Crop production potential of reclaimed mine sites for sustainable livelihoods

Benjamin Makimilua Tiimub^{1*}, Niyungeko Christophé², Bernice Awusi Atepre³, Richard Wonnsibe Tiimob⁴, Gideon Lakida Tiimob⁵, Elisha Nyannube Tiimob⁶, Isaac Baani⁷, Paul Amihere-Ackah⁸, & Joan Jackline Agyenta⁹

Zhejiang University, Hangzhou, China^{1,2}

University of Education, Winneba, Ashanti-Mampong Campus, Ghana^{3,7,8,9}

Savelugu Senior High School, Savelugu, Ghana⁴

Public Health Specialist (CE4MCH- Supervisory Section) at Catholic Relief Services, Tamale, Ghana⁵ Regional Maritime University, Nungua, Ghana⁶

benmakimit@yahoo.com¹



Article History

Received on 25 January 2023 1st Revision on 28 January 2023 Accepted on 7 February 2023

Abstract

Purpose: Potentiality of six reclaimed mine sites for crop production at Goldfields Ghana Limited, Tarkwa Mine was holistically assessed. **Research methodology:** Soil pH was traced using HI 9017 microprocessor meter while total nitrogen (TN), organic matter (OM) and organic carbon (OC) were determined by Kjeldahl digestion, distillation and Walkley-Black Methods. Calcium (Ca), magnesium (Mg), potassium(K), sodium (Na), were further determined in 1.0 M ammonium acetate (NH4OAc) extract, using hydrogen and aluminum in 1.0 M KCl, by EDTA titration and flame photometry.

Results: Optimum soil pH, compared with other parameters down the trend was less than 4.33. In cmolkg-1, OM at Ajopa natural forest soil (2.52) was greater than West Heap (2.08). TN differed significantly (p \leq 0.001) such that, Ajopa natural forest (0.13%) was greater than West Heap (0.11%). West Heap Ca (3.52) was greater than Bridge Dump Ground (BDG's) (1.78) while Mg (1.25) at BDG was greater than West Heap (1.22). West Heap's K (0.16) was greater than BDG's (0.13). Sodium was entirely low (\leq 5%). But acidity of Ajopa natural forest (1.90) was greater than BDG's (1.89) while effective cation exchange capacity (ECEC) of West Heap (5.95) was greater than BDG's (4.68).

Conclusions: The study assessed reclaimed mine soils in Tarkwa, Ghana. Findings show highly acidic pH and low nutrients, limiting crop productivity. Soil improvement with lime, organic matter, and suitable crops is required for sustainable livelihoods.

Limitation: Study sites sparsely located and require more experience to locate sampling points.

Contribution: Analyses clearly revealed poor agglomeration of cation exchange capacities due to inadequate fertility of the seven-year old reclaimed mine sites. Hence, it may not give good crop yields for sustainable economic livelihoods strategies without long-term augmented fertilization and liming.

Keywords: Cation Agglomeration, Goldfields, Liming, Mine Reclamation, Soil Fertility

How to Cite: Tiimub, B. M., Christophé, N., Atepre, B. A., Tiimob, R. W., Tiimob, G. L., Tiimob, E. N., Baani, I., Ackah, P. A., & Agyenta, J. J. (2023). Crop production potential of reclaimed mine sites for sustainable livelihoods. *Journal of Multidisciplinary Academic and Practice Studies*, 1(1), 1-13.

1. Introduction

Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an ore body, vein, or (coal) seam (Ali Elbeblawi, Abdelhak Elsaghier, Mohamed Amin, & Elrawy Abdellah, 2022). This term also includes soil removal (Sharma, Kumar, Singh, & Santal, 2023). Materials recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt, and potash. Any material that cannot be grown through agricultural processes or created artificially in a laboratory or factory is usually mined. Mining, in a broader sense, comprises the extraction of any non-renewable resource (e.g., petroleum, natural gas, and water) (Jowitt, Mudd, & Thompson, 2020).

The nature of mining processes has a negative impact on the environment, both during mining operations and years after the mine is closed (H. Liu et al., 2021). Although mining contributes approximately 5% of Ghana's Gross Domestic Product (GDP) in support of economic livelihoods (Afriyie, Abass, Frempong, Arthur, & Gyasi, 2023), its impact has led to most nations adopting regulations to moderate the negative effects of mining operations (Franken & Schütte, 2022). Mining and its activities exert pressure on the environment, and their natural processes contribute to the degradation and pollution of land and water bodies (Padhiary & Kumar, 2023). Universally, mining constitutes an engine of civilization, the backbone of science and technology, and the wheel for economic growth and development, as typified in the Tarkwa area, which hosts five major companies in the country and is surrounded by several small-scale mining companies. The influx of job seekers to the Tarkwa environs characterizes it with an uneven dominant male-to-female population distribution in a ratio higher than the national value of 49.85% male: 50.15% female from a total population of 29,448,118. Ghana's fertility rate is currently 3.94 children born to every woman in rural areas and 2.78 to every woman in urban areas, with a current population growth rate of 2.18% per annum. However, it is expected to reach 37,294,019 at a growth rate of 1.8% by 2030.

Gold mining has played a significant role in the socio-economic development of Ghana for the past hundred years (Cobbinah & Amoako, 2018), despite the deterioration of surface water bodies following the inappropriate discharge of mine sediment pollutants in the affected catchment areas (Bessah et al., 2021). Gold mining has recently become a problematic issue as it is recognized as the main source of mercury (Hg), lead (Pb), and heavy metal contamination of the environment through uncontrolled or improperly regulated forms and methods of mineral exploitation (galampsey operations), ore transportation, smelting and refining, and disposal of tailings and waste water around the mine site (Mohapatra & Kirpalani, 2016).

Land is an important asset that cannot be abandoned or destroyed. Several forms of life on Earth could be terminated if there was no land, apparently confirming the claim that when the last tree dies, the last man will die (Joffe, Khaira, & de Caen, 2021). The balance of the ecosystem is highly dependent on land; therefore, when the environment is disturbed, human life is at risk (Verma, 2021). Mining further constitutes a source of conflict with other competing land uses, such as farming, especially in areas where high-value farmland is scarce and where post-mining restoration may not be feasible for completely rejuvenating soil productivity. Social and environmental activists have intimated a potential link between mineral resources, conflict, and consequential underdevelopment (Teixeira, 2021). They further project sustainability functions of land use as a critical requirement for a prosperous livelihood because it offers security for the future and has long been a concern worldwide (Meyfroidt, 2018). Strategically, the Food and Agriculture Organization (FAO) of the United Nations Organization (UNO) in 1993 selected the theme "Harvesting Nations Diversity" for the celebration of that year's World Food Day, which sought to review and project relevant indicators for the attainment of food security and humanity (Manikas, Ali, & Sundarakani, 2023).

Amendments to land management policy laws encourage the rational and efficient utilization of land and natural resources, ensure the preservation of natural and cultural values, and prevent environmental damage based on the principles of sustainable development (Abaikyzy, Yerkinbayeva, Aidarkhanova, Aigarinova, & Baimbetov, 2020). In Ghana, over 200 registered gold mining companies operate from

small-to large-scale mining, with most of them located in the Wassa West District in the Western Region of Ghana, with Tarkwa as its administrative capital (Sabastian, 2022).

Most mining companies in Ghana's Western Region engage in open-pit (surface) mining for income to initiate local community development (Adu-Gyamfi, Brenya, & Abakah, 2016). Although mining contributes significantly to Ghana's Economic Recovery Programs, it is at a great environmental cost, as the exploitation of minerals depletes water, soil, and vegetation and poses human health hazards in the communities around the buffer zones (Emmanuel, Jerry, & Dzigbodi, 2018). Examples of these companies include Goldfields Ghana Limited Tarkwa Mines, Bogoso Mines, Bibiani Mines, and Wasa Mines, where several youths and adults are employed to work under varying conditions (Adu-Gyamfi et al., 2016). New Mont Gold Mining, Sand, and Gravel Mines in the Gonja District of Ghana, all of which have negative effects on the land, constitute a major threat to the inhabitants and stability of the entire ecosystem (Aminu et al., 2023). This study highlights the outcomes of laboratory analysis conducted to ascertain the suitability of reclaimed mine soils for sustenance of crop production based on its fertility at the Goldfields Ghana Limited, Tarkwa Mine in order of the following underlain objectives: i. physicochemical characteristics of mine reclaimed soils; ii. suitability of reclaimed mine soils for crop production; and iii. soil fertility enhancement measures for improved crop production.

2. Literature review

Mining refers to the extraction of valuable minerals and geological resources such as metals, coal, and non-metallic minerals such as potash and rock salt (Ali & Anwar, 2021). While mining significantly contributes to global economic growth, it generates severe environmental challenges both during active operations and long after mine closure (Y. Liu, Soroka, Han, Jian, & Tang, 2020). In Ghana, mining contributes approximately 5% to the national GDP (Afriyie et al., 2023), however, it also results in widespread land degradation, soil infertility, and water pollution (Franken & Schütte, 2022).

Mining not only affects ecological systems but also creates socio-economic conflicts. Unregulated artisanal and small-scale gold mining, often associated with mercury (Hg) and lead (Pb) contamination, exacerbates environmental degradation (Mohapatra & Kirpalani, 2016). Furthermore, mining competes with agricultural land use, particularly in regions where fertile farmland is scarce, creating long-term threats to food security. Scholars have highlighted that environmental deterioration from mining contributes to livelihood insecurities and undermines ecosystem balance.

Post-mining land reclamation is a crucial measure for restoring soil productivity. Effective land management policies ensure the rational use of natural resources while preserving ecological and cultural values (Abaikyzy et al., 2020). In Ghana, most companies operate open-pit mining, which destroys vegetation cover, reduces soil fertility, and contaminates water bodies (Adu-Gyamfi et al., 2016). Thus, reclamation is viewed not only as an environmental necessity but also as an opportunity for sustainable community development.

Previous studies have consistently shown that reclaimed soils are generally acidic (pH < 4.5), low in organic matter, and deficient in key nutrients such as nitrogen, calcium, magnesium, and potassium (Regasa, Haile, & Abera, 2023). These limitations constrain agricultural productivity unless soil fertility is enhanced through management practices, such as liming, composting, and organic or inorganic fertilization. A low cation exchange capacity (CEC), a critical indicator of nutrient retention, further reduces the potential for sustainable crop production.

Research highlights that soil amendment using organic inputs is key to improving the fertility of reclaimed sites. The application of compost, manure, and cover crops enhances organic matter and soil structure (Shakywal, Pradhan, Marasini, & Kumar, 2023). Integrated nutrient management approaches, including vermicompost and bio-enriched rock phosphate, are also effective in improving acidic soils for sustainable agricultural production. Additionally, perennial crops, such as oil palms, have been identified as viable alternatives because of their tolerance to a wide range of pH levels and marginal soil conditions (Agegnehu et al., 2021).

The Food and Agriculture Organization (FAO) has emphasized the importance of sustainable land use as a key component of global food security. In Ghana, reclaimed mine lands hold potential for environmental restoration and socio-economic development through agricultural ventures. Therefore, sustainable reclamation practices represent a pathway to balance ecological restoration and community livelihoods.

3. Research methodology

3.1. Study site

The study was conducted within the concession of Goldfields Ghana Limited, Tarkwa Mine, at the Tarkwa - Nsuaem Municipality in the Western Region of Ghana. Tarkwa Nsuaem Municipal is one of the Districts in the Western Region of Ghana, located between Latitude 400'N and 500 40'N and Longitude 10 45' W and 20 10'W. It is bounded to the north by the Wassa Amenfi East District, to the south by the Ahanta West District, to the west by the Nzema East Municipal District, and to the east by the Mpohor Wassa East District. The tropical climatic conditions around Tarkwa are characterized by two wet seasons: March-July and September-November. The area experiences an annual rainfall of about 1,744 mm and a daily sunshine of about 10 h interspersed with relative humidity, atmospheric pressure, and temperature ranges of 73%-98%, (99.0-100.7) kPa and (28-39) °C, respectively.

3.2. Source of sampling materials and sampling procedure

Six (6) data collection experts, sample bags, augers, shovels, markers, and flagging tapes were provided by the Environmental Department of Goldfields Ghana Limited (GGL). The GGL is located approximately 300 km by road west of Accra, the capital, at a latitude of 5° 15' N and longitude of 2° 00' W. The Tarkwa mine is located 4 km west of the town of Tarkwa, with good access roads and an established infrastructure (Kwesi et al., 2021). Each of the twenty (20) soil samples, comprising five (5) from each site, were collected from seven-year-old reclaimed soils at five different reclaimed mine site locations of the Gold Fields Tarkwa Mine, namely, West Heaps (WH), South Spoil Dump Point (SDP), Bamboo Dump (BAM), Bridge Dump Ground (BDG), and Mantraim North (MANT(N)) within the mine concession. An additional control sample was obtained from the outskirts of the mine concession from a naturally undisturbed site (Ajopa natural forest). Approximately 10 kg of soil samples were retrospectively selected to prevent variability in sample volumes among plots. To obtain a true representation, the sample frames were drawn using augers, shovels, sample bags, permanent markers, and flagging tapes. A purposive sampling technique was used to select the sites earmarked for coverage by the experts. These sites were assumed to have recovered from the deleterious impacts of mining and were suspected to contain sufficient soil of productive capacity at reasonable depths for plant growth upon adoption of reclamation interventions. Soil cores were collected at various depths (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, 20-25 cm and 25-30 cm) to investigate and analyze fertility or productivity dynamics by measuring the concentrations of chosen physico-chemical properties. The sampled soil was incorporated into well-labeled sampling bags and transported to the Council for Scientific and Industrial Research (CSIR) - Soils Research Institute laboratory at Kwadaso within the Kumasi Metropolis in Ghana for analysis. The precise sampling points were demarcated with flagging tape for future reference.

3.3. Laboratory analysis of the soil samples

Soil samples were air-dried at normal room temperatures for forty-eight hours (48hrs) and ground using a miniature pestle in a mortar (to facilitate proper digestion of the samples, since wet soil samples with high clay contents tend to clog, reducing the efficiency of the analyzer). Ground soil contents were then sieved using two-millimeter (2 mm) sieve and ashed in an oven for forty-eight hours for further analysis of soil pH, percentage soil organic matter, organic carbon and total nitrogen, exchangeable cations (calcium, magnesium, potassium and sodium), exchangeable acidity, cation exchange capacity and percentage base saturation.

pH was measured in a 1:1 suspension of soil and water using an HI 9017 microprocessor pH meter, whereas total nitrogen was determined by Kjeldahl digestion and distillation protocol. Organic matter and organic carbon were determined using the Walkley-Black Method (whereby, approximately 1 g soil was used with 10 ml of 0.1667M K₂Cr²O7 solution, 20 ml concentrated H₂SO₄, 200 ml water for

dilution, $10 \text{ ml H}_3\text{PO}_4$, 10 ml of NaF solution, diphenylamine as an indicator, and 0.5M FeSO₄ solution as a titrant). The exchangeable bases (Ca, Mg, K, and Na) were measured in 1.0 M ammonium acetate (NH₄OAc) extract. Exchangeable acidity was determined in 1.0 M KCl extract, calcium, and magnesium by EDTA titration; potassium and sodium by flame photometry; and effective cation exchange capacity (ECEC) was determined by the sum of exchangeable bases (calcium, magnesium, sodium, and potassium) and exchangeable acidity. Final analyses of the prepared soil samples were conducted at the Council for Scientific and Industrial Research (CSIR) - Soils Research Institute, Kumasi. Raw data obtained from laboratory analyses were subjected to statistical comparison using SPSS 22 (SPSS, Chicago, IL) software to run the two-way (two-factor comprising rows and columns without replication) analysis of variance at ($p \le 0.05$) level of significance between the various sites physico-chemical parameters. The average data of the physicochemical parameters were separated by their standard deviations.

4. Results and discussions

4.1. Soil pH

The average soil pH in all the sampled areas is shown in Figures 1,2,3 and table 1. The pH values from the various reclaimed mine sites, including the control, were extremely low (extremely acidic). It ranged from 3.25 (Ajopa-control site) to 4.32 (West Heap), displayed in the order West Heap (4.32) > SDP (3.85) > MANT 'N' (3.66) > BDG (3.63) > BAM (3.42) > AJOPA (3.25). A site-by-site comparison of the average pH showed no significant differences ($p \ge 0.138$). The effective source variations in the pH spatial distribution in soil samples were not significantly different from the rest of the parameters upon cross-examination both between the rows (p-value ≥ 0.451) and within columns (p-value ≥ 0.454) (Tables 2 and 3 in the appendix).

4.2. Soil organic matter (SOM in Cmolkg-1)

The average soil organic matter content of the various reclaimed sites, including the control site, is presented in Figure 1 and Table 1, respectively. Lower organic matter levels were observed in the SDP, BAM, BDG, and MANT 'N' soil samples, but a moderate level ranging between 2.08 - 1.15 was observed in the West Heap and the Ajopa control sites. The organic matter values at the reclaimed sites were in the descending order of Ajopa (2.52) > West Heap (2.08) > MANT 'N' (1.17) > SDP(1.15) > BAM (1.02) > BDG(0.73). Comparative average site-by-site soil OM content compared with mean pH and total nitrogen were not significantly different ($p \ge 0.482$). Effective source variations in the spatial distribution of OM in all the soils were not significantly different from other parameters at a gross screen both between the rows (p-value ≥ 0.451) and within columns (p-value ≥ 0.454) (Appendix Tables 2 and 3).

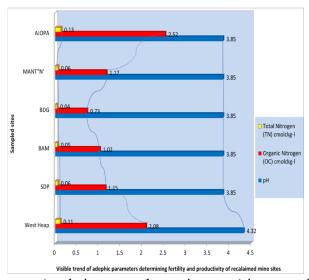


Figure 1. Edaphic parameters (total nitrogen and organic matter) in comparison with pH conditions determining the fertility and productivity of the five reclaimed mine sites at Gold Fields Ghana Limited, Tarkwa Mine in Ghana.

4.3. Total nitrogen (TN in Cmolkg-1)

The average site-by-site soil TN levels are shown in Figure 1 and Table 1. The percentage total nitrogen level at the SDP, BAM, BDG, and MANT 'N' sites were moderately lower than those at the West Heap and Ajopa control sites. Generally, TN in the various reclaimed sites vis-à-vis the control site displayed in a descending order was such that, TN at Ajopa (0.13%) was > West Heap (0.11%) > SDP (0.06%) = MANT

Table 1. Average concentrations of soil parameters (± SD) from various mine reclaimed sites at Goldfield Ghana Limited Tarkwa Mine

Parameter Parameter	West		DAMICD	DDC+CD	MANT"N'±S	AJOPA±S
(SI Unit)	Heap±SD	SDP±SD	BAM±SD	BDG±SD	D	D
pН	4.32 ± 0.64	3.85 ± 0.17	3.42 ± 0.26	3.63 ± 0.05	3.66 ± 0.02	3.25±0.43
Organic. Nitrogen (OC) cmolkg ⁻¹ .	2.08±063	1.15±0.30	1.02±0.43	0.73±0.69	1.17±0.28	2.52±0.80
Total Nitrogen (TN) cmolkg ⁻¹	0.11±0.04	0.06±0.02	0.05±0.03	0.04 ± 0.04	0.06±0.04	0.13±0.06
Calcium (Ca) cmolkg ⁻	3.52±2.10	0.89 ± 0.53	0.58±0.84	1.78±0.36	0.90 ± 0.52	0.82 ± 0.60
Magnesium (Mg) cmolkg- ¹ .	1.22±14.9 3	90.71±74.7 8	0.27±15.5 5	1.25±14.6 8	0.9±15.03	1.21±14.72
Potassium(K) cmolkg ⁻¹ .	0.16 ± 0.05	0.08 ± 0.03	0.08 ± 0.03	0.13±0.02	0.12 ± 0.01	0.1 ± 0.01
Sodium (Na) cmolkg ⁻¹ .	0.11±0.39	0.10 ± 040	0.05 ± 0.45	0.09 ± 0.41	0.08 ± 0.42	0.07 ± 0.43
Exchangeabl e Acidity (EA).	0.96±0.65	1.85±0.24	1.88±0.27	1.89±0.28	1.20±0.41	1.90±0.29
Effective cation exchange capacity (ECEC) cmolkg-1	5.95±2.18	2.71±1.06	2.66±1.11	4.68±0.91	3.11±0.66	3.5±0.27

^{&#}x27;N' (0.06%) > BAM (0.05) > BDG (0.04%). The average TN content of the reclaimed mine and AJOPA control sites were significantly different $(p \le 0.001)$ compared with pH and organic nitrogen on the sample graphical representation of visible trends in Figure 1. Effective source variations and spatial distribution of TN were not significantly different from other parameters upon cross screening both between the rows $(p\text{-value} \ge 0.451)$ and within columns $(p\text{-value} \ge 0.454)$ (Appendix Tables 2 and 3).

4.4. Exchangeable cations (Calcium, Magnesium, Potassium, Sodium)

4.4.1 Exchangeable calcium (Ca in Cmolkg-1)

Exchangeable Calcium levels at the various reclaimed sites in cmol_ckg⁻¹ ranged from 0.82 at Ajopa to 3.52 at West Heap (Figure 2 and Table 1). The average site-by-site calcium content in the soil samples was very low as illustrated in a descending order of West Heap Ca (3.52) > BDG (1.78) > MANT 'N' (0.93) > SDP (0.89) > Ajopa (0.82) > BAM (0.58) (Figure 2). The site-by-site Ca content in all the reclaimed soils compared with pH, exchangeable acidity, and effective cation exchange capacity was such that the Ajopa natural forest control site was not significantly different from others ($p \ge 1.231$), with alternative corresponding insignificant differences in the effective source variations and spatial

distribution both between the rows (p-value ≥ 0.451) and within columns (p-value ≥ 0.454) (Appendix Tables 2 and 3).

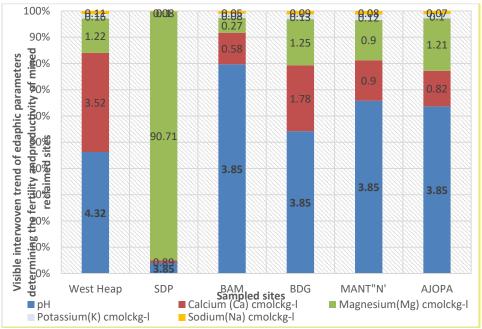


Figure 2: Edaphic parameters (Ca, Mg, K, and Na in comparison with pH) determining fertility and productivity of the five reclaimed mine sites at Gold Fields Ghana Limited, Tarkwa Mine in Ghana.

4.4.2. Exchangeable magnesium (Mg in Cmolkg-1)

The average Mg levels in the soils were quite low, ranging from 0.27 (BAM) to 1.25 (BDG) (Fig. 2). It showed an imbalanced descending pattern of Mg concentration at BDG (1.25) > West Heap (1.22) > Ajopa (1.21) > MANT 'N' (0.90) > SDP 90.71) > BAM (0.27) (Table 1). Average site-by-site Mg concentrations were significantly different ($p \le 0.000$) compared to the AJOPA control site. There were no corresponding differences in effective source variations and spatial distribution of Mg with other soil parameters grossly examined and compared both between the rows (p-value ≥ 0.451) and within columns (p-value ≥ 0.454) (Appendix Tables 2 and 3).

4.4.3. Exchangeable potassium (K in cmolkg⁻¹)

The average exchangeable potassium level in the soil samples was generally very low, ranging from 0.08 (SDP and BAM) to 0.16 (West Heap) (figure 2). The entire K pattern at the five study sites was in the order of West Heap (0.16) > BDG (0.13) > MANT 'N' (0.12) > AJOPA (0.10) > SDP (0.08) = BAM (0.08) sites (Table 1 and figure 2). The average site-by-site indicative K average concentration in the entire reclaimed mine and the Ajopa natural forest control sites were significantly different ($p \le 0.000$). Cross-examination of the data for source variations in distributed K from the six sites compared with pH and the other serial soil parameters showed significant differences between the rows (p-value ≥ 0.451) and within the columns (p-value ≥ 0.454) (Appendix Tables 2 and 3).

4.4.4. Exchangeable sodium (Na in cmolkg⁻¹)

Exchangeable Na levels were low in all soils, featuring less than 5% of the nutrient base (Fig 2). The Na concentrations recorded ranged from 0.05 at BAM to 0.11 at the West Heap with site-by-site descending order of West Heap Na (0.11) > SDP (0.10) > BDG (0.09) > MANT 'N' (0.08) > AJOPA (0.07) > BAM (0.05) (table 1). The pattern of variation in Na at all sites was not significantly different $(p \le 0.176)$. Comparative point source variations and spatial distribution of Na with pH and the other soil productivity parameters concurrently examined were also not significantly different between the rows $(p\text{-value} \ge 0.451)$ and within the columns $(p\text{-value} \ge 0.454)$ (Appendix Tables 2 and 3).

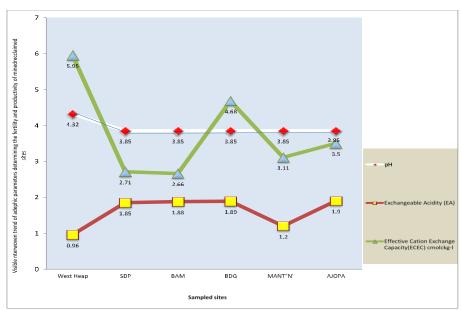


Figure 3. Exchangeable acidity and effective cation exchange capacity in comparison with *pH* condition determining fertility and productivity of reclaimed mine sites at Gold Fields Ghana Limited, Tarkwa Mine.

4.4.5. Exchangeable acidity (cmolkg⁻¹)

The average exchangeable acidity concentration in the reclaimed sites ranged from 0.96 in West Heap to 1.90 in the Ajopa Natural Forest (Fig. 3). There were closer margins of average variations in exchangeable acidity levels in the soils, detected in ascending order of Ajopa (1.90) > BDG (1.89) > BAM (1.88) > SDP (1.85) > BDG (1.83) > MNT (1.20) > West Heap (0.96) respectively (table 1 and figure 2). The comparative site-by-site average data were not significantly different ($p \le 1.688$), whereas the point source variations and spatial distribution of free exchangeable acidity compared with pH and other detectable physicochemical parameters concurrently examined within the study areas were not significantly different both between the rows (p - value ≥ 0.451) and within columns (p - value ≥ 0.454) (Appendix Tables 2 and 3).

4.4.6. Effective cation exchange capacity (ECEC in cmolkg⁻¹)

The effective cation exchange capacity of the various soils ranged from 2.66 at BAM to 5.95 in West Heap. Variations in ECEC of the entire study areas were juxtaposed in the descending order of West Heap (5.95) > BDG (4.68) > AJOPA (3.5) > MANT "N" (3.11) > SDP (2.71) > BAM (2.66) respectively (table 1 and figure 2). The data show a low trend of effective cation exchange capacity of the entire soil regime, except for the West Heap, which showed moderate ECEC potential (figure 3). The average pattern of ECEC in all sites compared with pH and the other soil productivity parameters were not significantly different ($p \le 4.437$), and its effective point source variations and spatial distributions were further not significantly different both between the rows (p-value ≥ 0.451) and within the columns (p-value ≥ 0.454) (Appendix Tables 2 and 3).

4.5. Discussion

Analysis of the results revealed that the spatial accumulative effects of all the physico-chemical parameters screened in terms of average concentrations from the AJOPA control, MANT 'N' and BAM site data were similar with no statistically significant differences ($p \le 1.838$; $P \le 1.697$ and $p \le 1.579$) in the optimum soil conditions as compared to BDG ($p \le 2.684$). The Ajopa natural forest, MANT' N, BAM, and BDG data showed significant variations with the West Heap ($p \le 889.198$). The results showed little variation in the spatial distribution of fertility effects at the study locations and the specific soil samples analyzed site-by-site. The analysis further showed insignificant differences in the effective source and spatial distribution of the soil physico-chemical parameters examined both within the rows (p-value ≥ 0.451) and between columns (p-value ≥ 0.454) (Appendix Tables 2 and 3).

4.5.1. Soil pH (Acidity)

Soil acidity (pH) is a key parameter for assessing soil fertility (Regasa et al., 2023). The current findings provide insight into all the reclaimed areas, including the control site, which manifested very low pH levels (< 4.33) and connoted extremely acidic conditions. However, the recommended pH for arable crops ranges between 5.8 (slightly acidic) and 7.5 (slightly alkaline) (Agegnehu et al., 2021). The availability of both macro- and micro-nutrients is essential as an indicator of plant growth regulation. The characteristics of the examined soils at the study sites indicated that the reclaimed areas and the control site may not support crop production unless allocated to species with good adaptation traits to thrive outside the optimal pH range of 6–7.5, as previously recommended. In contrast, tree crops, such as oil palm, which tolerate a wide range of soil pH (3.8–7.0) according to the specifications, could be considered in almost all reclaimed sites. Management practices such as liming and the addition of rock phosphate to improve soil pH are recommended for the reclamation of these degraded sites for crop cultivation (Sande, Tindwa, Alovisi, Shitindi, & Semoka, 2023).

4.5.2. Soil Organic Matter (SOM)

Soils with organic matter content less than 1.5% are considered low, between 1.5 and 3.0% as moderate, and above 3.0% as high for recommended crop production. The results from the Ajopa natural forest and West Heap reflected moderate soil organic matter content, while the others fell within the low range. The naturally undisturbed Ajopa natural forest exhibited improved organic matter content because it probably underwent cyclical decomposition and mineralization of the underlain organic residues over the past years. The entire OM, apart from the control site, was low and might not support a variety of crops to yield good results. The adoption of soil improvement practices, such as the application of organic poultry manure, cow dung, compost, and cover cropping as soil and water conservation initiatives, could synchronize the organic matter content for crop production.

4.5.3. Total nitrogen (N)

Soils with average total N content less than 0.10% were assessed to be low, whereas those with 0.10–0.20% were moderately rich. Hence, the entire soil regime under study revealed a low trend of TN. The productivity of these soil regimes could be further improved for higher sustainable arable crop yields within reclaimed mine sites.

4.5.4. Exchangeable cations (Ca, Mg, K, Na) in cmolckg-1

4.5.4.1. Calcium (Ca)

The results reflected a low exchangeable Ca content in the soils screened from all the reclaimed mine sites, including the Ajopa Natural Forest. The Ca content ranged from 0.58 to 3.52. These levels implicitly fall below the critical crop Ca requirement of 5 cmolkg⁻¹ in cultivable soils. The resultant Ca pattern from the chemical analysis confirmed the early report that soil *pH* and exchangeable Ca levels are directly related, and the lower the *pH*, the lower the Ca level in the soil. The implications are farreaching, as most arable crops may not perform up to expectations on such soils without amelioration of the *pH* through management practices such as liming and application of rock phosphate fertilizers to suit tillage requirements.

4.5.4.2. *Magnesium (Mg)*

Magnesium is an essential component of several primary and secondary minerals in the soil, which are largely insoluble in agricultural considerations. These constituents are the original sources of soluble or available Mg. Mg levels were low at all reclaimed mine sites. This might be due to the low pH levels of the various soils, suggesting that most soils are deficient in soluble Mg, as previously observed in a study that buttressed that many food or feed crops are further deficient in major nutrients, identifying an ideal soil to consist of 25% air, 25% water, 45% minerals, and 5% organic matter. Most cultivable soils do not meet ideal conditions. While clay soils are generally too tight, and due to a lack of calcium (even in high pH soils), they contain inadequate pore space, resulting in water logging and poor aeration, thereby failing to meet the ideal cultivable microenvironment conditions. Such soils remain wet for longer periods and become harder to work with as they dry out. Alternatively, sandy soils tend to exhibit deficiencies (large air pores and inability to hold enough water) but consolidate and become hard when worked under extremely wet conditions with excessive complementary Mg levels. One

method for ameliorating Mg deficiencies is the application of soil amendments, such as lime and rock phosphate fertilizers, to increase the pH while regulating Mg levels for improved crop production.

4.5.4.3. *Potassium (K)*

Except for the West Heap reclaimed site, which had a moderate average exchangeable potassium content of 0.16, all the other sampled areas, including the control site (Ajopa), showed average exchangeable potassium levels below the 0.15 cmolkg⁻¹ critical requirement in cultivable soils. Exchangeable potassium levels below 0.15 cmolkg⁻¹ are considered low and above 0.15 cmol_ckg⁻¹, moderate. The low average exchangeable potassium levels may be attributed to low pH conditions at the reclaimed mine sites. The application of lime and rock phosphate fertilizer can improve pH conditions and synchronize exchangeable potassium availability for food crop production. Earlier studies have suggested that the recovery of plant growth after water stress is related to the coordinated transport of water and K (+) from the root to the apical zone of the stem and expanding leaves. A recent evaluation of the ability of root systems to recover K⁺ (Rb⁺) uptake and transport capacity after exposure to high temperatures revealed that root warming through temperature adjustment improves potassium uptake and crop yield. The recovery of K⁺ (Rb) root transport capacity after high root temperature was observed to be slow as plants were grown in a root medium at 37 °C for 31 days and transferred to another at 25 °C for 48 or 96 h. Any signal of recovery was observed after 48 h without stress: both potassium root uptake and subsequent kinertism to plant tissues were inhibited; whereas 96h without stress led to restored potassium upward transport capacity, although the uptake was partially inhibited. The final observation showed that the root system of young olive plants is very sensitive to high temperatures, which is related to root potassium transport and plant growth. Considering the two processes involved in root potassium transport, the discharge of K+ to the xylem vessels was more affected than the uptake at the initial phase of high root temperature stress.

4.5.4.4. Sodium (Na)

Sodic soils are characterized by a disproportionately high concentration of Na in their cation exchange complex and are usually defined as soils containing an exchangeable sodium percentage greater than 15%. Sodic soils tend to occur in arid and semi-arid regions and are innately unstable, exhibiting poor physical and chemical properties that impede water infiltration, water availability, and plant growth. In all the comparatively understudied sites, the average exchangeable sodium content was low and ranged between 0.05 cmolkg⁻¹ from BAM to 0.11 cmolkg⁻¹ in West Heap. The soil Na + concentration was within the suitable range for food crop production. However, sodic soils may affect plant growth in the following ways: 1. exhibiting specific toxicity to sodium-sensitive plants; 2. portraying nutrient deficiencies or imbalances; 3. imparting alkaline conditions with a high pH (>8.5) due to the presence of high concentrations of sodium carbonates (Na₂CO₃); and 4. spread of Na-soil particles, which triggers poor physical conditions in the soil.

4.5.4.5 Exchangeable Acidity (EA)

Exchangeable acidity is defined as the extent of modification in soil pH due to the addition or availability of other soluble or insoluble acid- or base-inducing chemical elements and ions, such as Al, Fe, P, K, Ca, lime, and organic matter, which influence soil productivity and sustainable plant growth. Exchangeable acidity was found to be inversely related to soil pH. The average values recorded in this study ranged from 0.96 at West Heap to 1.90 at Ajopa Natural Forest. Generally, values greater than 0.30 are considered to be high. The application of lime and rock phosphate fertilizer could potentially raise the pH levels at the various reclaimed sites and neutralize acid-base conditions for improved crop production.

4.5.4.6. Effective Cation Exchange Capacity (ECEC)

The cation-exchange capacity (CEC) is the maximum quantity of total cations of any class that a soil can hold at a given pH value for exchanging with the soil solution. Alternatively, it is a measure of the number of negatively charged (electrophilic) sites available in the soil (Li, Wang, Liu, Zheng, & Xie, 2021). CEC is used as a measure of fertility, nutrient retention capacity, and the ability to protect groundwater from cation contamination (Nel, Bruneel, & Smolders, 2023). The CEC of the studied areas was low, except for that of the West Heap reclaimed site and Ajopa Natural forest. This effect

may be attributed to the low soil organic matter (SOM) levels in the study areas, apart from the West Heap reclaimed site and Ajopa Natural Forest. Management practices to improve soil organic matter content, such as organic manure (cow dung, poultry manure, and compost) application, mulching, leguminous cover cropping, and improved fallows, are recommended (Shakywal et al., 2023).

5. Conclusion

The pH displayed extremely acidic conditions in the reclaimed soils, including the Ajopa naturally undisturbed forest. The exchangeable cations (Ca, K, and Mg) and effective cation exchange capacities were low within the reclaimed sites, probably linked to the low soil pH conditions. Soil organic matter and total nitrogen levels were similarly low and attributable to the immature status of the naturally disturbed seven-year-old reclaimed sites, which are gradually undergoing gradual transformation. The soils are expected to further metamorphose through cyclical decomposition and mineralization to significantly improve their organic matter status. Cover cropping, application of animal manure, and compost may further ameliorate soil fertility. The application of lime and rock phosphate fertilizer at some recommended rates could improve the soil physico-chemical conditions by regulating pH and agglomerating exchangeable cations (Ca, K, and Mg) to boost crop production. Hence, the low ECEC records clearly revealed or confirmed the poor nutrient holding capacities of the seven-year-old reclaimed sites in the short run, and may not be able to produce sustainably high crop yields when subjected to agronomical ventures without further application of significant recommended soil improvement treatments.

5.1 Recommendations

Oil palm plantations serve as an alternative to other economic food crop cultivations on reclaimed mine sites because they tolerate a wider range of climatic and soil conditions. Joint research partnerships between agricultural research institutions and universities and mining companies should upscale similar case studies along different reclaimed mining sites in Ghana. Inculcating lime and organic manure into reclaimed degraded mine sites will be an innovative option to revitalize fertility and other physicochemical conditions within five to fifteen years in the medium and long term for productive crop cultivation.

Acknowledgement

The authors are grateful that the cost of soil sample collection and analysis was borne by the Environmental Department of Goldfields Ghana Limited, Tarkwa Gold Mines, and the Company's six (6) field technicians were supportive in the soil sampling process.

References

- Abaikyzy, M., Yerkinbayeva, L. K., Aidarkhanova, K. N., Aigarinova, G. T., & Baimbetov, N. S. (2020). The formation of land conservation principles as the framework for the implementation of the concept of sustainable development of society. *Journal of Landscape Ecology*, *13*(3), 23-38. doi:https://10.2478/jlecol-2020-0015
- Adu-Gyamfi, S., Brenya, E., & Abakah, E. (2016). Research Article Artisanal Mining and Its Ramifications on the People of Prestea. *Journal of Social Sciences*, 8(1), 12-24. doi:https://DOI:10.19026/crjbs.8.2693
- Afriyie, K., Abass, K., Frempong, F., Arthur, B., & Gyasi, R. M. (2023). The dynamics and livelihood implications of illegal mining in Ghana: A critical assessment. *Geographical research*, 61(1), 32-43. doi:https://doi.org/10.1111/1745-5871.12573
- Agegnehu, G., Amede, T., Erkossa, T., Yirga, C., Henry, C., Tyler, R., ... Sileshi, G. W. (2021). Extent and management of acid soils for sustainable crop production system in the tropical agroecosystems: a review. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, 71(9), 852-869. doi:https://doi.org/10.1080/09064710.2021.1954239
- Ali, B. J., & Anwar, G. (2021). An empirical study of employees' motivation and its influence job satisfaction. Ali, BJ, & Anwar, G. (2021). An Empirical Study of Employees' Motivation and its Influence Job Satisfaction. International Journal of Engineering, Business and Management, 5(2), 21-30.

- Ali Elbeblawi, M. M., Abdelhak Elsaghier, H. A., Mohamed Amin, M. T., & Elrawy Abdellah, W. R. (2022). Introduction to Mining. In M. M. Ali Elbeblawi, H. A. Abdelhak Elsaghier, M. T. Mohamed Amin, & W. R. Elrawy Abdellah (Eds.), *Surface Mining Technology* (pp. 1-23). Singapore: Springer Singapore.
- Aminu, M. a. B., Kabiru, G. I., Simon, D. C., Changde, A. N., Andarawus, Y., Nengak, M., . . . Simon, T. (2023). Interrogating The Effects of Sand Mining: A Case Study of Agila District, Ado Local Government Area, Benue State, Nigeria. *Fudma Journal of Sciences*, 7(4), 317-331. doi:https://doi.org/10.33003/fjs-2023-0704-1940
- Bessah, E., Raji, A. O., Taiwo, O. J., Agodzo, S. K., Ololade, O. O., Strapasson, A., & Donkor, E. (2021). Assessment of surface waters and pollution impacts in Southern Ghana. *Hydrology Research*, 52(6), 1423-1435. doi:https://doi.org/10.2166/nh.2021.051
- Cobbinah, P. B., & Amoako, C. (2018). From Gold Coast to Ghana: Changing political economy of mining towns. *Cities*, 83, 83-91. doi:https://doi.org/10.1016/j.cities.2018.06.011
- Emmanuel, A. Y., Jerry, C. S., & Dzigbodi, D. A. (2018). Review of environmental and health impacts of mining in Ghana. *Journal of Health and Pollution*, 8(17), 43-52. doi:https://doi.org/10.5696/2156-9614-8.17.43
- Franken, G., & Schütte, P. (2022). Current trends in addressing environmental and social risks in mining and mineral supply chains by regulatory and voluntary approaches. *Mineral Economics*, 35(3), 653-671. doi:https://hdl.handle.net/10419/308644
- Joffe, A. R., Khaira, G., & de Caen, A. R. (2021). The intractable problems with brain death and possible solutions. *Philosophy, Ethics, and Humanities in Medicine, 16*(1), 11. doi:https://doi.org/10.1186/s13010-021-00107-9
- Jowitt, S. M., Mudd, G. M., & Thompson, J. F. H. (2020). Future availability of non-renewable metal resources and the influence of environmental, social, and governance conflicts on metal production. *Communications Earth & Environment*, 1(1), 13. doi:https://doi.org/10.1038/s43247-020-0011-0
- Kwesi, E. A., Simpson, O., Lawerty, J., Mends, A., Assencher, C., & Baffoe, P. E. (2021). Land management problems in the mining communities of Tarkwa, Ghana-a look at boundary markers and resurveys. *Ghana Mining Journal*, 21(1), 11-21. doi:https://doi.org/10.4314/gm.v21i1.2
- Li, Z., Wang, P., Liu, L., Zheng, Y., & Xie, D. (2021). High negative surface charge increases the acidification risk of purple soil in China. *CATENA*, 196, 104819. doi:https://doi.org/10.1016/j.catena.2020.104819
- Liu, H., Wu, Q., Chen, J., Wang, M., Zhao, D., & Duan, C. (2021). Environmental impacts related to closed mines in Inner Mongolia. *Sustainability*, 13(23), 13473. doi:https://doi.org/10.3390/su132313473
- Liu, Y., Soroka, A., Han, L., Jian, J., & Tang, M. (2020). Cloud-based big data analytics for customer insight-driven design innovation in SMEs. *International Journal of Information Management*, 51, 102034. doi:https://doi.org/10.1016/j.ijinfomgt.2019.11.002
- Manikas, I., Ali, B. M., & Sundarakani, B. (2023). A systematic literature review of indicators measuring food security. *Agriculture & Food Security*, 12(1), 10. doi:https://doi.org/10.1186/s40066-023-00415-7
- Meyfroidt, P. (2018). Trade-offs between environment and livelihoods: Bridging the global land use and food security discussions. *Global Food Security*, 16, 9-16. doi:https://doi.org/10.1016/j.gfs.2017.08.001
- Mohapatra, D. P., & Kirpalani, D. M. (2016). Process effluents and mine tailings: sources, effects and management and role of nanotechnology. *Nanotechnology for Environmental Engineering*, 2(1), 1. doi:https://doi.org/10.1007/s41204-016-0011-6
- Nel, T., Bruneel, Y., & Smolders, E. (2023). Comparison of five methods to determine the cation exchange capacity of soil. *Journal of Plant Nutrition and Soil Science*, 186(3), 311-320.
- Padhiary, M., & Kumar, R. (2023). Assessing the environmental impacts of agriculture, industrial operations, and mining on agro-ecosystems *Smart internet of things for environment and healthcare* (pp. 107-126): Springer.

- Regasa, A., Haile, W., & Abera, G. (2023). Assessment of soil acidity and fertility status under different land uses types in Sayo District of Western Ethiopia. *Russian Agricultural Sciences*, *50*(2), 172-184. doi:https://doi.org/10.3103/s1068367424700137
- Sabastian, S. (2022). Occupational health and safety practices among small scale mining workers in Ghana; a case study of Wassa Amenfi (West, East And Central) Municipals. University of Education, Winneba.
- Sande, T. J., Tindwa, H. J., Alovisi, A. M. T., Shitindi, M. J., & Semoka, J. M. (2023). Enhancing sustainable crop production through integrated nutrient management: a focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilisers—a systematic review. *Frontiers in Agronomy*, *6*, 1422876. doi:https://doi.org/10.3389/fagro.2024.1422876
- Shakywal, V. K., Pradhan, S., Marasini, S., & Kumar, R. (2023). Role of organic manure for improving soil health. *Sustainable Management of Soil Health*, 53. doi:https://doi.org/10.35691/JBM.1202.0198
- Sharma, J. K., Kumar, N., Singh, N. P., & Santal, A. R. (2023). Phytoremediation technologies and their mechanism for removal of heavy metal from contaminated soil: An approach for a sustainable environment. *Frontiers in Plant Science*, 14, 1076876. doi:https://doi.org/10.3389/fpls.2023.1076876
- Teixeira, B. M. (2021). Underdevelopment, extractivism, and conflict in the Global South and the role of systemic alternatives. *Conjuntura Austral*, 12(59), 21-34. doi: https://doi.org/10.22456/2178-8839.113853
- Verma, A. K. (2021). Influence of climate change on balanced ecosystem, biodiversity and sustainable development: An overview. *International Journal of Biological Innovations*. doi:https://doi.org/10.46505/IJBI.2021.3213