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Research Paper

Effects of more than two decades of irrigation on the physical and chemical properties of two savanna soils at the golinga irrigation site near tamale

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Abstract: The Guinea savanna zone of Ghana is in the ustic moisture regime, receiving 900 - 1100 mm of rainfall. Irrigation projects were introduced to this zone about 3 decades ago to help provide additional moisture for agriculture. The Golinga irrigation project near Tamale is one of such projects. The Volta and Lima soil series were investigated to establish if irrigation has altered soil chemical and physical properties within the rooting zone of plants, the top soil (0-20 cm). Fifteen samples including a composite sample from the adjacent non-irrigated area which served as control were analyzed in the laboratory. Results from the irrigated area, showed low pH with values ranging from 4.45 to 5.84 (i.e. from very strongly to strongly acid) whiles the non-irrigated site recorded a pH of 6.49 (neutral). The pH of the irrigated site was more than 1.0 pH units lower than the pH of the non-irrigated site. The organic matter content, total nitrogen and available P were generally low for both sites. However, the available P content has been significantly reduced by irrigation. Other chemical properties significantly affected by irrigation include EC, Ca, Mg, K, Na and the ECEC. The result revealed that the texture of the soil at the irrigated site is generally silty loam while that of the non irrigated area is sandy loam.

Keywords: irrigated, non irrigated, pH, ECEC, organic matter, texture, Savanna, Golinga

Introduction

The Lima {Gleyic Lixisol (siltic)} and Volta {Gleyic Lixisol (Cleyic)} associations are formed over Voltaian sandstones and are the most extensive soils encountered in the lowlands of the Voltain geological formations in Ghana. The increasing demand for food and other agricultural products make the utilization and conservation of soil resources increasingly imperative. Under irrigation, soil and water compatibility is very important. If they are not compatible, the applied irrigation water could have adverse effects on the soil physical and chemical properties. Determining the suitability of land for irrigation requires a thorough evaluation of the soil properties, the topography of the land within the field and quality of water to be used for irrigation (Scherer et al., 1996).

Longenecker and Lyerly (1959) observed that soils that are under long-term irrigation establish equilibrium with the chemical composition of the irrigation water applied. Haslbach (1964) found that irrigation causes translocation of exchangeable cations from the topsoil to the subsoil. Irrigation also increased clay illuviation and mineral weathering, altered the surface horizon, pH and exchangeable sodium percentage (ESP), and modified the natural processes by increasing the rate of pedogenic activity (Ransom et al., 2004). Irrigation also alters the natural climatic factors of soil formation. Some soil processes, morphological and mineralogical properties of the soil that correlate with climate such as organic matter content, kind of clay and iron minerals, colour, various chemical extracts and presence of calcium carbonate ($CaCO_3$) and other soluble salts have been shown to be affected by local alterations in climate (Birkeland, 1999). Accumulation of soluble salts, exchangeable sodium, and calcium carbonate ($CaCO_3$) as well as increases in electrical conductivity (EC) and pH, occurred in soils as a result of irrigation (Dixon, 1960; Lynn, 1958 and Naddith, 1960). According to Osuman (2009) the pH of the Botanga irrigation site in the northern region of Ghana which averaged 6.2 (ie neutral) at the inception of the Botanga project has become strongly acidic (average value of 5.3) after decades of irrigation agriculture.

If irrigated agriculture is to continue to be a major contributor to world food supply, irrigation projects should be properly planned and monitored to prevent soil deterioration. An irrigation project therefore should aim at preserving the soil resources for future production as well as maintaining current production.

This study was thus designed to assess the impact of changes in hydrological regime on some selected soil physical and chemical properties at the Golinga irrigation site in northern Ghana.

Martial mad Methods

Soil samples for laboratory analyses were taken from Golinga irrigation site in the Tolon/Kumbungu District of the Northern Region of Ghana. The sampling site and indeed the whole of the Tolon District fall within the Voltain soil formation (Adu, 1995). The Golinga site lies on $09^0\ 21^{'}\ 14.14^{''}$ N and longitude $0^0\ 57^{'}\ 04.95^{''}$ W.

Soil sampling

The grid sampling method was used to collect both disturbed and core samples for laboratory analysis. A baseline was laid out on the edge of the dam wall. From this baseline, parallel transects were cut at 50 m intervals. Running perpendicular to the baseline were transects that were also cut at 50 m intervals to give a square grid of 50 m x 50 m. Fourteen soil samples were systematically taken from the intersection of these grids. One composite sample was also taken from an adjacent non-irrigated field to serve as control. The bulk samples were air-dried and sieved to eliminate particles > 2 mm. Soil chemical properties such as pH, electrical conductivity (EC), extractable bases, exchange acidity, effective cation exchange capacity (ECEC), percentage base saturation (PBS), organic matter content, total nitrogen (N), available phosphorous (P) were determined. Physical properties such as bulk density, porosity, texture and moisture content were also determined.

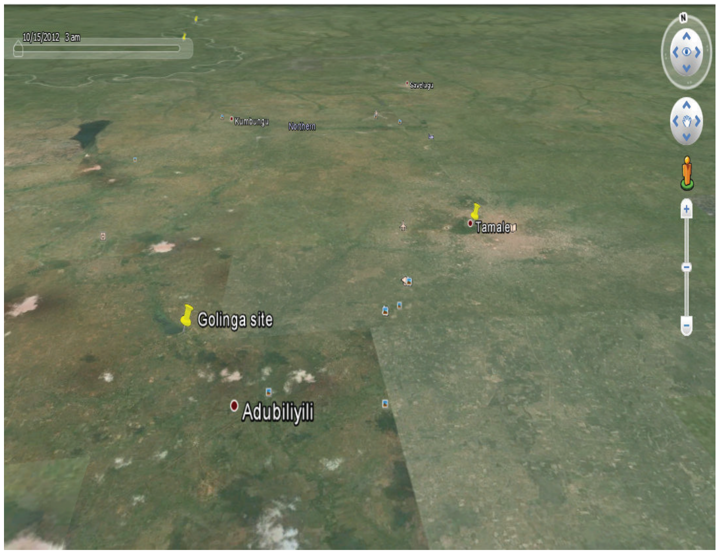

Figure 1. A 3D view of the Golinga Irrigation site

Chemical analyses

pH (1:1 H_2O) was determined in water with a glass electrode at a soil to water ratio of 1:1.

Electrical conductivity (EC) was determined by the saturation paste-extract method.

Extractable bases were determined by the Ammonium acetate (NH_4OAc) method using neutral 1M NH_4OAc pH 7 solution. Calcium (Ca) and magnesium (Mg) contents were determined using EDTA titration, while sodium (Na) and potassium (K) were determined by flame photometer.

Exchange acidity was determined by Mehlich's barium chloride-triethanolamine extraction, buffered at pH 8.2 (Mehlich, 1938). The soil was leached with an unbuffered salt solution (1M KCl solution) and Al in the leachate measured by titration (Coleman et al., 1959; Lin and Coleman, 1960; Mc Lean, 1965).

The Effective Cation Exchange Capacity (ECEC) was calculated by sum of the acidic and basic cations.

Percentage Base Saturation (PBS) was derived by expressing the total extractable bases (TEB) as a percentage of the ECEC.

Organic matter. Organic carbon content of the soil was determined using the Walkley Black (1935) procedure. Organic carbon content was converted to organic matter content by multiplying the organic carbon values with 1.724 Van Bemmelen factor.

Total nitrogen was determined by the Kjeldahl method.

Available phosphorous (P) was determined according to the method by Bray and Kurtz (1945).

Physical analyses

Particle size distribution was determined using the Bouyoucos Hydrometer method as modified by Day (1965).

Bulk density was determined by the core method. Core samples were oven dried after which the samples were weighed, and the oven-dry weight divided by the soil volume.

$$\rho_b = \frac{M_2 - M_1}{V}$$

Where: M2 is mass of dry soil and core sampler
M1 is mass of core sampler and
V is volume of core sampler

Porosity was determined using the formula:

$$\% \text{ pore space} = 100 - \frac{\rho_b \times 100}{\rho s}$$

Where: ρ_b = bulk density

ρ_s = particle density

Results

Soil reaction (pH) and electrical conductivity (EC)

The results of the pH analysis for all the fifteen (15) soil samples are given in (Table 1). The pH in water ranged from 4.45 to 5.84 that is, from very strongly to strongly acidic. The non-irrigated site recorded a pH of 6.63 (neutral). The pH values of the irrigated site are below the ideal nutrient solution pH of 6.0 to 6.5 (Brady and Weil, 2008). The pH of the irrigated site was significantly lower (P <0.001) than the non irrigated site (Table 3). The non-irrigated soil pH of 6.49 (neutral) showed the irrigated soils to be 10 times more acidic. The soil pH scale is logarithmic, meaning that each whole number is a factor of 10 larger or smaller than the ones next to it. Changes in soil pH resulting from changes in hydrological regime of soils have been widely reported (Cline 1961; Amatekpor, 1989, 1995; Ransom, et al., 2004). The pH values obtained from the irrigated site suggest that appreciable amounts of extractable bases have been leached from the surface layers of the soils. The acidity of the irrigated site might also be due to continuous application of ammonium sulphate fertilizer which is commonly used in most rice fields. The ammonium fertilizers undergo nitrification to release H^+ as follows:

$$NH_4 \;+\; 2O_2 \;\rightarrow\; NO_3^- \;+\; 2H^+ \;+\; H_2O$$

The low soil pH on the irrigated site may also affect phosphorous availability. Phosphorus is available to plants when soil pH is between 6.0 and 7.0 (Spector et al., 2001). If the soil solution is too acidic plants cannot utilize N, P, K and other nutrients they need. At pH of 4.45 to 5.84, nodulation of legumes may also be affected as it is reported that most legumes are able to nodulate and fix atmospheric Nitrogen into the soils at pH between 6.0 and 7.0 (Spector et al., 2001). Soil pH recorded at the irrigation site may also have negative effects on applied pesticides, herbicides and fungicides because these chemicals may not be absorbed by plants at low pH and may end up in garden water and rain water runoff, where they eventually become pollutants in streams, rivers, lakes, and ground water (Spector et al., 2001). The finding on pH at the Golinga site is corroborated by Osuman (2009), who reported that pH of soils at the Botanga irrigation site which averaged 6.2 (neutral) at the inception of the project has become strongly acidic (average value of 5.3) after about three decades of irrigation agriculture.

Electrical conductivity of the irrigated site ranged from 0.13 to 0.99 mmhos/cm (Table 1). The EC value for the non – irrigated site was 0.35. The results revealed that the soils were non saline However, the average EC value of 0.58 mmhos/cm of the irrigated site was significantly higher (P =0.003) than that of the non irrigated site (0.35 mmhos/cm) indicating a trend towards salinity (Table 3).

Soil organic matter (OM)

The organic matter content in the soil varied from 0.76% - 1.81% (Table 1). The low organic matter content recorded at the site might be due to the lack of decomposable materials such as grass vegetation and crop residue due to frequent burning observed at the site. Even if these decomposable materials are available, the low pH (4.45 to 5.84) content of the soil may also affect decomposition by lowering the availability of soil microorganisms for decomposition. Nartey (1994) cited poor internal drainage as a problem affecting in situ decomposition of organic matter of soils in the interior Guinea savanna. The soils of northern Ghana have been widely reported to be low in organic matter content (Adu, 1995). Irrigation did not affect soil organic matter content.

Total Nitrogen (N) and Available Phosphorous (P)

The soil was found to contain very low amounts of N with values ranging from 0.01 to 0.07% (Table 1). Brady and Weil (2008) reported N content of 0.15% as being representative of cultivated soils. The low Nitrogen content of the soil might be due to high nitrogen utilization by plants and high denitrification. In flooded soils such as those found in natural wetlands and rice paddies, losses of nitrogen by denitrification may be very high (Brady and Weil, 2008).

The available phosphorus (P) content of the soil was also low, ranging from 1.67 mg/kg to 6.22 mg/kg for the irrigated field and 12.3 mg/kg for the non-irrigated field (Table 1). Most Ghanaian soils are inherently deficient in P because they are highly weathered and have low levels of mineral apatite (Nye and Bertheux, 1957; Acquaye and Oteng, 1972). Similarly, soils in northern Ghana have been reported to contain low levels phosphorous (Russell, 1973; Nartey, 1994). Phosphorous fixation by Al has also been reported to be responsible for the low P content of soils in northern Ghana (Nartey, 1994). In spite of the reported inherent low P in the soils of northern Ghana, irrigation was found to have significantly reduced (P < 0.001) P content. The low pH of the irrigated field may be responsible for the low P. Phosphorous tends to be fixed in acidic soils. There was a high and positive correlation (r = 0.88) between pH and P (Figure 1).

Extractable bases and effective cation exchange capacity (ECEC)

The relative abundance of extractable bases in the soil was in order $Ca^{2+} > Mg^{2+} > K^+ > Na^+$. The Ca content ranged from 4.5 to 0.7 cmol/kg in the irrigated site while a value of 4.0 cmol/kg was obtained for the non irrigated site. The Mg^{2+} content ranged from 0.4 – 2.4 cmol/kg. The values of K^+ were low with values ranging from 0.11 to 0.47 cmol/kg. The values obtained for Na content were also low and ranged from 0.3 to 0.55 cmol/ kg. The effective cation exchange capacity of the soil was therefore low with values ranging from 2.17 to 8.41 cmol/kg (Table 1).

Irrigation was found to have significantly reduced all the basic cations (Table 3). The ECEC was thus significantly affected ($P < 0.001$) by irrigation.

However, the ECEC at both sites is within 3 – 15 cmol/kg range reported for most mineral soils (Buol et al., 2003). Tiessen et al. (1991) described the soils in Northern Ghana as having low ECEC because their mineralogy is dominated by low activity clay and quartz.

Particle size distribution

The results of the particle size analysis are given in (Table 2). Out of the fifteen (15) soil samples analysed, nine (9) were found to be silty loam in texture. The particle size distribution of the soil at the site is in order: silt > sand > clay (Table 2). The result revealed that the texture of the soil at the irrigated site was generally silty loam, whereas the texture of the non – irrigated plot was sandy loam. Over half of the particles were found to be silt size particles. The high silt content is indicative of their formation from alluvial flood sloughs (Kranjac, 1999). Silt contained in irrigation water might be the source of the silty nature of the top soils at the Golinga irrigation site

Bulk density and Porosity

The bulk density of the soil was low (≤ 1.5 g/cm^3). The porosity of the soil was thus found to be above 50 % (Table 2). The average bulk density value of 1.3 g/cm^3 is below the critical value of 2.1 g/cm^3, beyond which the plant growth is severely limited (Kar *et al.,* 1996). The low bulk density recorded at the site may be due to the textural class (silt loam). These soils generally have low bulk density in contrast to sandy soils. The values obtained are within the range of 1.15g/cm^3- 1.89g/cm^3 given by Agyare (2004) as bulk density of top soils in the Tolon – Kumbungu district. This finding is in contrast with Osuman (2009) who reported that the bulk density of soils at the Botanga site has increased because of the years of irrigation agriculture.

The porosity of the soil is moderate a little above 50 %. According to Brady and Weil (2008), an "ideal" medium-textured, well-granulated surface soil in good condition for plant growth will have approximately about 50 % of the total soil volume consisting of pores.

Table 1: Chemical Properties of soils at the Golinga irrigation and non- irrigated sites

		pH(H_2O)					Extractable bases (cmol/kg)					Exch. Acidity (Al + H)	ECEC	
Samples	Depth (cm)	1:1	O.M %	EC mmhos/cm	N %	P mg/kg	Ca	Mg	K	Na	TEB	cmol/kg	cmol/kg	PBS
GP1	0-20	5.68	1.16	0.13	0.03	4.78	2.7	1.6	0.18	0.18	4.63	1.2	5.83	79.42
GP2	0-20	5.50	1.63	0.81	0.06	5.26	2.7	1.6	0.23	0.36	4.86	0.8	5.66	85.87
GP3	0-20	5.84	0.94	0.32	0.02	5.98	0.7	0.4	0.11	0.19	1.37	0.8	2.17	63.13
GP4	0-20	4.57	1.62	0.99	0.07	2.07	2.4	1.87	0.37	0.44	5.08	0.8	5.88	86.39
GP5	0-20	4.60	1.46	0.85	0.04	1.40	1.9	1.6	0.32	0.55	4.34	1.1	5.44	79.78
GP6	0-20	4.79	0.99	0.30	0.02	1.91	2.4	1.6	0.28	0.19	4.47	0.9	5.37	83.24
GP7	0-20	5.29	1.05	0.79	0.03	3.03	1.3	0.8	0.11	0.14	2.39	0.9	3.29	72.64
GP8	0-20	5.50	1.4	0.68	0.05	2.87	2.7	1.47	0.31	0.16	4.61	0.9	5.51	83.67
GP9	0-20	5.68	1.81	0.65	0.05	6.22	4.5	2.4	0.35	0.22	7.51	0.9	8.41	89.3
GP10	0-20	4.59	1.16	0.37	0.03	3.27	2.4	1.2	0.31	0.33	4.24	0.8	5.04	84.13
GP11	0-20	4.73	0.76	0.71	0.01	2.87	1.6	1.6	0.27	0.14	3.61	1.2	4.81	75.05
GP12	0-20	4.88	1.4	0.67	0.04	3.35	2.9	1.87	0.47	0.3	5.58	1.0	6.58	84.8
GP13	0-20	4.45	1.28	0.45	0.03	1.67	2.1	0.8	0.18	0.15	3.27	1.1	4.37	74.83
GP14	0-20	5.56	1.11	0.49	0.04	3.59	2.9	0.8	0.22	0.26	4.22	1.2	5.47	77.86
Average	0-20	5.12	1.27	0.59	0.04	4.35	2.37	1.40	0.27	0.26	4.30	0.97	5.27	80.0
CHK	0-20	6.63	1.22	0.35	0.03	12.3	4.0	1.74	0.43	0.1	6.28	1.2	7.48	83.96

CHK (Check) = Non-irrigated site. GP(Grid plot) = Irrigated site

Table 2 Selected Soil physical properties of soil at Golinga irrigation site

Samples	ρ_b (g/cm□)	Porosity (%)	MC (AD/OD) Ratio	θg (%)	Particle size distribution % Sand	% Silt	% Clay	Texture
GP1	1.4	47	1.0	4.9	47.4	48.6	4.0	Silt Loam
GP2	1.3	51	1.1	10.5	58.5	34.7	6.8	Sandy Loam
GP3	1.4	47	1.3	28.6	73.0	24.8	2.2	Loamy Sand
GP4	1.3	55	1.1	9.8	43.5	47.3	9.2	Silt Loam
GP5	1.3	51	1.2	15.1	37.2	53.0	9.8	Silt Loam
GP6	1.3	51	1.1	7.9	29.9	62.0	8.0	Silt Loam
GP7	1.5	43	1.1	6.2	54.0	43.9	2.0	Sandy Loam
GP8	1.4	47	1.1	14.4	44.5	51.3	4.2	Silt Loam
GP9	1.2	55	1.1	4.4	41.8	50.0	8.2	Silt Loam
GP10	1.3	51	1.0	4.9	49.1	38.9	12.0	Loam
GP11	1.3	51	1.0	2.7	45.8	44.2	10.0	Loam
GP12	1.3	51	1.0	18	35.6	52.2	12.2	Silt Loam
GP13	1.2	55	1.1	9.7	23.9	70.0	6.0	Silt Loam
GP14	1.4	47	1.1	7	34.4	61.6	4.0	Silt Loam
CHK	1.4	47	1.0	2.7	53.9	44.1	2.0	Sandy Loam

CHK=Control, GP=Golinga Plot, AD=Air Dry, MC. Moisture Content, OD=Oven Dry, GP=Grid Plot,

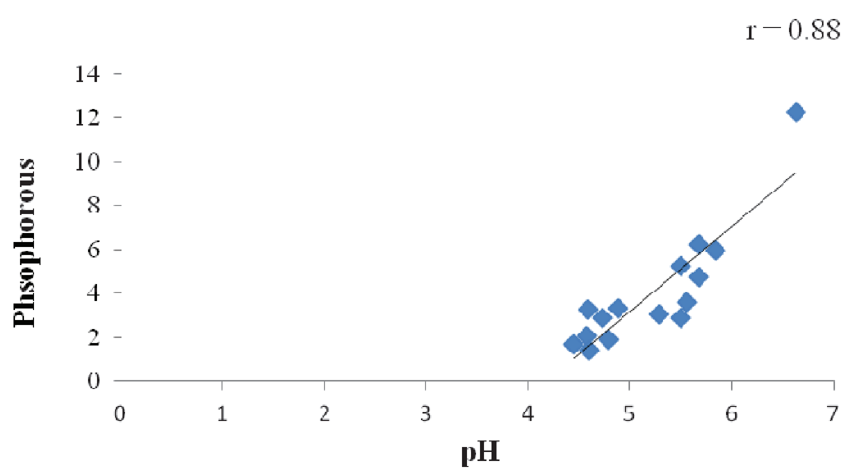

Figure 2: Relationship between pH and Phosphorous content

Table 3. Test of significant difference between some soil properties of the irrigated and non irrigated fields

Samples	pH(H□O) 1:1	EC mmhos/cm	P mg/kg	Extractable bases (cmol/kg) Ca	Mg	K	Na	Exch. Acidity (Al + H) cmol/kg	ECEC cmol/kg
GP1	5.68	0.13	4.78	2.7	1.6	0.18	0.18	1.2	5.83
GP2	5.50	0.81	5.26	2.7	1.6	0.23	0.36	0.8	5.66
GP3	5.84	0.32	5.98	0.7	0.4	0.11	0.19	0.8	2.17
GP4	4.57	0.99	2.07	2.4	1.87	0.37	0.44	0.8	5.88
GP5	4.60	0.85	1.4	1.9	1.6	0.32	0.55	1.1	5.44
GP6	4.79	0.30	1.91	2.4	1.6	0.28	0.19	0.9	5.37
GP7	5.29	0.79	3.03	1.3	0.8	0.11	0.14	0.9	3.29
GP8	5.50	0.68	2.87	2.7	1.47	0.31	0.16	0.9	5.51
GP9	5.68	0.65	6.22	4.5	2.4	0.35	0.22	0.9	8.41
GP10	4.59	0.37	3.27	2.4	1.2	0.31	0.33	0.8	5.04
GP11	4.73	0.71	2.87	1.6	1.6	0.27	0.14	1.2	4.81
GP12	4.88	0.67	3.35	2.9	1.87	0.47	0.3	1.0	6.58
GP13	4.45	0.45	1.67	2.1	0.8	0.18	0.15	1.1	4.37
GP14	5.56	0.49	3.59	2.9	0.8	0.22	0.26	1.2	5.47
CHK	**6.63**	**0.35**	**12.3**	**4.0**	**1.74**	**0.43**	**0.1**	**1.2**	**7.48**
t - probability	<0.001	=0.003	<0.001	<0.001	=0.035	<0.001	<0.001	<0.001	<0.001

CHK (Check) = Non-irrigated site. GP(Grid plot) = Irrigated site

Conclusion

The results of the study suggest that long – term irrigation at the Golinga irrigation site has affected some chemical and physical properties of the soils. Soil pH, EC, P, Ca, Mg, K, Na and the ECEC have all been significantly altered by more than two decades of irrigation at the Golinga site.

Reference

Acquaye D K, Oteng J W (1972). Factors influencing the status of phosphorous in surface soils of Ghana. Ghana Journal of Agriculture Science. 5: 221-228

Adu S (1995). Soils of Bole – Bamboi area; Northern Ghana. Soil Research Institute. (Council for Scientific and Industrial Research) Memoir number 14: 16 -52.

Agyare WA (2004). Soil characterizations and Modeling of spatial distribution of saturated hydraulic conductivity at two sites in the Volta Basin of Ghana. Australian Journal of Soil Research. 46: 5.

Amatekpor J K (1989). The effect of seasonal flooding on the clay mineralogy of a soil series in the Volta Lake draw down area. Land degradation and Rehabilitation. 2: 89-100.

Amatekpor J K (1995). Soil of the Volta Lake draw down area and their suitability for aquaculture. Legon. Agric. Research Extension Journal. 4: 87-96.

Birkeland P W (1999). Soils and geomorphology, 3rd edition Oxford University press, New York. pp 45-52

Bouyoucos G J (1962). Recalibration of hydrometer methods of making mechanical soil analysis. Agronomy Journal 43:434-438.

Brady N C, Weil R R (2008). The nature and properties of soil (14th edition). Prentice- hall Inc. New Jersey.

Bray R H, Kurtz L T (1945). Determination of total, organic, and available forms of phosphorus in soils. Soil Science. 59: 39-45.

Boul S W, Southhard R, Graham R C, Mcdaniel P A (2003). Soil genesis and classification, 5th edition, Iowa State University Press, Ames.

Cline M G (1961). The changing model of soil. Soil Science Society of America Proceedings. 25: 442-445

Coleman N T, Weed S B, Mccracken R J (1959). Cation exchange capacity and exchangeable cations in Piedmont soils of North Carolina. Soil Science Society of America Proceedings 23: 146 – 149.

Day P R (1965). Fractionation and particle size analysis. In. Black, C.A. (ed) methods of soil analysis. Agronomy No. 9 part 1, American Society of Agronomy. Madison, Wisconsin. 545 – 567.

Dixon R M (1960). The effects of irrigation on the chemical properties of some north central and southwestern Kansas soil. Master of Science thesis, Kansas State University.

Haslbach J (1964). The effects of irrigation in changing the properties of soil. III. Changes in some chemical properties of irrigated soil. Soils and fertilizers 28:500

Kar S, Varade S B, Subramanya T K, Ghildga B P, (1996). Soil physical conditions affecting root growth, bulk density and submerged temperature regimes effects. Agronomy journal 68: 23-26.

Kranjac-Berisavljevic G (1999). Recent weather changes in the interior savannah Agro- ecological Zone in Ghana: implication for agricultural production. Presented at Int. conference on Integrated Drought Management Lesson for Sub- Sahara Africa. 20- 22nd September, 1999.

Lin C, Coleman N T (1960). The measurement of exchangeable aluminum in soils and clays. Soil Science Society of America Proceedings. 24: 444 – 446.

Longenecker D E, Lyerly P J (1959). Chemical characteristics of soils of west Texas as affected by irrigation water quality. Soil Science. 87: 207-216.

Lynn W C (1958). The effects of irrigation on the chemical properties of some Kearny County soils. M. Sc. thesis. Kansas State University.
Mclean EO (1965). Aluminum. In C.A. Black (ed), methods of soil analysis. Agronomy. 9. American Society of Agronomy. Madison, Wis.
Mehlich A (1938). Uses of triethanolamine acetate-barium hydroxide buffer for the determination of some base exchange properties and lime requirements of soil. Soil Science Society of America Proceedings. 3: 162 – 166.
Naddith, B.I. (1960). The effects of known quality irrigation water on the chemical properties of soils of the western Kansas. MSc. Thesis. Kansas State University.
Nartey E (1994). Pedogenic changes and phosphorous availability in some soils of Northern Ghana. Unpublished MPhil Thesis. Department of Soil Science. University of Ghana. Legon
Nye P H, Bertheux M H (1957). The distribution of phosphorous in forest and savanna soils of the Gold Coast and its agricultural significance. Journal of Agric. Science. 49: 141-159.
Osuman F (2009). The impact of two decades of irrigation at Botanga on the soil physical and chemical properties. Unpublished BSc. dissertation. Department of agronomy, UDS, Tamale.
Ransom, M.D., Presley, D.R., Kluitenberg, G.J., & Finnell, P.R. (2004). Effects of thirty years of irrigation on the genesis and morphology of two semiarid soils in Kansas. Soil Science Society of America Journal 68: 1916 - 1926
Russell E W (1973). Soil conditions and plant growth. 10th edition. London. Longmans
Scherer T F, Seeli B, Franzen D (1996). Soil, water and plant characteristics important to irrigation EB-66. NRCS publications, North Dakota irrigation guide. County Soil survey report
Spector C, Trakhtenberg I, Levine E (2001). Nutrient Manager. The Handbook of Soils and Climate in Agriculture; the Topsoil on Tour Mini Curriculum and Hands on Test Kit by the LaMotte Company, and the Miami Museum of Science.
Tiessen H, Hauffe H K,. Mermut A R (1991). Deposition of harmattan dust and its influence on base saturation of soils in Northern Ghana. Geoderma, 49: 285-299.
Walkly A, Black I A (1934). An examination of the Degtjareff method for determining of soil organic carbon and a proposed modification of the chromic and acid titration method. Soil Science. 31: 29 – 38.