

# Crop production potential of reclaimed mine sites for sustainable livelihoods

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## 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 (NH<sub>4</sub>OAc) 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<sup>-1</sup>, 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 ( $< 5\%$ ). 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).

**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:** Goldfields, Soil fertility, Mine reclamation, Cation agglomeration, Liming

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## 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 ([STANDS4 LLC, 2017](#)). The term also includes the removal of soil ([General Kinematics Corporation \(GKC\), 2017](#)). 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 wider sense comprises extraction of any non-renewable resource (example, petroleum, natural gas, or even water) ([Ali, 2011](#)).

The nature of mining processes creates negative impact on the environment both during the mining operations and years after the mine is closed ([Gashenko, 2015](#)). Though mining contributes about 5% of Ghana's Gross Domestic Product (GDP) in support of economic livelihoods ([Owusu-Ansah et al., 2015](#)), its impact has led to most nations adopting regulations to moderate the negative effects ensuing from the operations ([Gashenko, 2015](#)). Mining and its activities cast pressures on the environment and its natural processes account for degradation and pollution of land and water bodies ([Ali, 2011](#); [Owusu-Ansah et al., 2015](#)). Universally, mining constitutes an engine of civilization, backbone of science and technology and the wheel for economic growth and development, as typified in the Tarkwa area which hosts five of the major companies in the country and is surrounded by several small-scale mining companies ([Eshun and Mireku-Gyimah 2002](#); [Ntibery, 2015](#)). The influx of job seekers to the Tarkwa environs characterizes it with 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 ([Eshun and Mireku-Gyimah, 2002](#); [World Urbanization Prospects \(WUP\) 2018](#)). 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 year, but is expected to reach 37,294,019 at growth rate of 1.8% by 2030 ([GSS 2017](#); [WUP, 2018](#)).

Gold mining has played a significant role in the socio-economic development of Ghana for the past hundred years ([Akabzaa et al., 2005](#)), in spite of the deterioration of surface water bodies following the inappropriate discharge of mine sediment pollutants in the affected catchment areas ([Davis et al., 1994](#); [Kuma and Younger 2001](#); [Kuma and Younger 2004](#); [Manu et al., 2004](#); [Obiri, 2007](#)). Gold mining in recent times has 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, disposal of the tailings and waste waters around the mine sites ([Essumang et al., 2007](#); [Hanson et al., 2007](#); [Obiri, 2007](#); [Singh et al., 2007](#)).

Land is an important asset, which 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 ([Arko, 2013](#)). The balance of the ecosystem is much dependent on land so when the environment is disturbed, the life of man is prone to danger ([Owusu-Ansah et al., 2015](#)). 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 in totally rejuvenating soil productivity ([Arko, 2013](#); [Owusu-Ansah et al., 2015](#)). Social and environmental activists intimated on the potential link between mineral resources, conflict and consequential underdevelopment ([Owusu-Ansah et al., 2015](#)). They further project sustainability functions of land use as a critical requirement for prosperous livelihood because it offers security for the future and has for a long time been of concern in the world ([Arko, 2013](#)). 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 attainments of food security and humanity ([FAO 1993](#)).

Amendment of land management policy laws encourages the rational and efficient utilization of land and natural resources; ensures the preservation of natural and cultural values and prevents environmental damage based on the principles of sustainable development ([Agenda 21, 1992](#); [Brilliant Earth, 2017](#)). In Ghana there are over two hundred registered gold mining companies operating from

small to large scale mining with most of them located in the Wassa West District in the Western Region of Ghana, which has Tarkwa as its administrative capital ([Opoku et al., 2014](#)).

Majority of the mining companies in Western Region of Ghana are engaged in open pit (surface) mining for income to initiate local community development ([Opoku et al., 2014](#); [Adu-Gyamfi et al., 2015](#); [Bansah, et al., 2016](#)). Even though mining contributes significantly to Ghana's Economic Recovery Programs, it is at a great environmental cost as exploitation of the minerals depletes water, soil, vegetation and poses human health hazards in the communities around the buffer zones ([Amonoo-Neizer and Amekor, 1993](#); [Bansah et al., 2016](#)). Examples of these companies are, Goldfields Ghana Limited Tarkwa Mines, Bogoso Mines, Bibiani Mines and Wasa Mines where several youths and adults are employed to work under varying conditions ([Yankson, 2010](#); [Adu-Gyamfi et al., 2015](#); [Ephraim and Ephraim, 2016](#)). New Mont Gold Mining, Sand and Gravel Mines in Gonja District of Ghana, all of which impact negative effects on the land constitute a major threat to the inhabitants and entire ecosystem stability ([Arko, 2013](#); [Opoku et al., 2014](#)). This paper 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 for the studies: i. physicochemical characteristics of mine reclaimed soils; ii. suitability of mine reclaimed soils for crop production; and iii. soil fertility enhancement measures towards improved crop production.

## **2. Methodology**

### **2.1. Study site**

The study was conducted within the concession of Goldfields Ghana Limited, Tarkwa Mine at the Tarkwa - Nsuaem Municipality in 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 Longitudes 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 and to the East by Mpohor Wassa East ([Tarkwa Nsuaem Municipal District 2019](#)). The tropical climatic conditions around Tarkwa are characterized by two wet seasons; March-July and September-November ([Ephraim and Ephraim, 2016](#)). The area experiences an annual rainfall of about 1,744 mm and a daily sunshine of about 10 hours interspersed with relative humidity, atmospheric pressure and temperature ranges of 73%-98%, (99.0-100.7) kPa and (28-39) °C respectively.

### **2.2. Source of sampling materials and sampling procedure**

Six (6) data collection experts, sample bags, auger, shovels, marker 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 5° 15' N and longitude 2° 00' W. The Tarkwa mine is located 4 km west of the town of Tarkwa with good access roads and an established infrastructure ([Tarkwa Nsuaem Municipal District 2019](#)). Each one of the twenty (20) soil samples comprising five (5) from each site were picked 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 outskirts of the mine concession from a naturally undisturbed site (Ajopa natural forest). About 10 kg of the soil samples were retrospectively picked in conformity to prevent variability of sample volumes among plots. In order to obtain a true representation, the sample frames were drawn using auger, shovels, sample bags, permanent markers and flagging tapes. A purposive sampling technique was used for the selection of sites earmarked for coverage by the experts. These sites were assumed to have recovered from the deleterious impacts of mining and suspected to contain enough soil of productive capacity at reasonable depths for plant growth upon adoption of reclamation interventions. Soil cores were taken 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 its fertility or productivity dynamics by measuring the concentrations of chosen physico-chemical properties. 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 then demarcated with flagging tape for future references.

### 2.3. Laboratory analysis of the soil samples

Soil samples were air dried at normal room temperatures for forty-eight hours (48hrs) and grounded using miniature pestle in a mortar (to facilitate proper digestion of the samples since wet soil samples with high clay contents tend to clog, reducing efficiency of the analyzer). Ground soil contents were then sieved using two-millimeter (2mm) 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 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, about 1 g soil was used with 10 ml of 0.1667M  $K_2Cr_2O_7$  solution, 20 ml concentrated  $H_2SO_4$ , 200 ml water for dilution, 10 ml  $H_3PO_4$ , 10 ml of NaF solution, diphenylamine as an indicator, 0.5M  $FeSO_4$  solution as a titrant) (Priyanka, 2015). The exchangeable bases (calcium, magnesium, potassium and sodium) were measured in 1.0 M ammonium acetate ( $NH_4OAc$ ) extract. Exchangeable acidity was determined in 1.0 M KCl extract, calcium and magnesium by EDTA titration; potassium and sodium by flame photometry; effective cation exchange capacity (ECEC) by the sum of exchangeable bases (calcium, magnesium, sodium and potassium) and exchangeable acidity (Odueze *et al.*, 2017). 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 column without replication) analysis of variance at ( $p \leq 0.05$ ) level of significance between the various sites physico-chemical parameters. The average data of the physico-chemical parameters were separated by their standard deviations.

## 3. Results and discussions

### 3.1. Soil pH

The average soil pH in all the sampled areas were as shown in Figures 1,2,3 and table 1. pH values from the various reclaimed mine sites including the control were very low (extremely acidic). It ranged from 3.25 (Ajopa-control site) to 4.32 (West Heap), displayed in the order with 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 was not significantly different ( $p \geq 0.138$ ). The effective source variations in 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  $\geq 0.451$ ) and within columns ( $p$  - value  $\geq 0.454$ ) (Tables 2 and 3 in the appendix).

### 3.2. Soil organic matter (SOM in $Cmolkg^{-1}$ )

The average soil organic matter content of the various reclaimed sites including the control site are presented in Figure 1 and Table 1 respectively. Lower organic matter levels showed up in the SDP, BAM, BDG and MANT 'N' soil samples but quite moderate level ranging between 2.08 - 1.15 featured in the West Heap and the Ajopa control sites. 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 contents compared with mean pH and total nitrogen were not significantly different ( $p \geq 0.482$ ). Effective source variations in spatial distribution of OM in all the soils were similarly not significantly different from other parameters at a gross screen both between the rows ( $p$  - value  $\geq 0.451$ ) and within columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

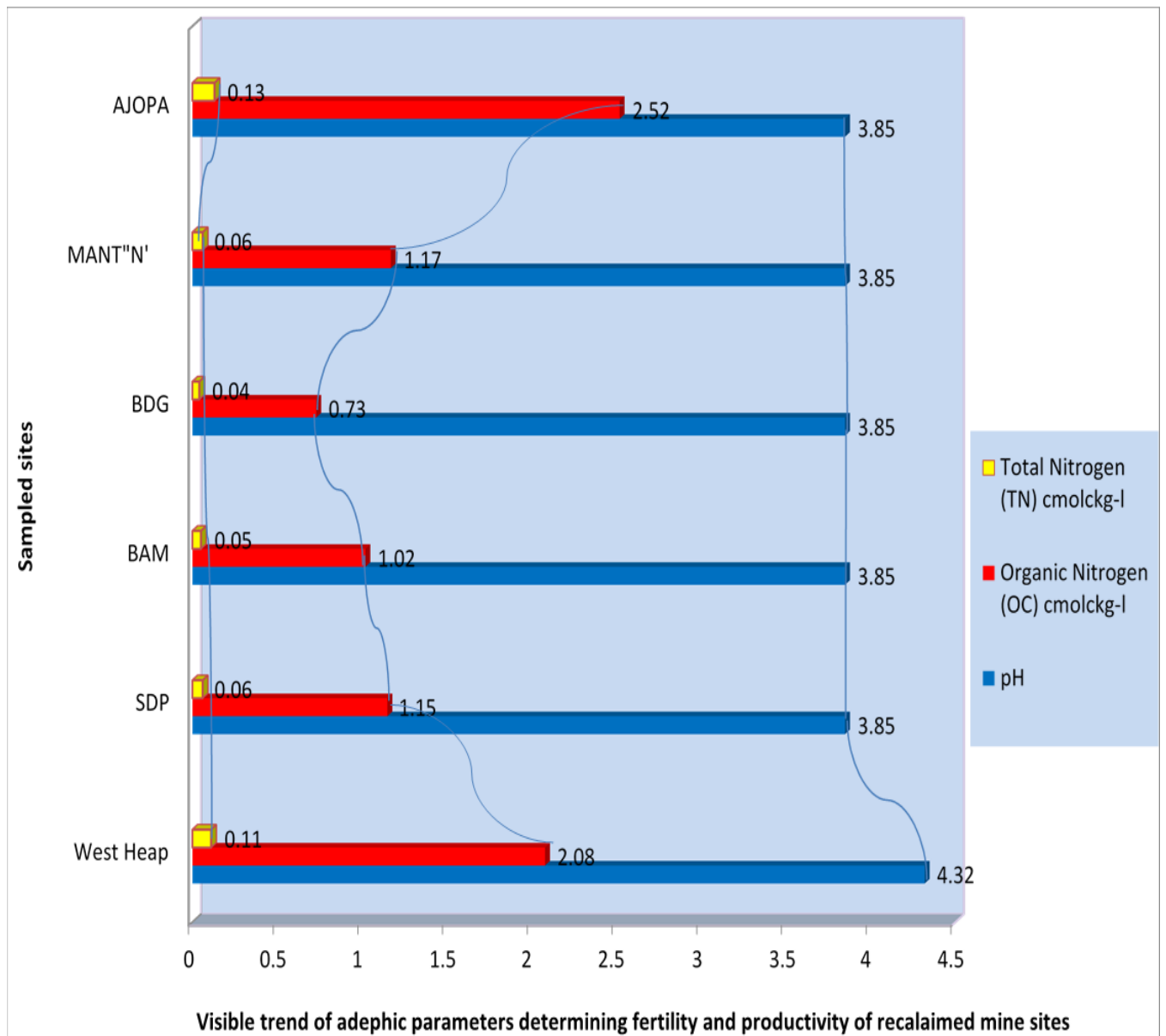


Figure 1: Edaphic parameters (total nitrogen and organic matter in comparison with pH condition determining the fertility and productivity of the five reclaimed mine sites at Gold Fields Ghana Limited, Tarkwa Mine in Ghana.

### 3.3. Total nitrogen (TN in $\text{Cmol kg}^{-1}$ )

The average site-by-site soil TN levels are presented in Figure 1 and Table 1. The percentage total nitrogen level at the SDP, BAM, BDG and MANT 'N' sites were moderately lower than 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 ( $\pm$  SD) from various mine reclaimed sites at Goldfield Ghana Limited Tarkwa Mine

Parameter (SI Unit)	West Heap $\pm$ SD	SDP $\pm$ SD	BAM $\pm$ SD	BDG $\pm$ SD	MANT''N' $\pm$ SD	AJOPA $\pm$ SD
pH	4.32 $\pm$ 0.64	3.85 $\pm$ 0.17	3.42 $\pm$ 0.26	3.63 $\pm$ 0.05	3.66 $\pm$ 0.02	3.25 $\pm$ 0.43
Organic. Nitrogen (OC) $\text{cmol kg}^{-1}$ .	2.08 $\pm$ 0.63	1.15 $\pm$ 0.30	1.02 $\pm$ 0.43	0.73 $\pm$ 0.69	1.17 $\pm$ 0.28	2.52 $\pm$ 0.80
Total Nitrogen (TN) $\text{cmol kg}^{-1}$	0.11 $\pm$ 0.04	0.06 $\pm$ 0.02	0.05 $\pm$ 0.03	0.04 $\pm$ 0.04	0.06 $\pm$ 0.04	0.13 $\pm$ 0.06
Calcium (Ca) $\text{cmol kg}^{-1}$ .	3.52 $\pm$ 2.10	0.89 $\pm$ 0.53	0.58 $\pm$ 0.84	1.78 $\pm$ 0.36	0.90 $\pm$ 0.52	0.82 $\pm$ 0.60
Magnesium (Mg) $\text{cmol kg}^{-1}$ .	1.22 $\pm$ 14.93	90.71 $\pm$ 74.78	0.27 $\pm$ 15.55	1.25 $\pm$ 14.68	0.9 $\pm$ 15.03	1.21 $\pm$ 14.72
Potassium(K) $\text{cmol kg}^{-1}$ .	0.16 $\pm$ 0.05	0.08 $\pm$ 0.03	0.08 $\pm$ 0.03	0.13 $\pm$ 0.02	0.12 $\pm$ 0.01	0.1 $\pm$ 0.01
Sodium (Na) $\text{cmol kg}^{-1}$ .	0.11 $\pm$ 0.39	0.10 $\pm$ 0.40	0.05 $\pm$ 0.45	0.09 $\pm$ 0.41	0.08 $\pm$ 0.42	0.07 $\pm$ 0.43
Exchangeable Acidity (EA).	0.96 $\pm$ 0.65	1.85 $\pm$ 0.24	1.88 $\pm$ 0.27	1.89 $\pm$ 0.28	1.20 $\pm$ 0.41	1.90 $\pm$ 0.29
Effective cation exchange capacity (ECEC) $\text{cmol kg}^{-1}$	5.95 $\pm$ 2.18	2.71 $\pm$ 1.06	2.66 $\pm$ 1.11	4.68 $\pm$ 0.91	3.11 $\pm$ 0.66	3.5 $\pm$ 0.27

'N' (0.06%) > BAM (0.05) > BDG (0.04%). The average TN contents of reclaimed mine and AJOPA control sites were significantly different ( $p \leq 0.001$ ) compared with pH and organic nitrogen on the sample graphical representation of visible trends on figure 1. Effective source variations and spatial distribution of TN was further not significantly different from other parameters upon cross screening both between the rows ( $p$  - value  $\geq 0.451$ ) and within columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

### 3.4. Exchangeable cations (Calcium, Magnesium, Potassium, Sodium)

#### 3.4.1 Exchangeable calcium (Ca in $\text{Cmol kg}^{-1}$ )

Exchangeable Calcium levels at the various reclaimed sites in  $\text{cmol kg}^{-1}$  ranged from 0.82 at Ajopa to 3.52 in 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 contents in all the reclaimed soils compared with pH, exchangeable acidity, effective cation exchange capacity was such that, the Ajopa natural forest control site was not significantly different from others ( $p \geq 1.231$ ), with alternative corresponding insignificant differences in the effective source variations and spatial distribution both between the rows ( $p$  - value  $\geq 0.451$ ) and within columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

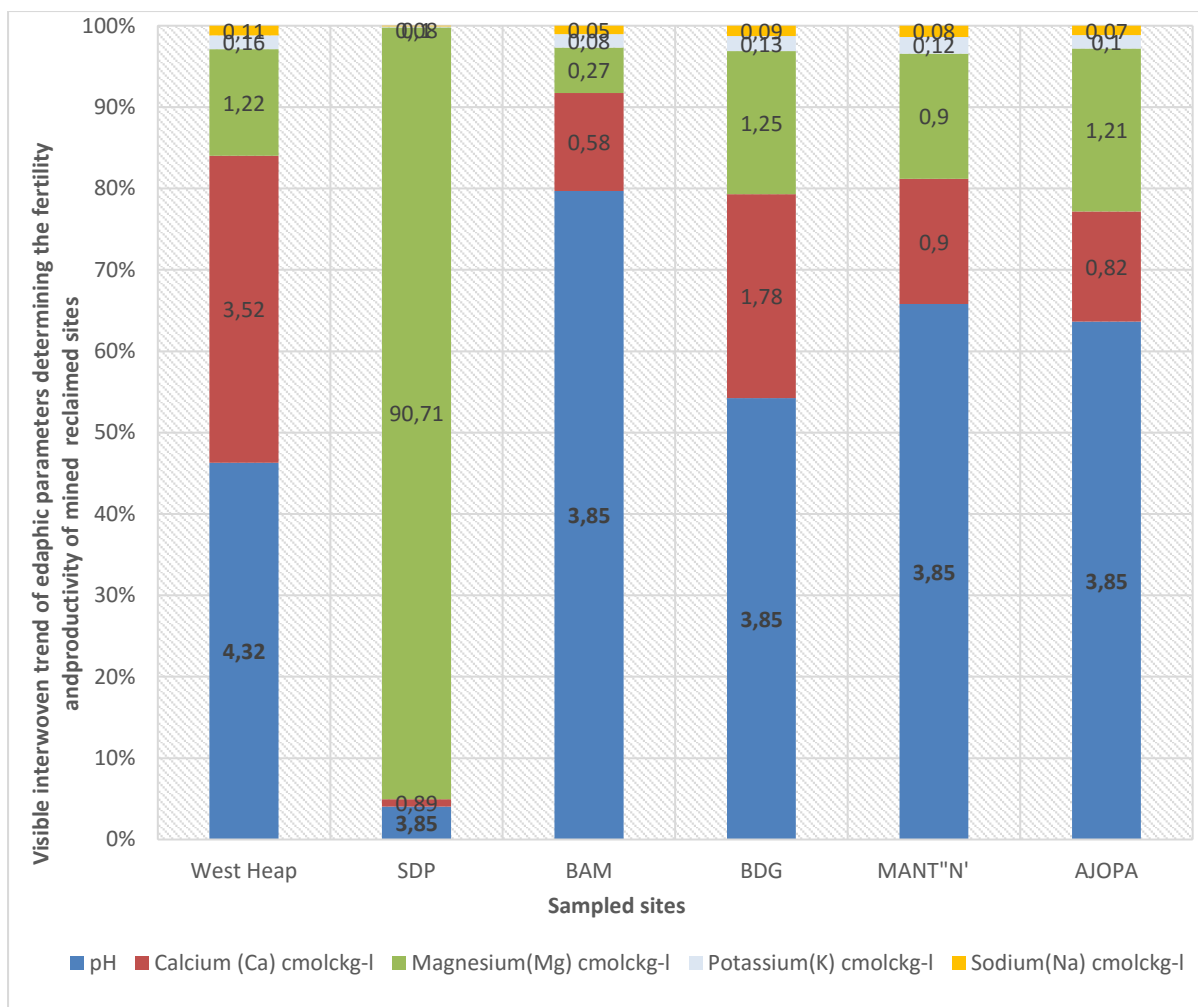


Figure 2: Edaphic parameters (Ca, Mg, K and Na in comparison with pH condition determining fertility and productivity of the five reclaimed mine sites at Gold Fields Ghana Limited, Tarkwa Mine in Ghana.

### 3.4.2. Exchangeable magnesium (Mg in $\text{Cmolkg}^{-1}$ )

Average Mg levels in the soils were quite low and ranged 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 entirely so significantly different ( $p \leq 0.000$ ) compared with 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  $\geq 0.451$ ) and within columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

### 3.4.3. Exchangeable potassium (K in $\text{cmolkg}^{-1}$ )

Average exchangeable potassium level in the soil samples were generally very low ranging from 0.08 at (SDP and BAM) to 0.16 (West Heap) (figure 2). The entire detective 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 so significantly different ( $p \leq 0.000$ ). 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  $\geq 0.451$ ) and within the columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

### 3.4.4. Exchangeable sodium ( $Na$ in $cmolkg^{-1}$ )

Exchangeable Na levels were low in the entire soils featuring at less than 5% of the nutrients 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 the entire sites was not significantly different ( $p \leq 0.176$ ). Comparative point source variations and spatial distribution of Na with pH and the other soil productivity parameters concurrently examined were also not significantly different both between the rows ( $p$  - value  $\geq 0.451$ ) and within the columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

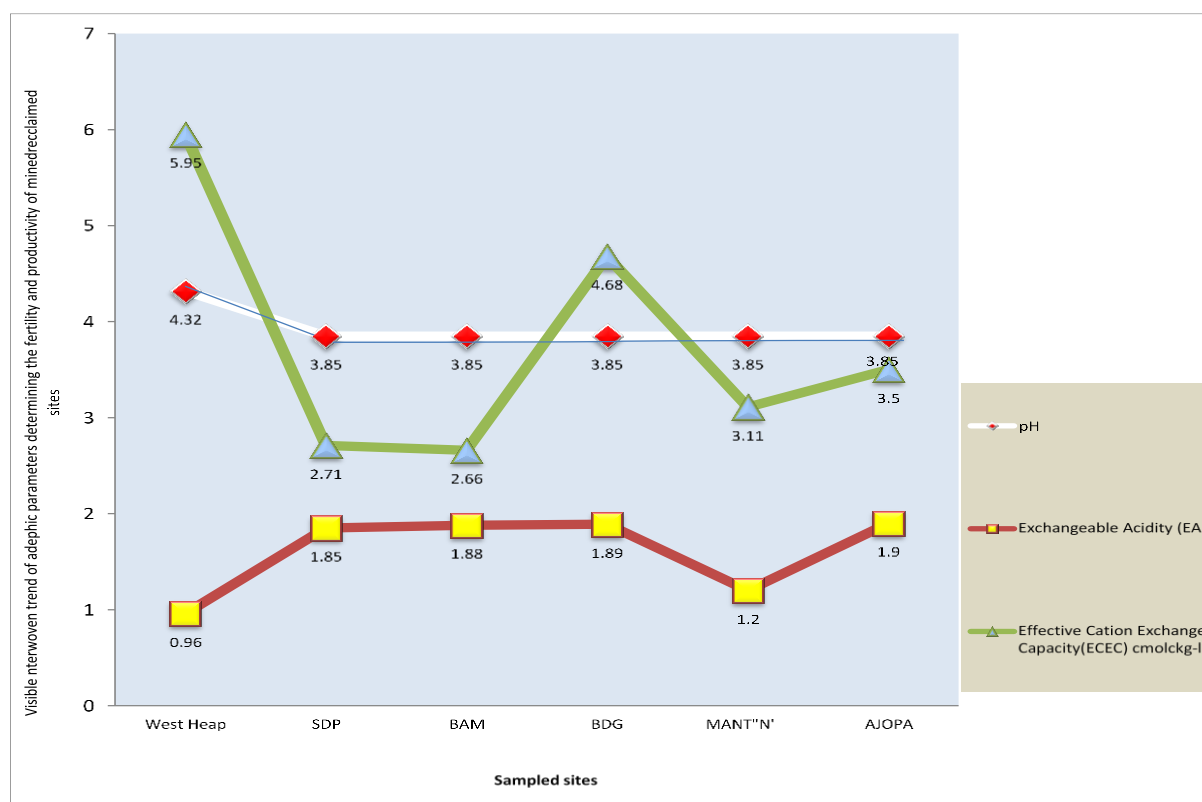


Figure 3. Exchangeable acidity and effective cation exchange capacity in comparison with pH condition determining fertility and productivity of reclaimed mine sites at Gold Fields Ghana Limited, Tarkwa Mine.

### 3.4.5. Exchangeable acidity ( $cmolkg^{-1}$ )

Average exchangeable acidity concentration in the entire reclaimed sites ranged between 0.96 from West Heap to 1.90 at 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 ( $p \leq 1.688$ ), 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 additionally not significantly different both between the rows ( $p$  - value  $\geq 0.451$ ) and within columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

### 3.4.6. Effective cation exchange capacity (ECEC in $cmolkg^{-1}$ )

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 shows low trend of effective cation exchange capacity of the entire soil regimes except the West Heap which showed moderate ECEC potential (figure 3). The average pattern

of ECEC in the entire sites compared with pH and the other soil productivity parameters were not significantly different ( $p \leq 4.437$ ) and its effective point source variations and spatial distributions were further not significantly different both between the rows ( $p$  - value  $\geq 0.451$ ) and within the columns ( $p$  - value  $\geq 0.454$ ) (Appendix Tables 2 and 3).

### 3.5. 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 sites data were indicatively similar with no statistically significant differences ( $p \leq 1.838$ ;  $P \leq 1.697$  and  $p \leq 1.579$ ) in the optimum soil conditions as compared to BDG ( $p \leq 2.684$ ). The Ajopa natural forest, MANT 'N', BAM and BDG data proved significant variations with the West Heap ( $p \leq 889.198$ ). The entire results projected little variations in 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 effective source and spatial distribution of the soil physico-chemical parameters examined both within the rows ( $p$  - value  $\geq 0.451$ ) and between columns ( $p$  - value  $\geq 0.454$ ) (Appendix tables 2 and 3).

#### 3.5.1. Soil pH (Acidity)

Soil acidity (pH) is a key parameter for assessing a soil's fertility status ([CUAFS \(No. 1\), 2005](#)). In this current finding, it gives an insight into all the reclaimed areas including the control site which entirely 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), ([Cornel Guide for Integrated Field Crop Management, 2005](#)). The availability or otherwise of both macro and micro-nutrients is essential as an indicator for plant growth regulation. Characteristics of the examined soils in the hitherto study sites signaled, the reclaimed areas as well as 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 and 7.5 recommended earlier by [Brady and Weil \(2002\)](#). Contrarily, tree crops such as oil palm which tolerate a wide range of soil pH (3.8 - 7.0) according to the specification of [Mutert \(1999\)](#); could be considered in almost all the reclaimed sites. Management practices such liming and addition of rock phosphate to improve soil pH, are the recommended practices to adopt towards the reclamation of these degraded sites for crop cultivation purposes ([Yan et al., 2015](#)).

#### 3.5.2. Soil Organic Matter (SOM)

Soils with organic matter content less than 1.5% have been considered as low and between 1.5 to 3.0% as moderate and above 3.0% as high for recommended crop production requirement ([Kannan et al., 2011](#); [Shi et al., 2016](#)). Results from Ajopa natural forest and West Heap reflected moderate soil organic matter contents while others fell within the low range. Ajopa natural forest being naturally an undisturbed soil exhibited improved organic matter content because it probably had over the past years, undergone cyclical decomposition and mineralization of the underlain organic residues. The entire OM apart from the control site was low and might not support a variety of crops to turn out good yield ([Yan et al., 2015](#)). Adoption of soil improvement practices such as application of organic poultry manure, cow dung or compost and cover cropping as soil and water conservation initiatives could synchronize organic matter content for crop production ([Shi et al., 2016](#)).

#### 3.5.3. Total nitrogen (N)

Soils with average total N content less than 0.10% are assessed to be low whereas those from 0.10 to 0.20% are moderately rich ([Odueze et al., 2017](#)). Hence, the entire soil regimes understudied revealed low trend of TN. Perhaps, it is by the application of nitrogen fertilizers and organic manures, that the productivity of these soil regimes could further be improved for higher sustainable arable crop yield within the reclaimed mine sites ([Yan et al., 2015](#)).

#### 3.5.4. Exchangeable cations (Ca, Mg, K, Na) in $\text{cmol}_c\text{kg}^{-1}$

##### 3.5.4.1. Calcium (Ca)

The results reflected low exchangeable Ca content of the soils screened from all the reclaimed mine sites including the Ajopa Natural Forest. The Ca contents ranged from 0.58 to 3.52. These levels implicitly fall below the critical crop Ca requirement of  $5 \text{ cmol}_c\text{kg}^{-1}$  in cultivable soils ([McLean, et al.,](#)

1983). The resultant Ca pattern featuring from the chemical analysis authenticate the early reportage that, soil *pH* and exchangeable calcium levels are directly related and the lower the *pH*, the lower the calcium level in the soil (McLean, *et al.*, 1983). The implications are far fetching, holding to the condition that most arable crops may not perform up to expectation on such soils without amelioration of the *pH* through management practices such as liming and application of rock phosphate fertilizers to suit most tillage requirement (Yan *et al.*, 2015).

#### 3.5.4.2. Magnesium (Mg)

Magnesium is an essential component of several primary and secondary minerals in the soil, which are largely insoluble for agricultural considerations. These constituents are the original sources of the soluble or available forms of Mg (Ding *et al.*, 2012). The Mg levels were low in all the reclaimed mine sites. This might be due to the low *pH* levels of the various soils suggesting why most soils are so deficient in soluble Mg as previously observed from a study which 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% mineral and 5% organic matter (Kinsey, 2015). According to (Kinsey, 2015), most cultivable soils fall short of the ideal conditions in some way. While clay soils are generally too tight, and due to a lack of calcium (even on high *pH* soils), it contains 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 as it dries out. Alternatively, sandy soils tend to exhibit deficiencies (so large air pores and unable to hold enough water – but consolidates and becomes hard when worked upon under extreme wet conditions, with excessive complimentary Mg levels. A means for amelioration of Mg deficiencies is the application of soil amendments such as, lime and rock phosphate fertilizer to up-adjust the *pH* while regulating the Mg level for improved crop production (Cornel Guide for Integrated Field Crop Management, 2005; Ding *et al.*, 2012; Kinsey, 2015).

#### 3.5.4.3. Potassium (K)

Except the West Heap reclaimed site which had moderate average exchangeable potassium content of 0.16 all the other sampled areas including the control site (Ajopa) portrayed average exchangeable potassium levels below the 0.15 cmolkg<sup>-1</sup> critical requirement in cultivable soils. Exchangeable potassium levels below 0.15 cmolkg<sup>-1</sup> is considered low and above 0.15 cmolkg<sup>-1</sup> is moderate (Cornel Guide for Integrated Field Crop Management, 2005; Yan *et al.*, 2015). The low average exchangeable potassium levels may be attributed to low *pH* conditions in the reclaimed mine sites. Application of lime and rock phosphate fertilizer could improve the *pH* condition and synchronize exchangeable potassium availability for food crop production (Yan *et al.*, 2015; Cornel Guide for Integrated Field Crop Management, 2005). Benlloch and Benlloch-González, (2016) earlier suggested that the recovery of plant growth after water stress is related to coordinated water and K<sup>(+)</sup> transport 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<sup>+</sup> (Rb<sup>+</sup>) uptake and transport capacity after being exposed to high temperatures revealed that root warming through temperature adjustment improves potassium uptake and crop yields (Benlloch-González *et al.*, 2017). The recovery of K<sup>+</sup> (Rb<sup>+</sup>) 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 yet. The final observation showed that the root system of young olive plants is very sensitive to high temperature related to root potassium transport and growth of the plant. Taking into account the two processes involved in root potassium transport, the discharge of K<sup>+</sup> to the xylem vessels was more affected than the uptake at the initial phase of high root temperature stress (Benlloch-González *et al.*, 2017).

#### 3.5.4.4. 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% (Bresler *et al.*, 2017). Sodic soils tend to occur within arid and semi-arid regions and are innately

unstable, exhibiting poor physical and chemical properties, which impede water infiltration, water availability and plant growth ([Bresler et al., 2017](#)). In all the sites comparatively understudied, the average exchangeable sodium content was low and ranged between 0.05 cmolkg<sup>-1</sup> from BAM to 0.11 cmolkg<sup>-1</sup> in West Heap. The soil Na concentration ascertained was within a very suitable requirement for food crop production ([Murphy, 2000](#)). However, sodic soils may impact plant growth by: 1. exhibiting specific toxicity to sodium sensitive plants ([Hassan et al., 2017](#)); 2. portraying nutrient deficiencies or imbalances ([Qadir et al., 2001](#); [Qadir and Schubert, 2002](#)); 3. imparting alkaline conditions with a high pH (>8.5) due to the presence of high concentrations of sodium carbonates (Na<sub>2</sub>CO<sub>3</sub>) ([Qadir et al., 2001](#); [Bresler et al., 2017](#)); and 4. spread of Na-soil particles that trigger poor physical condition of the soil ([Qadir et al., 2001](#); [Davis, et al., 2007](#)).

#### 3.5.4.5 Exchangeable Acidity (EA)

Exchangeable acidity is defined as the extent of modifications in soil pH conditions due to 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 turn to influence soil productivity and sustainable plant growth ([Benton, 2012](#); [Gitari et al., 2015](#)). Exchangeable acidity has been identified to be inversely related to the soil pH levels ([Onwuka et al., 2016](#); [Funakawa et al., 2016](#)). The average values recorded in this paper ranged between 0.96 from West Heap to 1.90 at Ajopa Natural Forest. Generally, values greater than 0.30 are noted to be high ([Funakawa et al., 2012](#); [Onwuka et al., 2016](#)). 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 ([Yan et al., 2000](#); [Onwuka et al., 2016](#)).

#### 3.5.4.6. Effective Cation Exchange Capacity (ECEC)

Cation-exchange capacity (CEC) is the maximum quantity of total cations, of any class, that a soil is capable of holding at a given pH value for exchanging with the soil solution. Alternatively, it is the measure of how many negatively-charged (electrophilic) sites are available in the soil ([Cornel Guide for Integrated Field Crop Management, 2005](#); [Astera, 2015](#)). The CEC is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination ([Davis, 2007](#)). The CEC of the studied areas were low except 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 ([Kannan et al., 2011](#)). Management practices to improve soil organic matter content such as organic manure (cow dung, poultry manure, compost) application, mulching, leguminous cover cropping and improved fallows are recommendable ([Sobek et al., 2000](#); [Yan et al., 2000](#); [Kannan et al., 2011](#); [Astera, 2015](#)).

## 4. Conclusion

The pH displayed an extremely acidic condition from the entire reclaimed soils including Ajopa naturally undisturbed forest. Exchangeable cations (Ca, K, and Mg) and effective cation exchange capacities were entirely 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 upon its organic matter status. Cover cropping, application of animal manure and compost may further ameliorate soil fertility. Application of lime and rock phosphates 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 years old reclaimed sites in the short run, and may not be able to produce the sustainably high crop yields when subjected to agronomical ventures without further application of significant recommended soil improvement treatments.

### 4.1. Recommendations

Oil palm plantations serve as an alternative suit to other economic food crops cultivation on these reclaimed mine sites since it tolerates wider range of climatic and soil conditions. Joint research partnership between Agriculture Research Institutions and Universities, mining companies should

upscale similar case studies along different reclaimed mining sites in Ghana. Inculcating lime and organic manure to the reclaimed degraded mine sites will be innovative options to revitalize fertility and other physico-chemical conditions within five to fifteen years in the medium and long terms for productive crop cultivation.

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**Appendix Table 1.** Analysis of variance: Two-Factor without Replication of soil sample data from Goldfields Ghana Limited Tarkwa Mine.

Summary	Count	Sum	Average	Variance
pH	6	22.13	3.688333	0.138697
Organic Nitrogen (OC)	6	8.67	1.445	0.48267
Total Nitrogen (TN)	6	0.45	0.075	0.00131
Calcium (Ca)	6	8.49	1.415	1.23127
Magnesium (Mg)	6	95.56	15.92667	1342.35
Potassium (K)	6	0.67	0.111667	0.000977
Sodium (Na)	6	0.5	0.083333	0.000467
Exchangeable Acidity (EA)	6	9.68	1.613333	0.176707
Effective cation exchange capacity (ECEC)	6	22.61	3.768333	1.688937
West Heap	9	18.43	2.047778	4.43769
SDP	9	101.4	11.26667	889.1985
BAM	9	10.01	1.112222	1.579269
BDG	9	14.22	1.58	2.684275
MANT"N'	9	11.2	1.244444	1.697903
AJOPA	9	13.5	1.5	1.8364

**Appendix Table 2.** ANOVA source variations within rows and columns of soil sample data from Goldfields Ghana Limited Tarkwa Mine.

Source of Variation	SS	df	MS	F
Rows	1201.68	8	150.21	0.999768
Columns	720.563	5	144.1126	0.959185
Error	6009.792	40	150.2448	
Total	7932.035	53		