources, becomes crucial for the sustainable utilization of the soils.

Table 4. The chemical properties of the soils along with the total nitrogen (N) and available phosphorus (P) content

No	pH	EC, dSm^{-1}	$CaCO_3$, %	Organic matter, %	Total N, %	Available P, mg kg^{-1}
1	7,70	0,51	12,93	1,61	0,18	24,26
2	7,09	2,15	5,44	3,17	0,29	31,92
3	6,63	0,59	6,37	3,13	0,29	15,24
4	7,96	13,07	4,93	1,87	0,24	16,72
5	7,64	0,62	9,90	1,15	0,16	25,28
6	5,72	0,79	5,13	1,40	0,22	12,43
7	8,04	14,41	17,12	1,37	0,11	2,47
8	8,17	7,62	15,06	0,88	0,09	3,38
9	7,86	4,77	6,69	2,47	0,23	4,97
10	7,92	2,97	15,93	1,81	0,20	2,72
11	7,70	2,13	15,94	1,24	0,16	10,43
12	7,78	0,40	17,11	1,86	0,24	5,64
13	7,82	1,55	17,33	1,21	0,20	24,56
14	7,77	12,24	17,60	0,97	0,10	1,41
15	7,89	1,80	18,22	1,38	0,16	6,44
16	7,95	13,40	17,34	0,98	0,10	4,37
17	7,97	5,19	19,18	1,66	0,19	33,11
Min.	*5,72*	*0,40*	*4,93*	*0,88*	*0,09*	*1,41*
Max.	*8,17*	*14,41*	*19,18*	*3,17*	*0,29*	*33,11*
Mean	*7,62*	*4,95*	*13,07*	*1,66*	*0,18*	*13,26*

Table 5. The contents of exchangeable cations (Na, K, Ca, and Mg) in the soils

No	Na, me 100g^{-1}	K, me 100g^{-1}	Ca, me 100g^{-1}	Mg, me 100g^{-1}	ESP, %	Ca/Mg	Ca/K	Mg/K
1	0,51	0,27	26,74	5,49	1,54	4,87	99,72	20,49
2	4,03	0,18	35,03	10,29	8,13	3,40	195,64	57,47
3	0,76	0,36	29,92	17,86	1,55	1,68	83,47	49,82
4	1,71	0,44	19,58	6,37	6,08	3,08	44,50	14,47
5	0,52	0,30	26,93	7,61	1,47	3,54	88,52	25,02
6	0,74	0,55	21,35	13,39	2,05	1,59	38,64	24,24
7	32,89	0,50	29,89	13,58	42,80	2,20	59,57	27,06
8	13,16	0,45	56,77	17,22	15,03	3,30	125,71	38,13
9	7,83	1,08	34,38	20,89	12,20	1,65	31,84	19,34
10	2,87	0,84	37,83	16,30	4,96	2,32	45,04	19,42
11	1,30	1,07	25,98	11,06	3,31	2,35	24,29	10,34
12	0,73	0,58	20,39	8,97	2,39	2,27	35,23	15,49
13	2,06	0,66	19,71	9,00	6,56	2,19	29,68	13,56
14	23,71	0,94	42,69	11,49	30,08	3,71	45,37	12,21
15	2,78	1,02	22,48	15,11	6,72	1,49	22,05	14,83
16	26,10	1,23	29,80	13,77	36,81	2,16	24,14	11,15
17	10,11	1,54	24,27	11,56	21,29	2,10	15,74	7,50
Min.	*0,51*	*0,18*	*19,58*	*5,49*	*1,47*	*1,49*	*15,74*	*7,50*
Max.	*32,89*	*1,54*	*56,77*	*20,89*	*42,80*	*4,87*	*195,64*	*57,47*
Mean	*7,75*	*0,71*	*29,63*	*12,35*	*11,94*	*2,58*	*59,36*	*22,38*

Approximately 24% of the soils have low total nitrogen content (<0.150%), 64% exhibit a moderate level (0.150%–0.250%), and 12% are determined to have a high level (>0.250%). For phosphorus availability, 59% of the soil samples have low levels (<13 mg kg^{-1}), 29% are at a moderate range (13–30 mg kg^{-1}), and 12% are considered sufficient (>30 mg kg^{-1}). In all soils, exchangeable calcium (Ca) and magnesium (Mg) contents are determined to be high (>10 me Ca 100g^{-1}, >3 me Mg 100 g^{-1}). Furthermore, 94% of the soils have high exchangeable sodium (Na) content (>0.7 me Na 100g^{-1}), 41% have high exchangeable potassium (K) content (>0.7 me K 100 g^{-1}), and 42% exhibit a moderate level (0.3–0.7 me 100 g^{-1}) of exchangeable K (Table 5). The relationships between basic cations (Ca, Mg, and K) in the soil are crucial for plant nutrition and fertilization. For optimal plant nutrition, the recommended Ca/K ratio is 12, Ca/Mg ratio is 6, and Mg/K ratio is 2. However, in all sampled soils, the Ca/Mg ratio is <6, Ca/K ratio is >12, and Mg/K ratio is >2 (Hazelton and Murphy, 2007). This indicates that, even in the presence of sufficient available potassium in the soil, plants would respond positively to potassium, emphasizing the necessity for potassium fertilization in rice-cultivated soils in Azerbaijan. Therefore, in all rice cultivation areas in Azerbaijan, it is imperative to apply potassium to the soil before seed or seedling planting.

Table 6. The available microelement content (Fe, Cu, Zn, and Mn) of the soils along with fertility classes

No	Fe, mg kg^{-1}	Cu, mg kg^{-1}	Zn, mg kg^{-1}	Mn, mg kg^{-1}	SFI	Fertility class
1	65,50	7,54	0,58	23,01	206,08	S1
2	52,75	13,23	0,30	73,78	52,35	S2
3	61,85	14,96	1,42	67,70	93,34	S1
4	51,68	9,00	1,38	47,72	57,32	S2
5	58,62	8,07	0,72	20,63	367,67	S1
6	218,82	21,14	1,34	116,85	62,67	S2
7	3,16	1,84	0,30	2,40	1,50	N
8	6,21	1,80	0,31	3,76	0,23	N
9	35,71	7,74	0,43	7,34	21,48	S3
10	25,80	6,82	0,32	15,03	11,47	N
11	23,47	5,45	0,28	6,24	71,74	S2
12	53,49	12,65	1,11	9,58	62,74	S2
13	48,58	10,52	0,54	10,52	43,89	S3
14	9,27	0,85	0,17	1,29	0,73	N
15	43,21	7,25	0,31	3,89	4,05	N
16	18,47	3,61	0,22	9,20	2,14	N
17	72,54	8,80	3,73	20,58	57,32	S2
Min.	*3,16*	*0,85*	*0,17*	*1,29*		
Max.	*218,82*	*21,14*	*3,73*	*116,85*		
Mean	*49,95*	*8,31*	*0,79*	*25,85*		

In all collected soil samples, the copper (Cu) and iron (Fe) contents are above the critical deficiency threshold (0.2 mg Cu kg^{-1}; 2.5 mg Fe kg^{-1}). This suggests that there would unlikely be a deficiency of Cu and Fe in rice cultivation. However, 52% of the soils exhibit manganese (Mn) levels below the critical threshold (14 mg Mn kg^{-1}), and 65% have zinc (Zn) levels below the critical threshold (0.7 mg Zn kg^{-1}) (Lindsay and Norvell, 1978). This indicates a potential risk of Zn and Mn deficiency in rice cultivation areas in Azerbaijan. Therefore, in the case of deficiencies, foliar application of these micronutrients might be necessary.

Furthermore, the productivity classes of the collected soils have been calculated and are presented in Table 6. Accordingly, 18% are classified as S1 (Good fertility), 35% as S2 (Moderate fertility), 12% as S3 (Marginal fertility), and 35% as N (Poor fertility). This indicates a significant overall low fertility capacity in rice-cultivated areas in Azerbaijan, primarily attributed to two factors. Firstly, in areas with salinity, the removal of salt by leaching, application of gypsum to soils in areas with barrenness to remove sodium, and in areas with low organic matter, increasing soil organic matter levels with low-salt plant-based composts are necessary. Secondly, proper fertilization from both soil and foliar sources is crucial. In rice cultivation, before sowing with seeds or seedlings, the application of potassium fertilizers is essential based on soil analysis results (Hossain et al., 2023; İslamzade et al., 2023), in addition to nitrogen (N) and phosphorus (P). Given the alkaline reaction of the regional soils, chemical fertilizers used must have a physiological acid reaction. Moreover, there is a dramatic Ca/K imbalance in the regional soils, and providing the required potassium from the soil through fertilization will not be feasible. Therefore, during the tillering period of the rice plant, balanced NPK + micronutrients (e.g., 17-17-17+me), and during the heading period, potassium-rich NPK+ micronutrients (e.g., 9-9-25+me) with zinc application should be carried out through foliar spraying. Thus, it is indisputable that proper soil reclamation and correct fertilization of rice fields will lead to increased crop yields.

Conclusion

In conclusion, this study comprehensively examined the physical and chemical properties of soil samples from rice cultivation areas in Azerbaijan, aiming to assess nutrient content, soil characteristics, and potential limitations on productivity and plant nutrition in rice farming. The results revealed a diverse range of soil properties, including variations in soil texture, pH levels, salinity, and nutrient content. The identified challenges, such as alkaline soil pH and high salinity, pose significant obstacles to rice cultivation. Recommendations for corrective measures, including the application of soil acidifying materials and the implementation of remediation methods for sodicity and salinity, were discussed. Moreover, the study highlighted the importance of proper fertilization, emphasizing the need for potassium application in rice-cultivated soils. Notably, micronutrient deficiencies, particularly in zinc and manganese, were identified, suggesting the potential necessity for foliar applications to address these deficiencies. The findings underscore the complexity of soil fertility in Azerbaijan's rice fields, calling for tailored strategies to enhance local practices and contribute valuable insights for sustainable rice farming globally. In summary, addressing the identified soil challenges and implementing appropriate corrective measures, along with precise fertilization strategies, will undoubtedly play a pivotal role in enhancing the fertility and productivity of rice-cultivated areas in Azerbaijan, ultimately contributing to the global pursuit of sustainable rice farming.

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References

Abdul Halim, N.S., Abdullah, R., Karsani, S.A., Osman, N., Panhwar, Q.A., Ishak, C.F., 2018. Influence of soil amendments on the growth and yield of rice in acidic soil. *Agronomy* 8(9): 165.

Arshad, M.A., Martin, S., 2002. Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture Ecosystem and Environment* 88(2): 153-160.

Borůvka, L., Vacek, O., Jehlička, J., 2005. Principal component analysis as a tool to indicate the origin of potentially toxic elements in soils. *Geoderma* 128(3-4): 289-300.

Bouyoucos, G.J., 1962. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 54(5): 464-465.

Bower, C.A., Wilcox L.V., 1965. Soluble Salts. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 933-951.

Bremner, J.M., 1965. Total nitrogen, In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 1149-1176.

Bueno C.S., Ladha, J.K., 2009. Comparison of soil properties between continuously cultivated and adjacent uncultivated soils in rice-based systems. *Biology and Fertility of Soils* 45(5): 499–509.

Fan, M.S., Jiang, R.F., Zhang, F.S., Lü, S.H., Liu, X. J., 2008. Nutrient management strategy of paddy rice-upland crop rotation system. *The Journal of Applied Ecology* 19(2): 424–432. [in Chinese]

Fukagawa, N.K., Ziska, L.H., 2019. Rice: Importance for Global Nutrition. *Journal of Nutritional Science and Vitaminology* 65: S2-S3.

Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Kumar, V., Kumar, V., Sharma, P.K., 2011. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation. *Soil Science Society of America Journal* 75(5): 1851–1862.

Hamoud, Y.A., Guo, X., Wang, Z., Shaghaleh, H., Chen, S., Hassan, A., Bakour, A., 2019. Effects of irrigation regime and soil clay content and their interaction on the biological yield, nitrogen uptake and nitrogen-use efficiency of rice grown in southern China. *Agricultural Water Management* 213: 934-946.

Hazelton, P., Murphy, B., 2007. Interpreting soil test results. What do the numbers mean? CSIRO Publishing, Melbourne. Australia. 152p.

Heald, W.R., 1965. Calcium and Magnesium. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 999-1010.

Hossain, M., Rahman, M., Morshed, M., Uddin, M., Hera, M., Sultana, N., Hashem, M., 2023. Yield response of rice (Oryza sativa L.) to elevated potassium applied under the irrigated ecosystem of Bangladesh. *Eurasian Journal of Soil Science* 12(2): 104 - 110.

İslamzade, R., Hasanova, G., Asadova, S., 2023. Impact of varied NPK fertilizer application rates and seed quantities on barley yield and soil nutrient availability in chestnut soil of Azerbaijan. *Eurasian Journal of Soil Science* 12(4): 371 - 381.

Juhos, K., Szabo, S., Ladanyi, M., 2016. Explore the influence of soil quality on crop yield using statistically-derived pedological indicators. *Ecological Indicators* 63: 366–373.

Katayanagi, N., Fumoto, T., Hayano, M., Takata, Y., Kuwagata, T., Shirato, Y., Sawano, S., Kajiura, M., Sudo, S., Ishigooka, Y., Yagi, K., 2016. Development of a method for estimating total CH4 emission from rice paddies in Japan using the DNDC-Rice model. *Science of The Total Environment* 547: 429-440.

Ladha, J.K., Fischer, K.S., Hossain, M., Hobbs, P.R., Hardy, B., 2000. Improving the productivity of rice–wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI partnership research. IRRI Discussion Paper No. 40. IRRI, Los Baños, the Philippines.

Ladha, J.K., Pathak, H., Padre, A.T., Dawe, D., Gupta, R.K., 2003. Productivity trends in intensive rice–wheat cropping systems in Asia. In: Improving the productivity and sustainability of rice–wheat systems: Issues and impacts. Ladha, J.K., Hill, J.E., Duxbury, J.M., Gupta, R.K., Buresh, R.J., (Eds.). ASA, CSSA, and SSSA, Madison, WI, USA. pp.45–76.

Li, D., Nanseki, T., Chomei, Y., Fukuhara, Y., 2018. Impact of soil chemical properties on rice yield in 116 paddy fields sampled from a large-scale farm in Kinki Region, Japan. IOP Conference Series: Earth and Environmental Science 185: 012026.

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

Lu, D., Moran, E., Mausel, P., 2002. Linking Amazonian secondary succession forest growth to soil properties. *Land Degradation and Development* 13(4): 331-343.

Maftukhah, R., Ngadisih, N., Murtiningrum, M., Mentler, A., Keiblinger, K., Melcher, A., Zehetner, F., Kral, R., 2022. Contrasting rice management systems – Site-specific effects on soil parameters. *Eurasian Journal of Soil Science* 11(3): 225-234.

Matsumoto, S., Kasuga, J., Taiki, N., Makino, T., Arao, T., 2015. Inhibition of arsenic accumulation in Japanese rice by the application of iron and silicate materials. *Catena* 135: 328-335.

Mohidem, N.A., Hashim, N., Shamsudin, R., Che Man, H. 2022. Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture* 12(6): 741.

Moran, E.F., Brondizion, E.S., Tucker, J.M., da SilvaForsberg, M.C., McCracken, S., Falesi, I., 2000. Effects of soil fertility and land use on forest succession in Amazonia. *Forest Ecology and Management* 139(1-3): 93-108.

Mori, M., Kotaki, K., Gunji, F., Kubo, N., Kobayashi, S., Ito, T., Itabashi, H., 2016. Suppression of cadmium uptake in rice using fermented bark as a soil amendment. *Chemosphere* 148: 487-494.

Mousavi, S.F., Yousefi-Moghadam, S., Mostafazadeh-Fard, B., Hemmat, A., Yazdani, M.R., 2009. Effect of puddling intensity on physical properties of a silty clay soil under laboratory and field conditions. *Paddy and Water Environment* 7(1): 45–54.

Obade, V.P., Lal, R., 2016. Towards a standard technique for soil quality assessment. *Geoderma* 265: 96-102.

Olsen,S.R., Dean, L.A., 1965. Phosphorus. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 1035-1049.

Peech, M., 1965. Hydrogen-Ion Activity. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 914-926.

Pratt, P.F., 1965. Potassium. In: Methods of soil analysis. Part 2. Chemical and microbiological properties. Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark F.E. (Eds.), Soil Science Society of America. Madison, Wisconsin, USA. pp. 1022-1030.

Rowell, D.L., 1996. Soil Science: methods and applications. Longman, UK. 350p.

Timsina, J., Connor, D.J., 2001. Productivity and management of rice-wheat cropping systems: Issues and challenges. *Field Crops Research* 69(2): 93–132.

USDA, 2001. Soil Quality Test Kit Guide. United States Department of Agriculture, Agricultural Research Service, Natural Resources Conservation Service, Soil Quality Institute. USA. 82p. Available at [Access date: : 11.07.2023]: https://www.nrcs.usda.gov/sites/default/files/2022-10/Soil%20Quality%20Test%20Kit%20Guide.pdf

Walkley, A., Black, C.A., 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29–38.