



Characterization of Soil Properties Under Continuous Irrigation Practice

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Abstract

Continuous irrigation, though essential for agricultural productivity in semi-arid regions, can significantly alter soil physical and chemical properties over time. In Kano State, Nigeria, there is limited recent data on how continuous irrigation affects different soil textures such as sandy loam and loamy soils. This study aims to assess the impact of continuous irrigation on the physical and chemical properties of soils under Watari Irrigation Scheme, with a focus on identifying implications for sustainable soil management. Soil samples were collected from irrigated and adjacent non-irrigated (control) fields of sandy loam and loam textures at two depths: 0-30cm and 30-60cm, replicated three times. A total of 24 samples were analyzed for physical properties (moisture content, bulk density, hydraulic conductivity), and chemical properties (organic matter, salinity (EC), Sodium Adsorption Ratio (SAR), Total Dissolved Solids (TDS), Cation Exchange Capacity (CEC), pH (H₂O), pH (CaCl₂), Sodium (Na⁺), Calcium (Ca²⁺), Magnesium (Mg²⁺), Potassium (K⁺). Standard laboratory procedures were used, and statistical analysis was performed using SPSS v25 with ANOVA at a 5% significance level. Results showed that the texture-dependent respond to continuous irrigation. Bulk density slightly decreased in irrigated sandy loam (1.48 to 1.46g/cm³) and slightly increased in loam (1.41 to 1.42g/cm³), with a corresponding decrease in porosity. Moisture content was higher in non-irrigated sandy loam (15.67%) also higher in irrigated loam (16.46%). The results of this study indicates that non-irrigated soils retain more moisture but exhibit higher salinity and sodium accumulation particularly in sandy loam, TDS levels reached 262.4mg/l compared to 108.8mg/l in irrigated soil. Loamy soil demonstrated superior moisture retention (16.46%) and lower bulk density (1.41g/cm³), making it more suitable for water-intensive crops. Pearson correlation analysis (-0.67) revealed a negative relationship between bulk density and moisture content, indicating that compacted soils retain less water. This indicates that continuous irrigation may contribute to nutrient leaching and reduce soil fertility over time. Other properties EC, pH, Na⁺, Ca²⁺, K⁺, SAR, and TDS do not show significant variations in the two conditions. The findings show that continuous irrigation reduces soil salinity and enhances nutrient availability, however, it may contribute to compaction in sandy loam soils. These highlight the need for texture-specific soil management. Gypsum application and organic amendments are recommended for sodium-affected soils, while strategic irrigation scheduling is necessary to optimize water use efficiency. These results provide valuable indicators for sustainable irrigation practice and strategies, soil management and crop selection (such as organic amendments and optimized irrigation scheduling, to maintain soil nutrients balance and fertility in Watari irrigation project under semi-arid agricultural systems).

Keywords: Soil characterization, continuous irrigation, salinity, sandy loam loamy soil, Watari.

1.0 Introduction

Soil is one of the most important parameters of considerations when it comes to irrigation practices and it is an integral part of the ecosystem that produces food and fiber. Soil properties are reflections of the dominant factors of soil formation such as parent material, climate, organism, relief and time. The influence of these factors on soil is distinct but has interdependent effects on soil, and it is their combined effect that gives rise to distinct soil type. The knowledge of soil properties is very useful in determining soil characteristics, quality and productivity [1], [2]. Water availability is a major constraint to agricultural productivity in semi-arid regions such as Northern Nigeria where irrigation is essential to boost agricultural activity. particularly under structured schemes like the Watari Irrigation Project. However, part of the notable effects of long-term irrigation is degradation of soil quality by the alteration of the physical and chemical properties.

Several studies have been documented on the effects of irrigation on soil quality, increase in bulk density, reductions in porosity, salts accumulation, and essential nutrients depletion over time [3], [4], [5]. While these effects are well recognized globally, there is limited understanding and awareness on how continuous irrigation affects different soil textures under localized conditions in the semi-arid environment such as watari irrigation project of Kano State [6,], [7]. Furthermore, available studies in the region were mostly generalized, lacking specific insight on the impact of continuous irrigation on soil texture.

Globally, studies have reported the impacts of compaction, salinization, and nutrient depletion under prolonged irrigation. This study sought to address and evaluate effects of continuous irrigation on the physical and chemical properties of sandy loam and loam soils of Watari irrigation project, Kano State. The findings of this research would serve as a guide to stakeholders and policy makers for sustainable irrigation strategies in watari

irrigation project and in similar agro-ecological zones. This is with a view to make proper recommendations on the implications of the current condition of the soil use in the area.

2.0 Materials and Methods

2.1 Description of the Study Area

The Watari irrigation project lies between latitude 12°05' 54.54"N; 12°12' 17.8"N and longitude 8°08' 50.62"E; 8° 17'E 28.05'E in Savanna ecological zone and located on the downstream of the dam. The mean annual temperature is 26°C. Rainfall typically occurs in the months of June to September. August being the wettest month. with an annual value of 850 mm [8]. The area covers a total of 4,574 hectares, with the main canal stretched to about 10 km in length, the command area consists of 8 sectors with sector 8 as the kanju pilot farm. The net irrigable land area per sector is as follows:

Table 1: Area of Irrigable Land in Watari Irrigation Scheme

S/N	Sector	Area (Hectares)
1	1	160
2	2	170
3	3	216
4	4	72
5	5	172
6	6	100
7	8	72
8	Total	962

Source: KNARDA (2023)

Studies have shown the importance of examining soil physical parameters in monitoring the productivity and suitability to different management practices. Recent reports by [9] and [8] emphasize the importance of monitoring soil quality for sustained agricultural output in the zone.

2.2 Soil Sampling and Preparation

Soil samples were randomly collected from three locations at a depth of 0-30 and 30-60cm under irrigated and non-irrigated conditions. A total of 24 samples representing the depth x treatment combination in three replicates was obtained and samples were air-dried and sieved (2mm), [10]. The samples were analyzed using standard procedure at the soil and water laboratory of Agricultural and Environmental Engineering, Bayero University, Kano.

Particle size distribution was determined using the Bouyouscos hydrometer method [11], porosity and bulk density were determined using core method [12]. Hydraulic conductivity was determined using a constant head permeameter apparatus (D 1702) [13]. Gravimetric moisture content was measured by oven drying at 105 °C for 24hours as described by [11]. Organic carbon was measured using the Walkley-Black wet oxidation method and converted to Organic matter (OM) by multiplying by a factor of 1.724 [16]. Field capacity and wilting points were determined using a pressure plate apparatus method [15]. Electrical conductivity and pH were determined in deionized water suspension (1:2:5) using a calibrated EC meter (LABLINE AUTO CONDUCTIVITY METER) and pH meter (HANNAH pH209) in the same suspension respectively, [13]. Sodium (Na⁺), Calcium (Ca²⁺), Magnesium (Mg²⁺), Cation Exchange Capacity CEC, were all determined using a Flame photometry (for K⁺ and Na⁺) and atomic absorption spectrophotometry (AAS) extracted with 1M NH₄OAc for Ca²⁺ and Mg²⁺ [13].

$$\text{Bulk Density (BD)} = \frac{\text{Oven - dry weight of soil (g)}}{\text{Volume of core (cm}^3\text{)}} \quad (1)$$

$$\text{Porosity (\%)} = \frac{(1 - \text{BD})}{\text{PD}} \times 100 \quad (2)$$

$$\text{Sodium Adsorption Ratio (SAR)} = \frac{[\text{Na}^+]}{(\sqrt{([\text{Ca}^{2+}]][\text{Mg}^{2+}]})/2)} \quad (3)$$

where BD is the bulk density, PD is the particle density, SAR is sodium adsorption ratio, Na⁺ is sodium ion, Ca²⁺ is the calcium ion, and Mg²⁺ is the magnesium ion.

The data collected were subjected to analysis of variance (ANOVA) and statistically analyzed using SPSS version 25. Mean values were separated using Least Significant Difference (LSD) at a 5% significance level.

3.0 Results and Discussion

3.1 Results

Tables 2, 3, 4 and 5 represent the mean values of the result obtained from the analyzed samples.

Table 2: Physical properties of sandy loam soil

S/N	Property	Irrigated	Non-irrigated
1	Porosity (%)	46.67	47.8
2	Bulk Density (g/cm ³)	1.46	1.48
3	Hydraulic Conductivity (cm/hr)	54.93	49.66
4	Field Capacity (%)	17.77	17.88
5	Wilting Point (%)	7.78	8.48
6	Moisture Content (%)	14.17	15.67
7	Organic Matter (%)	1.15	0.98

Table 3: Chemical properties of sandy loam soil

S/N	Property	Irrigated	Non-irrigated
1	EC (dS/m)	0.18	0.36
2	pH (H ₂ O)	6.32	6.35
3	pH (CaCl ₂)	5.83	5.89
4	Na ⁺	0.62	0.88
5	Ca ²⁺	3.65	3.83
6	Mg ²⁺	1.26	1.69
7	K ⁺	1.66	2.01
8	SAR	0.37	0.63
9	CEC	10.46	11.24
10	TDS	115.20	228.27

Table 4: Physical properties of loam soil

S/N	Property	Irrigated	Non-irrigated
1	Porosity (%)	48.50	49.67
2	Bulk Density (g/cm ³)	1.42	1.41
3	Hydraulic Conductivity (cm/hr)	130.04	133.91
4	Field Capacity (%)	13.14	13.83
5	Wilting Point (%)	6.33	7.42
6	Moisture Content (%)	16.46	16.01
7	Organic Matter (%)	1.35	1.39

Table 5: Chemical properties of loam soil

S/N	Property	Irrigated	Non-irrigated
1	EC (dS/m)	0.18	0.29
2	pH (H ₂ O)	6.34	6.34
3	pH (CaCl ₂)	5.78	5.78
4	Na ⁺	0.45	0.39
5	Ca ²⁺	3.49	3.59
6	Mg ²⁺	1.30	1.83
7	K ⁺	1.49	1.63
8	SAR	0.30	0.29
9	CEC	10.92	12.09
10	TDS	117.33	187.73

3.2 Discussion

3.2.1 Physical properties of soil

The values of bulk density showed minimal but notable variation across soil types and irrigation treatments. In sandy loam, bulk density was slightly decreased under irrigation (from 1.48 to 1.46g/cm³), while in loam, it was increased marginally from 1.41 to 1.42g/cm³. These variations are subtle but indicate that soil compaction due to irrigation is dependent upon texture and may not always follow a uniform trend. This is contrary to the findings by [15], that reported increased bulk density under long-term irrigation. This study suggests that good field

practices and soil texture may improve compacted soils. Porosity exhibited a slight decrease under irrigation in both soil types (sandy loam 47.83% to 46.67% and 49.67% to 48.50% in loam). These reductions confirm the inverse relationship between bulk density and porosity. This is as supported by [16] and [5], who demonstrated that irrigation-induced changes in soil structure can lead to reduced pore space, especially in coarser soils. Moisture content in sandy loam was slightly higher under non-irrigated conditions (15.67%) compared to irrigated (14.17%). In contrary, loam soils retained more moisture under irrigation (16.46%) than in non-irrigated (16.01%), highlighting the role of soil texture in water retention. These findings align with [5], who noted that finer-textured soils such as loam possess greater capillary action and better moisture-holding capacity than sandy soils. Field capacity and wilting point were also slightly lower in irrigated soils, indicating that frequent irrigation might lead to soil structure or nutrient status alteration. These results confirm that soil texture influences the ability of soil to serve as storage for available plant water, a trend that was also observed by [17] in semi-arid irrigated systems. Hydraulic conductivity was slightly lower in irrigated soils than non-irrigated in both soil types. In loam, it decreased from 133.91cm/hr to 130.04cm/hr, while in sandy loam it was slightly increased from 49.66 cm/hr to 54.93 cm/hr. This variability could be attributed to micro-aggregation changes or tillage effects and is consistent with findings by [3], who reported similar marginal reductions in water infiltration in irrigated semi-arid soils.

3.2.2 Chemical Properties of Soil

Electrical conductivity (EC) and Total Dissolved Solid (TDS) were higher in non-irrigated soils, particularly in sandy loam (EC: 0.36 ds/m; TDS: 228.27 mg/l) than in irrigated counterparts (EC:0.18 ds/m; TDS: 115.2 mg/l). these results suggest that leaching under irrigation helped remove soluble salts, especially in coarser soils. This observation supports findings by [4] and [18], who emphasized that leaching under controlled irrigation can mitigate salinity buildup in arid soils. The values of soil pH were relatively stable across all treatments and textures, with minor variation between H₂O and CaCl₂ media (ranging from 5.78 to 6.35). This slight alkalinity falls within the optimal range for most crops. Similar pH stability under irrigation was reported by [19], suggesting that pH is less influenced by irrigation compared to other chemical properties. Exchangeable Mg²⁺ and K⁺ levels were consistently higher in non-irrigated soils. Mg²⁺ in loam it was 1.83 Cmol/kg (non-irrigated) and 1.30 Cmol/kg (irrigated). This suggests possible nutrient leaching due to frequent water application. Similarly, K⁺ decreased slightly under irrigation in both soil types. Significant differences observed in Mg and CEC ($p < 0.05$), with higher values in non-irrigated soils. These patterns are consistent with [3] and [20], who reported dilution and downward movement of base cations under irrigation in sandy and loamy soils. The values of Cations exchange capacity CEC were generally higher in loam soils than in sandy loam, this was expected due to greater organic matter and clay content. The CEC values in non-irrigated soils were 12.09 Cmol/kg and 11.24 Cmol/kg in loam and sandy loam respectively. . This reinforces the established principle that soil texture and organic matter enhance nutrient-holding capacity [5]. Similarly, the values of Sodium Adsorption Ratio (SAR) were low in all samples, which indicates no immediate sodicity threat. However, the slightly higher SAR values in non-irrigated sandy loam (0.63) suggest minor sodium accumulation though negligible. According to [4], SAR below 1.5 is considered safe, but monitoring is still advised, particularly in light soils.

3.2.3 comparing sandy loam and loam textured soils

Loam soils consistently perform better sandy loam in terms of higher moisture retention, more stable chemical properties, better nutrient-holding capacity (higher CEC), and greater resistance to irrigation-induced leaching. These outcomes reaffirm that soil texture plays a pivotal role in soils response to irrigation, as supported by [5] and [6].

3.2.4 Correlation Analysis

A negative Pearson correlation ($r = -0.67$) was observed between bulk density and moisture content, this indicate that the ability of soil to hold moisture decreases when the soil is highly compacted. This is consistent with the findings of [16] and [5], who also reported low moisture content in compacted soils.

3.2.5 Water Retention and Availability

Sandy loam (non-irrigated) retains slightly more moisture than the irrigated soil. Irrigated and non-irrigated loamy soils hold more water than sandy loam due to better structure. Irrigation significantly enhances moisture content and prevent excessive dryness. Non-irrigated soils reach the wilting point faster, which reduces plant survival in dry conditions.

3.2.6 Impact of Salinity and Nutrient Balance

Salt accumulation (high EC and TDS) in non-irrigated soils poses a threat to plant growth by affecting osmotic balance and nutrient uptake. This was more pronounced in sandy loam. Irrigation appears to mitigate salinity risks through leaching, emphasizing its role in salt-sensitive crop production. Cation Exchange Capacity (CEC) is

moderate in all cases (10.46 to 12.09 Cmol/kg) this means that the soils have high potentials to retain nutrients. Sodium Adsorption Ratio (SAR) is also within acceptable limits but slightly high in non-irrigated soils. Sodium (Na^+) levels are much higher in non-irrigated soils, which can cause soil degradation over time. Potassium (K^+), Calcium (Ca^{2+}), and Magnesium (Mg^{2+}) levels remain stable in both soil type.

4.0 Conclusion

From the results obtained, it showed that as the bulk density increases there was a corresponding decrease in the moisture content, this indicates that denser soils retain less moisture, making sandy loam soils drier than loamy soils. Therefore, to maintain good moisture content of sandy loam, irrigation should be made priority (apply water as at when due) to prevent drying. In addition, non-irrigated soils require good management to prevent salinity buildup and sodium accumulation. Notably, Loamy soils are good at water retention and nutrient availability and therefore the best choice for high-value crops. Hence, it is recommended that; i) regular soil test, and strategic irrigation planning be conducted, these can help maintain optimal soil health. ii) salinity management (gypsum, organic matter) for non-irrigated soils to reduce sodium buildup. iii) crop selection should consider moisture availability and salt tolerance. These results highlight the vital role played by soil texture in determining soil responses to continuous irrigation. Finally, it was observed that Sandy loam soils are more vulnerable to degradation under continuous irrigation, than loam soils which showed greater resilience and better nutrient stability.

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