Journal of Kerbala for Agricultural Sciences Issue (3), Volume (12), (2025)

A study on the impacts of continuous cropping on some soil indicators properties for the period 2017 to 2024 in Bazian Plain, Sulaimaniyah governorate, Iraq.

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https://doi.org/ 10.59658/jkas.v12i3.4357

Received: Apr. 08, 2025

Accepted: Aug. 01, 2025

Published: Sep. 15, 2025

Abstract

Continuous cultivation significantly impacts soil health, altering its physical and chemical properties, which are critical for sustainable agriculture. This study evaluates the effects of long-term agricultural practices in the Bazian Plain, Sulaimaniyah Governorate, Kurdistan Region, focusing on key soil properties across ten locations over the period 2017–2024. Soil samples were collected annually from greenhouses following standardized agricultural practices, emphasizing the cultivation of the cucumber variety A1. Key soil parameters analyzed include bulk density, permeability, porosity, organic matter, and root and shoot system distributions. Results indicate a progressive increase in bulk density, particularly in Latif Awa and Kani Big, reaching critical values of 1.48g.cm-3 by 2024, which reflect compaction due to continuous tillage. Permeability and porosity declined across all sites, limiting water infiltration and root penetration. Organic matter content decreased significantly, with Warmizyar and Zeika experiencing reductions to critical levels of 1.93% and 2.08%, respectively, indicating severe nutrient depletion. Root and shoot systems were notably reduced, with Kani Big showing the most pronounced decline in root length from 268 cm in 2022 to 211 cm in 2024.

Keywords: Green Houses, Continues Cultivation, Soil Physical Properties, Soil Chemical Properties.

Introduction

These properties are crucial for assessing soil quality and its suitability for agriculture and other uses. Key chemical properties include nutrient concentrations (like nitrogen, phosphorus, and potassium), pH level, and the presence of various elements. Understanding these properties is vital for managing soil health and predicting how it will interact with pollutants and contaminants [1].

Soil properties are significantly influenced by the vegetation cover, which directly or indirectly affects the soil's characteristics. Vegetation plays a critical role in soil formation and determines both its current and future conditions. The relationship between vegetation cover and soil quality is strongly associated with the prevailing topography.

Additionally, soil texture and composition are critical factors in vegetation distribution and growth. This is due to the significant effect that soil properties, particularly water retention capacity, have on its ability to support plant life. A previous research [2] demonstrated that soils cultivated with plants and trees tend to have higher infiltration rates, attributed to an increase in soil porosity and pore size distribution. This is accompanied by a reduction in the hydrophobic characteristics of the soil, facilitating better water movement and availability.

Inherent properties, such as soil texture and mineralogy, play a crucial role in determining the soil's capacity to store carbon and nutrients, its native pH, aggregation, water-holding capacity, and other essential characteristics [3]. However, the natural characteristics of soils have increasingly been modified by human activities. Practices such as tillage, cropping, and management of carbon and nutrient flows through erosion, organic amendments, and residue harvesting have altered the natural balance of carbon and nutrients, as well as the physical and biological health of the soil [4].

Thus, soil health can be assessed through both inherent and dynamic properties, which are linked to the soil's genoforms and phenoforms, respectively, while it is well recognized that nutrient availability and soil pH are critical factors that influence crop productivity, biological and physical limitations are often more challenging to measure. Recent research has significantly expanded our understanding of the role that soil biology and physics play in various ecosystem processes. To address these complexities, soil health testing has emerged as a tool to assess both biological and physical processes in the soil, alongside traditional nutrient testing. This integrated approach can be invaluable for land managers in addressing production constraints.

Effective indicators of soil health should be agronomically relevant, cost-effective, and sensitive to management practices. Consequently, soil health frameworks have been developed to enable routine interpretation of biological and physical tests, which were once primarily used in research settings and were not readily accessible to the public. Even Soil Organic Matter (SOM), which is regularly assessed in agricultural settings, has become a key indicator in these broader frameworks [5].

Soil Organic Matter (SOM), which is routinely included in standard nutrient analysis tests, has not traditionally been interpreted in the context of standard nutrient analysis reports. Early soil health frameworks, such as the Soil Management Assessment Framework (SMAF)and the Comprehensive Assessment of Soil Health (CASH). Sought to bridge this gap. The CASH framework quantifies key soil health indicators, identifies specific constraints to soil health (e.g., compaction, low labile C and N), and suggests management practices to address these constraints, thereby providing practical tools for farmers, consultants, and applied researchers [6].

To optimize soil conditions for sustainable cropping systems, a deeper understanding of the impacts of continuous cropping (CS) on soil's physical, chemical, and biological properties is essential. Presented valuable data for assessing how management practices under continuous cropping systems affect soil functions, including both agronomic and environmental soil functions, through changes in key soil indicators. The primary impact of continuous cropping on soil quality (SQ) is often related to the accumulation of soil organic matter (SOM), which is influenced by the type and quantity of carbon (C) inputs from crop biomass and manure, as well as management practices such as tillage. These factors affect both the rate of SOM decomposition and its stratification within the soil profile [7].

The accumulation of SOM can improve soil quality by reducing bulk density (bd), surface sealing, and crust formation. Additionally, it enhances aggregate stability, cation exchange capacity, nutrient cycling, and biological activity by fostering conditions that improve biological nitrogen fixation and optimize the use of water and nutrients. Appropriate continuous cropping systems can help reduce dependence on synthetic fertilizers and other inputs, promoting both ecological and agronomic sustainability [8].

Materials and Methods

The study was conducted in the Bazian area, located in the Sulaimaniyah governorate, northeastern Iraq, approximately 20 km southwest of Sulaimaniyah governorate at coordinates 35°N latitude and 45°E longitude. This region is a central agricultural hub, housing at least 4,000 greenhouses, with an elevation ranging from 837 to 847 meters above sea level.

Describe the Study Area

The motivation for this study arose from a 2014 investigation on the spread of nematodes in the Bazian Plain, which observed the excessive use of soil and chemical fertilizers and reports from farmers indicating a decrease in crop production. This study focused on two key aspects: the length of the study period and the abundance of soil samples collected from one of the most significant agricultural areas in the region. Ten sites were selected, representing diverse agricultural houses throughout 16.38 km. During the survey, efforts were made to select farmers who employed similar agricultural practices and services to ensure the accuracy and consistency of the results. These soil samples were collected from no fewer than 360 greenhouses.

A range of chemical and physical soil properties was analyzed to assess soil health after years of intensive agricultural use over the seven-year study period. Agricultural groups cultivating the cucumber *Cucumis sativus* (A1 variety) were selected for the study, as this variety is the most commonly grown due to its high yield and resistance to pests. Initial soil samples were collected before the spring crop was planted, between February 25 and 29, 2014. Chemical and physical analyses of the soil were conducted annually throughout the study period. At the end of each agricultural season, the length of the cucumber stem was measured from the base to the growing tip, and the root length was also recorded [9].

Soil

Soil samples were collected from conventional greenhouses, and efforts were made to ensure consistency by selecting farmers who follow similar agricultural practices, as this represents the prevailing method in the region. Samples were collected at the end of the spring season for all study sites, aiming to capture data as comprehensively as possible.

The excessive use of soil through continuous cultivation has led to the degradation of both the physical and chemical properties of the soil. The research specifically focused on the cucumber crop, which is widely grown in the greenhouses of the region and is particularly susceptible to the adverse effects of repeated cultivation. Soil analyses were performed for the properties mentioned below.

Table (1): Soil analyses were performed for the properties mentioned below

Soil Analysis	Procedure	Source
Soil Texture Soil bulk density g.cm-3 Permeability cm. hour-1 Porosity cm3.cm-3	[10]	Soil and plant analysis (Laboratory index) by John Ryan George Stephen, International Center for agriculture Research in the Dry Areas. And Abdul Rashid National Center for Agriculture research, Islamabad, Pakistan
Organic Matter %	[11], [12]	
E.C. ds.m $^{-1}$, PH, N (%) Availa P (ppm) Soluble K^+, Na^+,Ca^{+}2, Mg^+ ,Cl^- Meq. l^{-1}, CaCO3 (%)	[13]	

Climate

Bazian's climate in winter is cold, and rainfall gets to the freezing point at the end of January and February, in the middle and end of December, snowfall is higher, and rainfall quantities reach 800mm per year. In the summer climate is hot and dry, getting to 45°c, and in September wind is faster compared to other months. Also, in June, the wind is fast but not like in September.

Table (2): Average Climate Data for Bazian city / 2024

Months	Temperature °C			Precipitation (rain) mm.	Wind speed (M. hr.$^{-1}$)	Humidity (%)	Sun hours (hr)	Pressure (Mb)
	Max.	Min.	Avg.					
Jan-2024	11	3	7	207.8	5.3	76	80	1022.3
Feb-2024	16	5	8	132.3	4.9	68	82	1022.8
Mar-2024	18	7	12.5	89.6	9.5	53	110.4	1018.1

April-2024	25	11	18	125.2	8.3	42	145	1016.1
May-2124	30	18	24	65.3	10.2	30	153	1013.4
June -2024	39	23	31	0	11.9	11	158	1009.3
July-2024	42	26	34	0	10.6	10	162	1010.5
Aug-2024	43	25	33	0	9.9	7	160	1011.2
Sep-2024	36	22	28	0	11.3	23	144	1012.8
Oct-2024	28	15	21.5		8.6	38	108	1017.1
Nov-2024	20	7	13.5		7.7	73	94	1024.1
Dec-2024	13	3	8		5.6	66	75	1025.3

Table (3): GPS Locations for the study area in the Bazian plain

Locations no.	Villages	Latitude	Longitude
Location 1	Mewk	35°34'28.7"N	45°10'14.6"E
Location 2	Tui awlia	35°33'50.3" N	45°10'14.6"E
Location 3	Kani big	35°33'47.6"N	45°10'32.9"E
Location 4	Shuwankara	35°33'51.1"N	45°11'34.1"E
Location 5	Qushqaya	35°33'33.2"N	45°11'46.9"E
Location 6	Qushqaya	35°33'25.8"N	45°11'36.0"E
Location 7	Halay sarchawa	35°31'53.9"N	45°11'56.1"E
Location 8	Zeika	35°31'26.5"N	45°13'17.9"E
Location 9	Warmizyar	35°31'04.6"N	45°15'17.7"E
Location10	Latif awa	35°29'32.1"N	45°13'53.6"E

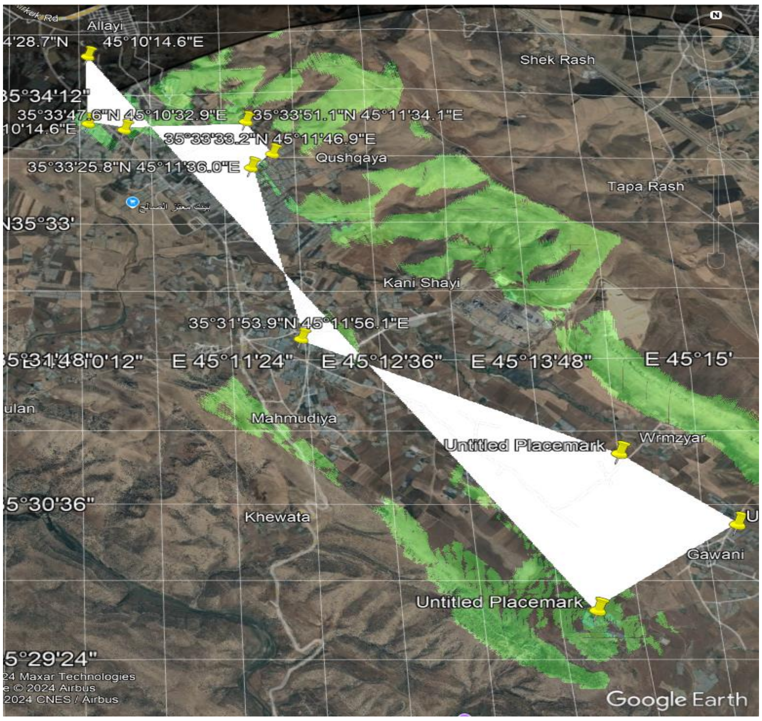

Figure (1): Location study in Bazian plain, Sulaimaniyah governorate, North of Iraq

Results and Discussion

In 2017, Electronic Conductivity. (ds.m^{-1}) Values are moderate across villages, with the highest in Warmizyar (0.547). Salinity is relatively low, indicating no significant issues. pH Most soils are slightly alkaline, ranging from 7.39 (Halay Sarchawa) to 8.66 (Mewk). High alkalinity in some villages may affect nutrient availability. Nitrogen (N% %) Moderate nitrogen levels, highest in Qushqaya (0.564). Available P (ppm) Peaks at 74.75 in Kani Big, while some villages like Shuwankara have significantly low levels (~8-10 ppm), indicating nutrient imbalance. Soluble K^+ is generally low, with Kani Big at its minimum (0.127 meq. l^{-1}). Potassium supplementation might be necessary. Soluble Na^+ Low levels across sites, highest in Kani Big (0.896 meq. l^{-1}), but not alarming. Soluble Ca^{2+} and Mg^{2+} Calcium levels vary, highest in Kani Big (6.095 meq. l^{-1}). Magnesium levels are moderate, peaking in Kani Big (7.69 meq. l^{-1}). Cl^-: Moderate, with Kani Big being the highest (1.643 meq. l^{-1}). $CaCO_3$ (%) High values, especially in Mewk (29.59%), indicating alkaline soils [14].

Table (4): Some chemical soil properties of the study areas in 2017

Village name	E.C. ds m^{-1}	PH	N (%)	Availa P (ppm)	Soluble K^+ meq. l^{-1}	Soluble Na^+ meq. l^{-1}	Soluble Ca^{+2} meq. l^{-1}	soluble Mg^{+2} meq.l^{-1}	Cl^- meq .l^{-1}	$CaCO_3$ (%)
Mewk	0.381	8.66	0.391	34.85	0.168	0.152	3.449	1.84	0.575	29.59
Tui awlia	0.792	7.74	0.275	09.83	0.154	0.234	2.067	2.44	0.355	25.36
Kani big	0.325	7.73	0.463	74.75	0.127	0.896	6.095	7.69	1.643	27.34
Shuwan-kara	0.321	7.59	0.275	08.96	0.175	0.195	2.243	2.74	0.465	25.63
Qushqaya	0.325	8.54	0.458	14.73	0.134	0.347	4.092	3.04	0.647	25.21
Qushqaya	0.536	7.49	0.564	12.97	0.104	0.354	4.298	2.44	0.472	25.83
Halay sarchawa	0.474	7.39	0.365	17.25	0.111	0.323	3.891	2.54	0.441	23.26
Zeika	0.388	8.29	0.265	10.06	0.107	0.173	2.494	1.99	0.277	25.87
Warmizy ar	0.547	7.54	0.295	11.19	0.116	0.265	2.546	1.94	0.465	26.48
Latif awa	0.385	7.79	0.332	06.25	0.144	0.317	2.199	2.44	0.348	25.79

In 2018, results were since Electronic Conductivity Slight increases in many villages (Mewk: 0.412; Tui Awlia: 0.563). Warmizyar shows slight improvement. pH is more neutralized in some areas (7.29 in Tui Awlia). Minor alkalinity persists in Mewk. N (%) Nitrogen levels decrease significantly in some villages (Shuwankara: 0.125%), indicating potential soil degradation. Available P Declines are noticeable across sites, with the lowest in Latif Awa (6.25 ppm). Soluble K^+: Spikes in Kani Big (1.323 meq. l^{-1}), indicating localized enrichment. Soluble Na^+ consistently low, highest in Warmizyar (0.153 meq. l^{-1}). Soluble Ca^{2+} and Mg^{2+} calcium and magnesium levels are steady but lower compared to 2017. Cl^-: Levels drop slightly, most notable in Mewk (0.29 meq. l^{-1}). $CaCO_3$ (%) ranges are narrow, with peaks in Mewk (32.5%) [15].

Table (5): Some chemical soil properties of the study areas in 2018

Village name	E.C. ds m-1	PH	N (%)	Avail. P (ppm)	Soluble K+ meq. l-1	Soluble Na^{+} meq. l-1	Soluble Ca^{+2} meq. l-1	soluble Mg^{+2} meq.l-1	Cl^{-} meq. l-1	$CaCO_3$ (%)
Mewk	0.412	7.63	0.219	29.65	0.138	0.122	1.94	1.91	0.29	32.5
Tui awlia	0.563	7.29	0.127	08.21	0.199	0.076	0.99	1.83	0.23	20.3
Kani big	0.335	7.35	0.099	21.18	1.323	0.121	2.11	3.26	0.87	28.6
Shuwan-kara	0.347	6.97	0.125	09.76	0.013	0.079	1.55	2.84	1.39	23.3
Qushqaya	0.519	8.11	0.223	10.32	0.033	0.137	2.12	3.23	1.77	26.9
Qushqaya	0.428	7.46	0.219	12.91	0.051	0.089	0.83	1.77	0.78	26.2
Halay sarchawa	0.396	6.99	0.232	14.85	0.039	0.079	2.34	2.16	0.55	26.9
Zeika	0.314	7.22	0.184	08.57	0.155	0.126	1.96	0.99	0.59	22.4
Warmizyar	0.442	7.65	0.126	10.45	0.096	0.153	2.27	1.65	0.44	24.3
Latif awa	0.486	7.38	0.158	07.84	0.178	0.098	1.79	0.79	1.23	27.9

Electronic Conductivity: Sharp increase in some areas (Mewk: 1.386; Tui Awlia: 1.424). Possible salinity issues are emerging. pH Variability observed, with a slight shift towards neutral in some sites. Nitrogen (N% %) is increasing in specific villages (Latif Awa: 0.395%). Available P: Significant reductions, particularly in Kani Big (0.99 ppm). Soluble K^{+} Overall decrease, with the highest still in Kani Big (1.534 meq. l^{-1}). Soluble Na^{+} Peaks in Shuwankara (1.356 meq. l^{-1}), indicating possible salinity-related challenges. Soluble Ca^{2+} and Mg^{2+} Decline in calcium and magnesium levels, especially in Warmizyar. Cl^{-} Mostly stable but with occasional increases. $CaCO_3$ (%) Consistently high, showing limited change [16].

Table (6): Some chemical soil properties of the study areas in 2019

Village name	E.C. ds m^{-1}	PH	N (%)	Available. P (ppm)	Soluble K^+ meq $.l^{-1}$	Soluble Na^+ meq $.l^{-1}$	Soluble Ca^{+2} meq. l^{-1}	soluble Mg^{+2} meq. l^{-1}	Cl^- Meq. l^{-1}	$CaCO_3$ (%)
Mewk	1.386	8.061	0.288	24.95	0.254	0.172	2.94	4.64	0.59	12.5
Tui awlia	1.424	0.492	0.326	01.19	0.427	0.098	1.42	2.76	0.35	22.8
Kani big	0.133	1.633	1.435	00.99	1.534	0.044	2.53	4.15	0.99	24.1
Shuwan-kara	0.153	0.313	0.143	01.47	0.243	1.356	1.98	3.74	1.42	26.8
Qushqaya	0.171	0.333	0.163	02.15	0.263	0.126	2.53	3.93	1.82	29.4
Qushqaya	0.159	0.351	0.181	00.89	0.281	0.985	1.23	2.67	0.93	28.7
Halay sarchawa	0.273	0.339	0.169	00.87	0.124	0.099	2.73	3.12	0.67	27.4
Zeika	0.212	0.454	0.281	01.14	0.386	0.127	2.33	1.89	0.71	24.9
Warmizyar	0.294	0.396	0.223	01.55	0.324	0.265	2.63	2.55	0.56	24.8
Latif awa	0.126	0.477	0.395	00.91	0.496	0.076	2.13	1.69	1.32	30.4

Electronic conductivity stabilizes in most villages, though some outliers remain. pH: Slight increases in Qushqaya and Halay Sarchawa. Nitrogen (N% %): Gradual recovery in nitrogen levels in many areas. Available P: Large variability persists, with enrichment in Mewk and depletion in Shuwankara. Soluble K^+ Small recoveries noted. Soluble Na^+: Reduction across most sites; Shuwankara drops significantly. Soluble Ca^{2+} and Mg^{2+} Calcium and magnesium are steady; enrichment in Kani Big. Cl^- Levels increase slightly across sites. $CaCO_3$ (%) Peaks in Zeika (29.59%).

Table (7): Some chemical soil properties of the study areas in 2020

Village name	E.C. ds m^{-1}	PH	N (%)	Available. P (ppm)	Soluble K^+ Meq. l^{-1}	Soluble Na^+ meq $.l^{-1}$	Soluble Ca^{+2} meq. l^{-1}	soluble Mg^{+2} meq. l^{-1}	Cl^- Meq. l^{-1}	$CaCO_3$ (%)
Mewk	0.510	8.66	0.394	34.85	0.128	0.453	3.24	1.94	0.531	20.51
Tui awlia	0.820	7.75	0.185	10.56	0.163	0.235	2.01	2.44	0.385	22.09
Kani big	0.355	7.74	0.316	44.94	0.136	0.896	6.04	7.69	1.676	26.09
Shuwankar	0.355	7.67	0.185	29.16	0.109	0.195	2.19	2.74	0.493	29.39
Qushqaya	0.355	8.55	0.317	14.98	0.109	0.348	4.04	3.04	0.673	28.99
Qushqaya	0.530	7.54	0.473	13.15	0.113	0.351	4.24	2.44	0.567	29.59

Halay sarchawa	0.543	7.48	0.274	17.45	0.124	0.328	3.84	2.54	0.474	26.99
Zeika	0.417	8.35	0.175	10.26	0.116	0.173	2.44	1.99	0.364	29.59
Warmi zyar	0.579	7.55	0.205	11.37	0.125	0.265	2.49	1.94	0.495	30.19
Latif awa	0.413	7.89	0.247	06.45	0.153	0.318	2.14	2.44	0.377	29.49

E.C. Stabilization in many villages (Mewk: 0.414; Tui Awlia: 0.612). Slight declines in Kani Big and Shuwankara. pH Consistent alkalinity (Mewk: 8.23), with some villages nearing neutrality (Halay Sarchawa: 6.96). Nitrogen (N% %) Slight recovery in nitrogen levels, with the highest in Mewk (0.427%). Nitrogen remains critically low in Zeika (0.079%). Available P Mixed trends significant recovery in Kani Big (76.4 ppm) but drops in Shuwankara (4.26 ppm). Soluble K^+ remains steady, highest in Kani Big (0.136 meq. l^{-1}). Soluble Na^+ Stable levels, Kani Big still leads (0.935 meq. l^{-1}). Soluble Ca^{2+} and Mg^{2+} Peaks observed in Kani Big for both calcium (6.09 meq. l^{-1}) and magnesium (7.49 meq. l^{-1}). Cl^- : Slight increase in most villages; highest in Kani Big (1.76 meq. l^{-1}). $CaCO_3$ (%) Slight variations, with Latif Awa and Halay Sarchawa showing slight reductions [17].

Table (8): Some chemical soil properties of the study areas in 2021

Village name	E.C. ds m^{-1}	PH	N (%)	Available. P (ppm)	Soluble K+ meq. l^{-1}	Soluble Na^+ meq. l^{-1}	Soluble Ca^{+2} meq. l^{-1}	soluble Mg^{+2} meq. l^{-1}	Cl^- meq. l^{-1}	$CaCO_3$ (%)
Mewk	0.414	8.23	0.427	34.64	0.181	0.193	3.14	1.94	0.65	29.5
Tui awlia	0.612	7.31	0.082	05.18	0.160	0.246	2.06	2.24	0.47	27.6
Kani big	0.147	7.35	0.212	76.4	0.136	0.935	6.09	7.49	1.76	26.6
Shuwankara	0.142	7.16	0.085	04.26	0.113	0.205	2.24	2.54	0.58	24.9
Qushqaya	0.147	8.11	0.212	10.43	0.116	0.352	4.09	2.84	0.76	24.5
Qushqaya	0.322	7.06	0.370	08.26	0.114	0.363	4.29	2.24	0.59	25.1
Halay sarchawa	0.292	6.96	0.170	12.55	0.121	0.334	3.89	2.34	0.56	22.5
Zeika	0.202	7.86	0.079	05.36	0.117	0.183	2.49	1.79	0.39	25.1
Warmizyar	0.362	7.11	0.105	06.47	0.126	0.275	2.54	1.74	0.58	25.7
Latif awa	0.202	7.36	0.140	01.55	0.154	0.325	2.19	2.24	0.46	25.6

E.C. Noticeable increase in salinity in several villages (Tui Awlia: 1.593; Kani Big: 1.125). pH Mostly steady, with Halay Sarchawa remaining near neutral (6.98). N (%)

Small recovery in nitrogen content across villages (Qushqaya: 0.344%). Available P Improvements in most villages, with Mewk at 27.85 ppm. Soluble K^+ is generally low, with minor improvements in Halay Sarchawa (0.192 meq. l^{-1}). Soluble Na^+ Slight increases in several locations; highest in Kani Big (0.168 meq. l^{-1}). Soluble Ca^{2+} and Mg^{2+} both remain steady, with Kani Big retaining the highest values. Cl^- Decreases in some sites; minor increases in Shuwankara and Mewk. $CaCO_3$ (%) Peaks at Zeika (30.1%), indicating a buildup of lime in the soil.

Table (9): Some chemical soil properties of the study areas in 2022

Village name	E.C. ds m^{-1}	PH	N (%)	Available. P (ppm)	Soluble K+ meq. l^{-1}	Soluble Na^+ meq. l^{-1}	Soluble Ca^{+2} meq $.l^{-1}$	soluble Mg^{+2} meq. l^{-1}	Cl^- Meq. l^{-1}	$CaCO_3$ (%)
Mewk	0.481	8.16	0.349	27.85	0.179	0.162	2.44	1.64	0.48	32.5
Tui awlia	1.593	7.33	0.218	10.43	0.235	0.195	0.82	2.25	0.42	22.6
Kani big	1.125	7.32	0.349	67.55	0.208	0.168	4.85	7.52	1.71	24.6
Shuwankara	1.126	7.18	0.215	09.56	0.181	0.141	1.46	2.51	0.53	29.9
Qushqaya	1.125	8.13	0.344	15.34	0.181	0.141	2.85	2.85	0.71	23.5
Qushqaya	1.364	7.08	0.586	13.53	0.185	0.145	3.05	2.25	0.54	27.1
Halay sarchawa	1.278	6.98	0.357	17.85	0.192	0.152	2.65	2.35	0.51	27.5
Zeika	1.187	7.88	0.205	10.66	0.188	0.148	1.25	1.84	0.34	30.1
Warmizyar	1.345	7.13	0.235	11.76	0.197	0.157	1.36	1.75	0.53	26.7
Latif awa	1.182	7.38	0.274	06.85	0.225	0.185	0.95	2.25	0.41	25.8

E.C. Significant reductions in Mewk (0.253), Tui Awlia (0.46), and other sites, showing improvement in salinity management. pH generally steady, Tui Awlia reaches peak alkalinity (8.25). N (%) Declines noted in several villages, with Mewk and Kani Big leading recovery (0.28–0.29%). Available P: Improvement in Mewk (24.42 ppm) but decline in Qushqaya (14.27 ppm). Soluble K^+ Recoveries noted across sites, with Kani Big at 0.471 (meq. l^{-1}). Soluble Na^+ Reduced levels in most areas; stabilizing across villages. Soluble Ca^{2+} and Mg^{2+} Increase in calcium (Mewk 3.85 meq. l^{-1}) and magnesium (Kani Big: 3.48 meq. l^{-1}). Cl^- Levels remain stable across sites. $CaCO_3$ (%) A marked reduction in some areas, especially Latif Awa (18.46%) [18].

Table (10): Some chemical soil properties of the study areas in 2023

Village name	E.C. ds.m^{-1}	PH	N (%)	Availa P (ppm)	Soluble K^+ meq. l^{-1}	Soluble Na^+ meq. l^{-1}	Soluble Ca^{+2} meq. l^{-1}	soluble Mg^{+2} meq. l^{-1}	Cl^- Meq.l^{-1}	$CaCO_3$ (%)
Mewk	0.253	7.17	0.28	24.42	0.471	0.22	3.85	3.63	0.59	25.26
Tui awlia	0.46	8.25	0.16	19.37	0.159	0.20	1.47	2.23	0.44	21.06
Kani big	0.391	8.24	0.29	41.94	0.128	0.46	4.51	3.48	0.73	30.06
Shuwan-kara	0.338	7.18	0.16	18.53	0.104	0.17	1.65	2.53	0.55	28.36
Qushqaya	0.296	8.05	0.29	14.27	0.163	0.31	2.58	2.83	0.73	27.96
Qushqaya	0.271	6.61	0.15	02.47	0.106	0.12	0.77	0.23	0.26	8.56
Halay sarchawa	0.543	7.94	0.25	16.82	0.118	0.29	2.34	2.33	0.53	25.96
Zeika	0.457	7.81	0.15	19.63	0.102	0.15	0.91	1.78	0.36	38.56
Warmizyar	0.614	7.05	0.18	10.67	0.119	0.24	2.95	1.73	0.55	29.16
Latif awa	0.451	7.73	0.52	05.82	0.147	0.28	1.62	2.23	0.33	18.46

In the year 2024, the E.C. stabilized across most villages, with moderate levels (Tui Awlia: 0.633; Mewk: 0.539). pH Increasing alkalinity in Qushqaya (8.89) and Zeika (8.64). N (%): Nitrogen slightly recovers in some areas (Mewk: 0.329%), but is low in others (Tui Awlia: 0.182%). Available P: Peaks in Mewk (34.8 ppm) and Tui Awlia (29.3 ppm), with declines in other villages. Soluble K^+ Significant stabilization (Mewk: 0.169 meq. l^{-1}; Qushqaya: 0.122 meq. l^{-1}). Soluble Na^+ Minor increases noted (Qushqaya: 0.391 meq. l^{-1}). Soluble Ca^{2+} and Mg^{2+} Mewk and Kani Big retain the highest calcium levels, and magnesium levels are consistent. Cl^- Small fluctuations, generally stable. $CaCO_3$ (%) Peaks in Zeika (26.3%) and remains stable in most locations [19].

Table (11): Some chemical soil properties of the study areas in 2024

Village name	E.C. ds.m^{-1}	PH	N (%)	Availa P (ppm)	Soluble K^+ meq. l^{-1}	Soluble Na^+ meq. l^{-1}	Soluble Ca^{+2} meq. l^{-1}	soluble Mg^{+2} meq. l^{-1}	Cl^- Meq. l^{-1}	$CaCO_3$ (%)
Mewk	0.539	8.41	0.329	34.8	0.169	0.152	3.44	1.84	0.53	22.5
Tui awlia	0.633	8.09	0.182	29.3	0.152	0.282	0.09	1.67	0.40	28.8
Kani big	0.164	8.08	0.314	15.8	0.126	0.449	4.12	4.92	1.69	27.8
Shuwan-kara	0.152	7.94	0.195	18.4	0.109	0.246	0.27	1.97	0.51	26.1
Qushqaya	0.181	8.89	0.317	24.2	0.122	0.391	2.12	2.27	0.69	25.7
Qushqaya	0.341	7.84	0.471	32.4	0.138	0.427	2.32	1.67	0.52	26.3
Halay sarchawa	0.317	7.74	0.248	16.7	0.117	0.371	1.92	1.77	0.49	23.7
Zeika	0.227	8.64	0.181	29.5	0.124	0.229	2.52	1.22	0.32	26.3
Warmizyar	0.381	7.89	0.214	30.6	0.119	0.317	0.57	1.17	0.51	26.9
Latif awa	0.229	8.14	0.248	15.7	0.141	0.361	1.22	1.67	0.39	25.2

The analysis of electrical conductivity (E.C.) over the study period revealed dynamic changes in soil salinity. Initially, moderate E.C. values were observed across the villages in 2017, with Warmizyar showing the highest salinity (0.547 ds. m^{-1}). A significant rise in salinity levels was noted in 2019, particularly in Mewk (1.386 ds. m^{-1}) and Tui Awlia (1.424 ds. m^{-1}), indicating potential risks of soil degradation. However, by 2023, effective management practices may have led to a reduction in salinity across many sites, like Mewk (0.253 ds.m^{-1}). These findings underscore the importance of monitoring salinity levels in intensively cultivated soils to mitigate potential long-term productivity losses [20].

The pH levels across the sites remained predominantly alkaline throughout the study period. Villages such as Mewk and Qushqaya consistently exhibited high pH values, with peaks of 8.66 in 2017 and 8.89 in 2024, respectively. While alkaline soils can be advantageous for certain crops, extreme alkalinity may restrict the availability of essential nutrients, such as phosphorus and micronutrients. Neutral to slightly acidic pH levels in Halay Sarchawa and Shuwankara suggest a greater balance in soil chemistry in these locations. The persistence of high pH levels in other villages highlights the need for targeted amendments, such as the application of organic matter or acidifying fertilizers, to optimize soil conditions for crop growth [21].

Nitrogen levels (% N) displayed fluctuating trends across the years, reflecting variations in fertilizer use and potential losses due to leaching or volatilization. In 2017, the highest nitrogen content was recorded in Qushqaya (0.564%), while levels in Zeika and Shuwankara were notably low. A significant decline in nitrogen availability was observed in 2018, with Tui Awlia dropping to 0.127%, suggesting over-cultivation or inadequate fertilization. Although recovery was noted in select villages, such as Mewk (0.427%) in 2021, the overall trend indicates the need for balanced nitrogen management strategies to sustain soil fertility under continuous cropping systems. Available phosphorus levels demonstrated pronounced variability over the years. In 2017, Kani Big exhibited a significant phosphorus surplus (74.75 ppm), while many other sites were deficient [22].

A decline in phosphorus availability became apparent in subsequent years, with several villages such as Shuwankara and Latif Awa showing critical shortages. By 2023, phosphorus enrichment was observed in Mewk (24.42 ppm), possibly due to targeted fertilization practices. These results emphasize the critical need for site-specific phosphorus management to address deficiencies and prevent over-application, which can lead to environmental concerns such as eutrophication. The concentrations of soluble cations, including potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), revealed significant spatial and temporal variability. Notably, potassium levels were consistently low across most villages, except for Kani Big, which peaked in 2019 (1.534 meq. l^{-1}). Sodium concentrations were generally stable but showed localized increases in Kani Big and Shuwankara. Calcium and magnesium, essential for soil structure and plant nutrition, exhibited relatively consistent levels, with the highest values recorded in Kani Big. [23]

Table (12): Some soil physical and other properties for the study areas in 2017

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability $cm. hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.28	0.84	0.53	1.5	20.4	740
Tui awlia	Clay Loam	1.3	0.76	0.45	3.9	26.6	670
Kani big	Clay Loam	1.32	0.79	0.49	3.79	21.3	300
Shuwan-kara	Clay Loam	1.29	0.83	0.51	3.68	24.9	630
Qushqaya	Clay Loam	1.31	0..79	0.50	3.32	26.4	700
Qushqaya	Clay Loam	1.33	0.83	0.44	3.49	27.2	700
Halay sarchawa	Clay Loam	1.23	0.78	0.45	3.55	29.3	630
Zeika	Clay Loam	1.29	0.86	0.51	2.95	34.8	400
Warmizy ar	Clay Loam	1.32	0.82	0.49	2.8	31.7	599
Latif awa	Clay Loam	1.34	0.69	0.55	3.22	33.8	730

In 2017, the soil across all sites exhibited a clay loam texture, which provides a balanced environment for water retention and drainage. Bulk density values ranged from 1.23 g. cm^{-3} (Halay Sarchawa) to 1.34 g. cm^{-3} (Latif Awa), indicating moderate compaction levels. Permeability values were highest in Zeika (0.86 cm. $hour^{-1}$) and lowest in Latif Awa (0.69 cm. $hour^{-1}$), reflecting localized variations in soil structure. Porosity ranged from 0.44 cm^3. cm^{-3} to 0.55 cm^3. cm^{-3}, with higher values indicating better aeration and water-holding capacity. Organic matter (OM) levels varied, with Zeika showing the highest value (34.8%) and Warmizyar the lowest (2.8%). Root system distribution was most extensive in Tui Awlia (26.6 cm), and shoot lengths were highest in Mewk (740 cm), suggesting favorable conditions for plant growth. [24]

Table (13): Some soil physical and other properties for the study areas in 2018

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability cm. $hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.28	0.84	0.53	3.5	31.3	740
Tui awlia	Clay Loam	1.3	0.76	0.45	3.9	29.6	670
Kani big	Clay Loam	1.32	0.79	0.49	3.79	26.7	300
Shuwan-kara	Clay Loam	1.29	0.83	0.51	3.68	28.7	630
Qushqaya	Clay Loam	1.31	0.79	0.5	3.32	29.9	700
Qushqaya	Clay Loam	1.33	0.83	0.44	3.49	34.4	700
Halay sarchawa	Clay Loam	1.23	0.78	0.45	3.55	31.4	630
Zeika	Clay Loam	1.29	0.86	0.51	2.95	34.4	400
Warmizy ar	Clay Loam	1.32	0.82	0.49	2.8	32.9	599
Latif awa	Clay Loam	1.34	0.69	0.55	3.22	30.5	730

In 2018, bulk density remained consistent with 2017 levels, ranging between 1.23 g. cm^{-3} (Halay Sarchawa) and 1.34 g. cm^{-3} (Latif Awa). Permeability stayed stable, but slight declines were noted in some areas. Porosity ranged from 0.44 to 0.55 cm^3. cm^{-3}, with Latif Awa maintaining the highest porosity, supporting its robust plant growth. OM levels remained stable in most locations but slightly increased in Mewk (from 1.5% to 3.5%). Root system distributions improved in Zeika (from 34.8 cm to 34.4 cm), and shoot lengths remained stable, indicating minimal deterioration in soil structure during this year. [25]

Table (14): Some soil physical and other properties for the study areas in 2019

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability $cm. hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.357	0.93	0.67	3.64	32.39	719
Tui awlia	Clay Loam	1.377	0.85	0.59	4.04	26.39	649
Kani big	Clay Loam	1.397	0.88	0.63	3.93	29.39	279
Shuwan-kara	Clay Loam	1.367	0.92	0.65	3.82	33.39	609
Qushqaya	Clay Loam	1.387	0.88	0.64	3.46	27.39	679
Qushqaya	Clay Loam	1.407	0.92	0.58	3.63	32.39	679
Halay sarchawa	Clay Loam	1.307	0.87	0.59	3.69	36.39	609
Zeika	Clay Loam	1.367	0.95	0.65	3.09	39.39	379
Warmizy ar	Clay Loam	1.397	0.91	0.63	2.94	31.39	578
Latif awa	Clay Loam	1.417	0.78	0.69	3.36	30.39	709

By 2019, bulk density increased across most sites, reaching up to 1.417 g. cm^{-3} in Latif Awa. This rise indicates the onset of compaction due to continuous cultivation. Permeability improved in Mewk (0.93 cm. $hour^{-1}$), but decreases were noted in areas like Latif Awa (0.78 cm. $hour^{-1}$). Porosity remained relatively stable, ranging between 0.58–0.69 cm^3/cm^3. However, OM levels continued to decline in Warmizyar (2.94%). Root system distribution showed a noticeable drop in Kani Big (279 cm), while shoot lengths in Tui Awlia and Mewk were slightly reduced. [26

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Table (15): Some soil physical and other properties for the study areas in 2020

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability cm. $hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.46	0.89	0.71	4.4	32.6	738
Tui awlia	Clay Loam	1.48	0.81	0.63	4.8	31.8	668
Kani big	Clay Loam	1.5	0.84	0.67	4.69	29.4	298
Shuwan-kara	Clay Loam	1.47	0.88	0.69	4.58	28.6	628
Qushqaya	Clay Loam	1.49	0.84	0.68	4.22	29.9	698
Qushqaya	Clay Loam	1.51	0.88	0.62	4.39	27.9	698
Halay sarchawa	Clay Loam	1.41	0.83	0.63	4.45	32.6	628
Zeika	Clay Loam	1.47	0.91	0.69	3.85	31.4	398
Warmizy ar	Clay Loam	1.5	0.87	0.67	3.7	33.8	597
Latif awa	Clay Loam	1.52	0.74	0.73	4.12	32.9	728

In 2020, significant increases in bulk density were observed, with Latif Awa reaching 1.52 g. cm^{-3} and Kani Big, following closely at 1.5 g. cm^{-3}. Permeability declined in Latif Awa (0.74 cm. $hour^{-1}$) and remained low in several locations. Porosity also decreased in compacted soils, with Halay Sarchawa maintaining relatively high values (0.69 cm^3.. cm^{-3}). OM levels showed a slight recovery in Mewk (4.4%) and Halay Sarchawa (4.45%). Root and shoot system distributions were stable in Mewk (738 cm and 32.6 cm, respectively), but Kani Big showed further reductions in root distribution (298 cm).

Table (16): Some soil physical and other properties for the study areas in 2021

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability $cm.\ hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.31	0.96	0.79	4.59	31.1	731
Tui awlia	Clay Loam	1.33	0.88	0.71	4.99	27.1	661
Kani big	Clay Loam	1.35	0.91	0.75	4.88	30.1	291
Shuwankara	Clay Loam	1.32	0.95	0.77	4.77	34.1	621
Qushqaya	Clay Loam	1.34	0.91	0.76	4.41	28.1	691
Qushqaya	Clay Loam	1.36	0.95	0.7	4.58	33.1	691
Halay sarchawa	Clay Loam	1.26	0.9	0.71	4.64	27.1	621
Zeika	Clay Loam	1.32	0.98	0.77	4.04	30.1	391
Warmizy ar	Clay Loam	1.35	0.94	0.75	3.89	32.1	590
Latif awa	Clay Loam	1.37	0.81	0.81	4.31	31.1	721

The year 2021 showed stabilization in some soil properties, with bulk density decreasing slightly in Halay Sarchawa (1.26 g. cm^{-3}) and Mewk (1.31 g. cm^{-3}). Permeability increased in Mewk (0.96 cm. $hour^{-1}$), indicating improvements in soil structure. Porosity remained high in Latif Awa (0.81 cm^3.. cm^{-3}), supporting its better aeration. OM levels peaked in Halay Sarchawa (4.64%) and Shuwankara (4.77%). However, root distribution continued to decline in Kani Big (291 cm), reflecting the long-term effects of soil degradation despite moderate recovery in OM and porosity.

Table (17): Some soil physical and other properties for the study areas in 2022

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability $cm.\ hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.22	0.88	0.73	3.71	30.24	708
Tui awlia	Clay Loam	1.24	0.8	0.65	4.11	26.24	638
Kani big	Clay Loam	1.26	0.83	0.69	4	29.24	268
Shuwan-kara	Clay Loam	1.23	0.87	0.71	3.89	33.24	598
Qushqaya	Clay Loam	1.25	0.83	0.7	3.53	27.24	668
Qushqaya	Clay Loam	1.27	0.87	0.64	3.7	32.24	668
Halay sarchawa	Clay Loam	1.17	0.82	0.65	3.76	26.24	598
Zeika	Clay Loam	1.23	0.9	0.71	3.16	29.24	368
Warmizy ar	Clay Loam	1.26	0.86	0.69	3.01	31.24	567
Latif awa	Clay Loam	1.28	0.73	0.75	3.43	30.24	698

In 2022, bulk density decreased slightly in most areas, such as Halay Sarchawa (1.17 g cm^{-3}) and Mewk (1.22 g cm^{-3}), suggesting effective soil management practices. Permeability ranged between 0.73 cm. $hour^{-1}$ (Latif Awa) and 0.9 cm. $hour^{-1}$ (Zeika). Porosity showed stabilization, with Latif Awa maintaining its high value (0.75 cm^3.. cm^{-3}). However, OM levels began to decline slightly, particularly in Mewk (3.71%) and Warmizyar (3.01%). Root and shoot systems showed slight reductions across most sites, particularly in Kani Big (268 cm root distribution). [27]

Table (18): Some soil physical and other properties for the study areas in 2023

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability $cm.\ hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.34	0.8	0.66	2.89	27.75	690
Tui awlia	Clay Loam	1.36	0.72	0.58	3.29	23.75	620
Kani big	Clay Loam	1.38	0.75	0.62	3.18	26.75	250
Shuwan-kara	Clay Loam	1.35	0.79	0.64	3.07	30.75	580
Qushqaya	Clay Loam	1.37	0.75	0.63	2.71	24.75	650
Qushqaya	Clay Loam	1.39	0.79	0.57	2.88	29.75	650
Halay sarchawa	Clay Loam	1.29	0.74	0.58	2.94	33.75	580
Zeika	Clay Loam	1.35	0.82	0.64	2.34	30.75	350
Warmizy ar	Clay Loam	1.38	0.78	0.62	2.19	28.75	549
Latif awa	Clay Loam	1.4	0.65	0.68	2.61	27.75	680

By 2023, bulk density increased again, reaching critical levels in Latif Awa (1.4 $g.\ cm^{-3}$) and Warmizyar (1.38 $g.\ cm^{-3}$). Permeability continued to decrease, with the lowest value recorded in Latif Awa (0.65 $cm.\ hour^{-1}$). Porosity showed corresponding reductions, with values as low as 0.50–0.57 $cm^3.\ cm^{-3}$ in many sites. OM levels dropped significantly in Warmizyar (2.19%) and Zeika (2.34%), reflecting long-term degradation. Root and shoot distributions suffered, with Kani Big exhibiting the lowest root distribution (250 cm).

Table (19): Some soil physical and other properties for the study areas in 2024

Village name	Soil Texture	Soil bulk density $g.cm^{-3}$	Permeability $cm.\ hour^{-1}$	Porosity $cm^3.cm^{-3}$	Organic Matter %	Root System Distributions (cm)	Shoot System Distribution (cm)
Mewk	Clay Loam	1.42	0.74	0.59	2.63	27.27	651
Tui awlia	Clay Loam	1.44	0.66	0.51	3.03	33.27	581
Kani big	Clay Loam	1.46	0.69	0.55	2.92	26.27	211
Shuwan-kara	Clay Loam	1.43	0.73	0.57	2.81	30.27	541
Qushqaya	Clay Loam	1.45	0.69	0.56	2.45	24.27	611
Qushqaya	Clay Loam	1.47	0.73	0.5	2.62	29.27	611
Halay sarchawa	Clay Loam	1.37	0.68	0.51	2.68	33.27	541
Zeika	Clay Loam	1.43	0.76	0.57	2.08	26.27	311
Warmizy ar	Clay Loam	1.46	0.72	0.55	1.93	28.27	510
Latif awa	Clay Loam	1.48	0.59	0.61	2.35	27.27	641

In 2024, soil degradation continued, as indicated by rising bulk density, which peaked at 1.48 g. cm^{-3} in Latif Awa. Permeability dropped further, particularly in Latif Awa (0.59 cm. $hour^{-1}$) and Tui Awlia (0.66 cm. $hour^{-1}$). Porosity fell to its lowest levels in most sites, with Qushqaya and Halay Sarchawa showing values around 0.50–0.57 cm^3. cm^{-3}. OM levels reached critical lows in Warmizyar (1.93%) and Zeika (2.08%). These changes correlated with reduced root system distribution, particularly in Kani Big (211 cm), and shoot system distribution in Warmizyar (510 cm). [28]

All study sites are characterized by clay loam soil, which is a favorable texture for agriculture due to its balance of water retention and drainage. This texture supports moderate permeability and porosity, but excessive clay content could lead to compaction, particularly under continuous cultivation. Bulk density gradually increased across the years, particularly in villages like Kani Big and Latif Awa, where values reached 1.46–1.48 g. cm^{-3} by 2024. High bulk density is an indicator of compaction, likely resulting from repeated tillage and heavy machinery use. Compacted soils restrict root growth and reduce water infiltration and aeration. In contrast, Halay Sarchawa consistently maintained lower bulk density levels (~1.29 g/cm^3 in 2023), suggesting better soil management practices or lower mechanical stress. Permeability decreased significantly over time, particularly in Latif Awa (0.59 cm. hour^{-1} in 2024) and Tui Awlia (0.66 cm. hour^{-1}). Reduced permeability can impede water infiltration and increase surface run-off, leading to soil erosion and nutrient loss. This decline is likely a result of compaction and reduced porosity caused by continuous cultivation practices. Porosity also showed a declining trend, dropping from values around 0.73–0.79 in earlier years to 0.50–0.59 in 2024 in some locations. Reduced porosity reflects a loss of soil structure, which could negatively impact water and air movement within the soil profile, thereby affecting root growth and microbial activity. [29]

Soil organic matter (SOM) decreased notably across all sites over the years, with Mewk declining from 3.71% in 2022 to 2.63% in 2024. The reduction in SOM is indicative of soil degradation and highlights the impact of continuous cultivation without adequate organic matter replenishment. SOM plays a crucial role in maintaining soil structure, nutrient cycling, and water-holding capacity. Low organic matter levels suggest the need for practices like organic amendments, crop rotation, or reduced tillage.

Root distribution showed a gradual decline in many sites, such as Kani Big (from 268 cm in 2022 to 211 cm in 2024). This reduction could result from increasing bulk density and reduced porosity, which restricts root penetration. Conversely, Halay Sarchawa maintained relatively stable root system distributions, highlighting the importance of effective soil management practices to sustain root health. Shoot system distribution exhibited similar declines, reflecting the adverse effects of deteriorating soil physical properties on plant growth. Warmizyar and Kani Big showed significant reductions, with shoot lengths dropping to 510 cm and 211 cm, respectively, in 2024. This decline underscores the interdependence between soil health and crop productivity. [30]

Across the study sites, electrical conductivity (EC) generally increased at first but improved in many villages by 2023–2024, while soil pH remained alkaline throughout, particularly in Mewk and Qushqaya. Total nitrogen (%) showed continuous declines in some areas, pointing to over-cultivation and nutrient depletion, and available phosphorus fluctuated, suggesting inconsistent management of P fertilizers. Exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) were variable, indicating localized management issues and/or crop effects, and $CaCO_3$ (%) persisted at high levels, limiting nutrient availability and reinforcing alkaline conditions. Physically, initial soils exhibited moderate bulk density with adequate porosity and relatively high soil organic matter (SOM), supporting robust root and shoot development. Over time, bulk density began to rise with minor declines in porosity and permeability and early signs of SOM depletion;

subsequently, compaction increased notably, porosity decreased further, and SOM continued to decline, accompanied by reduced root and shoot distributions. By the final interval, bulk density peaked in most areas, coinciding with the lowest permeability and porosity values, critically low SOM, and clear evidence of severe soil degradation at some sites, with root and shoot systems suffering markedly as a consequence.

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