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Evaluation of Silicate-Based Rocks as Soil Conditioners

Mervat Hassan [1+], El Toney Mohamed [2] and Mohamed Kamail [1]

[1] Central Metallurgical R &D Institute

[2] Agriculture College, Ain Shames University

Abstract. The paper aims at evaluation of finely crushed basalt as a cheap soil conditioner to increase food crops production. Basalt from different localities of Egypt was collected and characteristic was using XRD and XRF. The results from XRD analysis of fresh samples of Baharia Oasis, El Arish and El Fayium basalt show plagioclase as the most abundant minerals in addition to olivine and pyroxene. However, the XRD pattern of altered basalt at Suez and Fayium showed the presence of a phyllosilicate as a main component in addition to calcite and zeolite. XRF data revealed the abundance of a number of macro- micronutrients that are essential for plant growth (notably calcium, magnesium, and trace elements: iron, manganese, zinc, and copper) and relatively low amounts of phosphorus and potassium. Crushing, Grinding, particle size, work index and energy consumption of four basaltic samples were carried out. The average of the sum of the 4 basic cations (Ca, Mg, K, and Na in cmol/kg of crushed basalt) for each of particle size fraction of the studied basalt provided a sound basis for determining the effective cation exchange capacity (ECEC) of the fraction. The trend of ECEC is analogous to that shown for the individual cations. That is, the ECEC increases to a maximum as the particle size of the crushed basalt fraction decreases to > 125um. The basalt dust has great effects on decreasing the salinity of soils based on the soils texture.

Keywords: Depleted soils, silicates rocks, CEC, micro nutrients

1. Introduction

Basalt is dark colored, fine grained volcanic rock consisting predominantly of minerals that are silicates of calcium, magnesium, iron, and potassium. The minerals include augite, plagioclase feldspar, olivine, and magnetite with minor orthoclase feldspar and calcium phosphate. Basalt tends to be dense and massive, but it can also be vesicular. This stone can be altered by weathering processes to some alternative minerals. In the arid and semiarid conditions of Egypt, the physical and mechanical weathering dominates over the chemical weathering consequently cracking and exfoliations are done. Volcanic stones, formed at high temperatures, are not chemically stable even at ambient temperatures in the presence of water, which is the principal agent of alteration. Naturally, the basalt is weathered to an assemblage of clay minerals and zeolite. Clay minerals clean up toxic soils, replacing lost nutrients and quickly restoring the land to organic status. Zeolite is the aluminosilicate members of the family of microporous solids known as “molecular sieves.” In agriculture, zeolite minerals are used as a soil treatment. It provides a source of slowly released cations. Zeolite can also act as water moderators, in which they will adsorb up to 55% of their weight in water and slowly release it under plant demand. This property can prevent root rot and moderate drought cycles.

Silicate-based soil conditioners have been used to modify the properties, and thereby improve the productivity of highly weathered tropical soils for more than 70 years [1]-[9]. Gillman [10] concluded that, “a single large application of the basalt cinders may obviate the need to apply Ca and Mg for many years, as well as reduce the leaching losses of applied NH_4 and K over a similarly long period”. Zdrilic and Dumitru [6] studied the complex interactions that occur when rock dust is added to the soil. Harly [11] concluded that, the type of rock dust, the nature of the soil to which the dust is applied, and rates of weathering and mineral

+ Corresponding author. Tel.: +020-25010642; fax: +020-25010639.
E-mail address: Hassan_mervat@yahoo.com.

breakdown are extremely important factors in the effective use of rock dusts. Harley and Gilkes [7] recommended the use of rock dust as a slow release fertilizer for it is not readily leached from the soil, it is acceptable to 'organic' farmers, it is affordable in developing countries and it can reduce stockpiles of quarry or mining by-products. The study aims at enhancement of cereal crop productivity in saline soils using basalt dust as soil conditioner,

2. Material and Techniques

Representative samples were collected from different localities namely; Cairo-Suez Road (Gebel El Abu Terrify), Widdan El Farras (6^{th} October-El Fayium Road), Baharia Oasis and El Arish (Northern Sinai). The mineralogy of representative samples was determined by means of a Philips Powder Diffractometer Model PW 1170 employing CoKα radiation on randomly oriented specimens. All samples were scanned over the 2θ degree range 4–60. A representative specimens were powdered to a size of <4 µm. Clay minerals were concentrated by centrifugation, and the <2 µm fraction separated. Air-dried oriented mineral aggregates were prepared by pipetting suspensions (~5 mg/cm ^{2}) onto glass slides. Samples were solvated with ethylene glycol and subjected to thermal treatment (550 ℃ for 2 h).

Quantitative analysis of the major elements of basalt was determined by X-ray Fluorescence Spectroscopy using Philips PW l300. Closed primary crushing using jaw crusher circuit with 6.63 mm screen was conducted for crushing basalt from different localities. Secondary crushing circuit was performed using gyratory crusher and screen 3.36 mm. The power consumption for crushing one hundred ton basalt to pass 100 % less than 3.36 was determined. The grinding work index for basalt was determined. Samples of each size fraction of the basalt from localities feedstock was washed (aqueous ethanol / aqueous glycerol) to remove soluble salts from the particle surfaces. The exchangeable basic cations were extracted from the variable charge surfaces of the crushed minerals by a 0.1 M $BaCl_2$ / NH4Cl solution using the method of Gillman and Sumpter [12]. Cations analysis of the centrifuged supernatant liquids was performed on ion chromatography. Saline soils (sandy, Suez 2 and clayey, Kafre El Sheikh) were incubated for 3 months on dark with different doses and sizes of Fayium basalt + manure to studies the effect of basalt on soils salinity.

3. Results and Discussion

3.1. Mineralogy

The mineralogical composition of the studied samples of Gebel Abu Terrify obtained by XRD is reported in Fig. 1. Clinopyroxene (Augite), feldspar (albite) and olivine (forestrite) are pyrogenic crystals, as remnant of basalt. Smectite is the principal clay minerals phases present in these samples. Smectite was identified by its expansion from about 14.5 A to ~ 17 A after glycol treatment. Calcite and analcime are recognized in the samples as main non-clay minerals in variable concentrations by characteristic X-ray diffraction peaks at 2ϴ values of 0.304 (040 diffraction) and 0.344 nm (104 diffraction) respectively. Traces of anatase, halite, gibbsite and illite are recognized by characteristic X-ray diffraction peaks at 0.294 nm (101 diffraction), 0.368 (200 diffraction), 0.214 (002 diffraction) and 0.1 nm respectively.

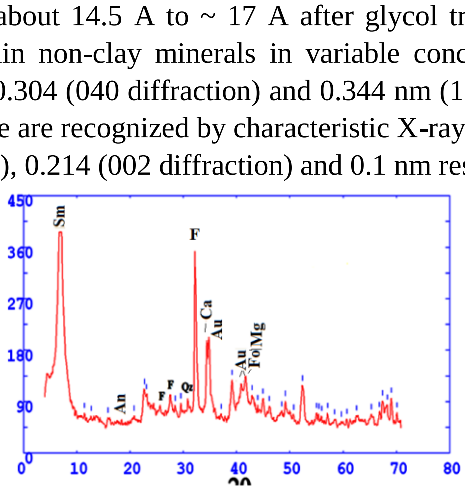

Fig. 1: XRD patterns of samples from G. Abu Terrify, representative basalt used in agriculture

Sm=Smectite; An= Analciam; Ca= Calcite; Au=Augite; F=Feldspar; M= Magnetite; Qz=Quartz; Fo= Forestrite

The results from XRD analysis of fresh samples of Baharia Oasis, El Arish and El Fayium basalt show plagioclase as the most abundant minerals in addition to forsterite (Mg_2SiO_4) and fayalite ($Mg_2Fe_2O_3$).

Clinopyroxene auguite [(Ca, Na)) Mg, Fe^{3+}, $AlFe^{3+}$, Ti) (Si, Al)^2 O^6] and enstatite ($MgSiO_3$) are recognized. Iron oxide and oxyhydroxide represented by goethite and hematite which recognized by characteristic reflections at 4.18 and 2.69A respectively. Meanwhile, iron carbonate represented by siderite (Fig. 2). However, the XRD pattern of altered basalt showed the presence of a phyllosilicate such as kaolinite, smectite, illite, chlorite and celadonite. These minerals are indicated by reflections in the 7.14- 14A range. In some patterns this low-angle peak is fairly sharp suggesting the presence of a well crystallized mineral; in other patterns the peak is broad and diffuse, suggesting the presence of asymmetrical phyllosilicate minerals e.g. smectite (Fig. 3).

XRD analysis of the <2 mm clay fractions showed that smectite is a common constituent in the altered basalt. In general, the presence of smectite in the clay fraction was indicated by a 14 A reflection in the air-dried, upon Mg- saturated that shifts to an 18 Å reflection following glycerol solvation.

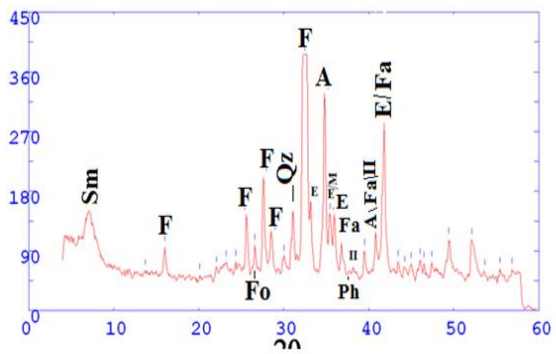

Fig. 2: XRD pattern of Fayium basalt.

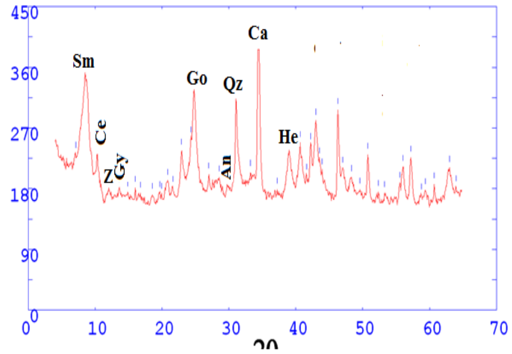

Fig. 3: Highly altered basalt from Fayium.

Fa=Fayalite; Fo=Forestrite; Ph=Phosphate; II=Illuminate; E=Enstatite; A=Augite

An=Anhydrite; Ce= Celadonite; Gy=Gypsum; H=Hematite; Go=Goethite; Z=Zeolite

3.2. Chemical Composition of Basalt

Basalt of G. Abu Terrify, Cairo-Suez Road, generally has a composition of 40–54wt% SiO_2, 2–3wt% total alkalis, 1–2 wt% Ti, 11–12wt% Fe_2O_3 and 7-12wt% Al_2O_3. CaO contents ranged from 7-12wt%, those of MgO commonly in the range 2 to 15wt%. Chemical composition of G Abu Terrify basalt varied based on the alteration process. Table 1 shows chemical analysis of basalt samples from three localities of Baharia Oasis.

Table 1: Chemical Analysis of Representative Basalt Samples

Oxides	Wt.% <4mm Terrify	Wt.% <4mm Baharia	Wt.% <4mm Fayium	Wt.% <4mm El Arish
SiO_2	40.88	51.99	52.26	53.04
Al_2O_3	6.83	15.70	13.88	18.93
Fe_2O_3	10.85	12.57	11.32	12.22
MgO	14.85	8.04	5.75	6.43
CaO	11.94	7.8	9.56	10.59
Na_2O	1.54	4.06	2.64	2.78
K_2O	0.61	1.89	0.87	0.58
Zn	0.018	0.014	0.013	0.013
Ti	0.99	1.32	0.99	1.16
Zr	0.022	0.022	0.022	0.021
Ni	0.008	0.016	0.008	0.0085
P	0.15	0.26	0.22	0.26
S	0.13	0.10	0.11	0.007
Mn	0.008	0.015	0.007	0.12
Cl	0.05	0.035	0.001	0.010
L.O.I	13.68	2.60	2.36	1.15

These basalt characterized by higher total alkali and K_2O compared with MgO content. According to TAS classification, basalt of Baharia Oasis is trachyite andesite. The increase in loss in weight of analyzed revealed the abundance of SiO_2 content which ranged between 50-55%, total alkali ranged between 2.5-5%, meanwhile, MgO ranged from 4- 7%, those of CaO ranged from 9-13%. Low loss in weight revealed low degree of alteration compared with the other basalts from different localities.

However, the chemical composition of highly altered basaltic samples from Widdan El Farras, Fayium revealed low SiO_2 content (14-27%), total alkali ranged from 2.3-2.8%, high CaO (17-30%), low MgO (4%) and high Loss in weight (19-35%). The previous data confirmed by XRD pattern of altered basalt from Widdan El Farsa. The alteration products were trioctahedral smectite, chlorite, celadonite and calcite. On the other hand the fresh samples revealed abundance of SiO_2, Al_2O_3, NaO, TiO_2 and low loss in weight (Table 1).

3.3. Crushing, Grinding, Work Index and Power Consumption of Basalt

Primary crushing circuit using jaw crushing and secondary crushing circuit using gyratory crusher for crushing studied basalt to pass 100 % from sieve size 3.36 mm were used and Table 2 shows the 80 %, 50 % and 25 % passing sizes. These products less than 3.36 mm could be investigated in soil reclamation and agronomy studies.

- Calculation of Crushing Power Consumption

The calculation of crushing power based on bond crushing law: (1).

$$\frac{P}{m} = 0.316 \ w_i \left(\frac{1}{\sqrt{D_P}} - \frac{1}{\sqrt{D_F}} \right) \tag{1}$$

where P, power in KW, W_i is the work index of crushed ore, m is amount of ore to be crushed in one hour, D_p and D_F the d_{80} passing of crushed product and feed (mm). Therefore in order to calculate the crushing power, the work index of basalt is necessary to be determined.

Table 2: Crushed, Grinding, Work Index and Power Consumption of Basalt

Basalt Locality	Size, mm			Work Index, KW/ton	Power Consumption, KW for 100 ton / hr	Size, micron	
	d_{80}	d_{50}	d_{25}			d_{80}	d_{50}
El-Baharia	2.680	1.482	0.503	99.95	1068	302	132
El-Suez	2.253	1.243	0.503	47.89	736	338	181
El-Faiyum	2.413	1.076	0.201	22.56	272	240	100
El-Arish	2.109	1.437	1.007	35.55	325	285	136

- Determination of Work Index of Basalt from Different Localities

The Bond grindability test for basalt was conducted with -3.36 mm dry feed in standard bond ball mill with 30.5 cm diameter and 30.5 cm length following a standard procedure outline described in the literature. The work index was determined at a test sieve of 150 µm. The ball mill work index (Wi) was calculated from:

$$W_i = \frac{44.5}{P_1^{0.23} \times (Gbp)^{0.82} \times \left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}} \right)} \times 1.10 \quad KW/t \tag{2}$$

3.4. Cation Exchange Capacity (CEC) of Crushed Basalt from Different Localities

For each of the basic cations analyses, the amount of the exchangeable cation increases as the particle size decreases until a maximum is reached; at this point the finer particle sizes do not appear to exchange more cations from their surfaces. Calcium attained the highest concentrations in the extracting solution of all the studied basalt (22- 12.59 cmol/kg) followed by Magnisum (3.3 -1.8 cmol/kg) of crushed basalt in the < 125 um size fraction (Fig 4). The average of the sum of the 4 basic cations (in cmol/kg of crushed basalt) for each of particle size fraction of the studied basalt provided a sound basis for determining the effective cation exchange capacity (ECEC) of the fraction. The trend shown in Fig. 4 is analogous to that shown for the individual cations. That is, the ECEC increases to a maximum as the particle size of the crushed basalt fraction decreases to > 125um. The particle size fraction with a modal diameter of <125um produced a lower excheangeable cations as well as ECEC compared with that of +125um, probably as a result of flocculation of colloids causing a reduction in the charge density on external surfaces [8] especially basalt of G. Abu Terrify, Suez as this basalt highly altered to clay minerals, calcite and zeolite. Based on Fig. 4, it is recommended that the basalt be crushed to particles with a diameter > 250 um. This will result in a finely crushed soil amendment with a range of particle sizes up to 250 um, and an ECEC (at pH~ 8) of 25 – 15cmol/kg of crushed basalt.

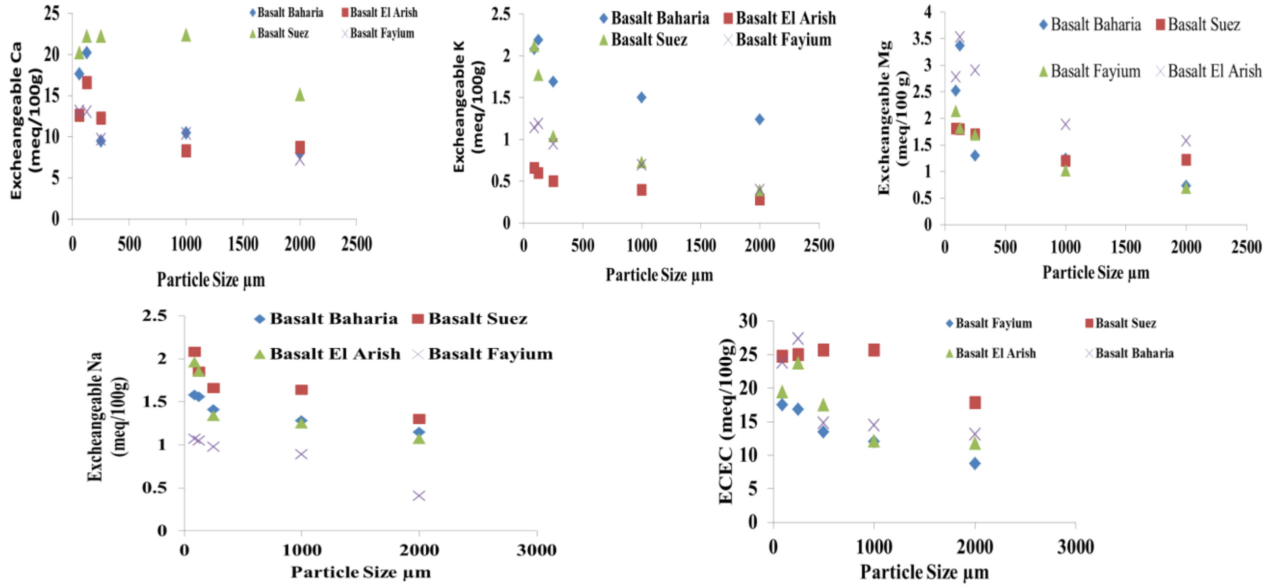

Fig. 4: Cation exchange capacity of studied basalt

3.5. Effects of Crushed Basalt on Soil Salinity

Table 3 showed the properties of studied saline soils after incubation with Fayium basalt. The salinity of sandy soil from Suez (Suez 2) decreased from 6.48 to<1 mS/cm. This decrease in salinity accompanied by decreasing all the cations concentration especially Na (decreases from 229 to 31 meq/.l) and Ca (decreased from 589 to 47meq/l). However, the decrease of salinity of clay soil from Kafre El Sheikh was lower compared with that of sandy soil from Suez (9.7 to 4.4).). However, pH of both soils increases due to dissolution of basalt and release of cations. The differences in decreasing salinity between the two types of soils incubated with basalt revealed the effects of soil texture.

Table 3: Effects of Fayium Basalt with Different Particles Size and Doses/Fertilizer on Salinity of Sand and Clay Soils

Meq/l	Suez soil + manure					Kafr El sheikh soil + manure				
	Soil	Size/Doses				Soil	Size/Doses			
	Suez 2	+125 µm/75g	+125µ m/300g	<4m/75g	<4m/300g	Kafre El Sheikh	+125 µm/75g	+125µm/300g	<4m/75g	<4m/300 g
Na	229.5	32.8	41.2	34.2	36.48	271.6	244	167.3	191.4	196.7
Nh4	-	1.98	2.73	3.3	8.89	7.58	-	3.48	-	-
K	13.2	19.47	15.9	31.2	18.83	20.4	86.8	21.9	29.4	24.77
Mg	119.3	21.97	29.05	22.6	30.04	50.36	16.9	28.46	45.8	34.2
Ca	589.6	47.1	66.5	58.1	99.15	52.12	52.2	34	54.15	35.9
Salinity	6.48	1.08	1.32	1.52	1.16	9.7	5.29	4.8	4.18	4.17
PH	7.48	7.7	7.84	7.78	7.93	7.61	8.04	8.18	8.03	8.1

4. Acknowledgements

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