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Volcanic Ash as a Material for Soil Conditioner and Fertility

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ABSTRACT

A field trail was conducted to test the effect of volcanic ash application on some soil properties and potato crop grown in The Res. Station, Fac. of Agric., Cairo Univ. located at Wadi El-Natron region, El-Behira Governorate, Egypt. The results show that iron oxides, silica and alumina represented 91.5, 6.0 and 2.5% of the total amorphous materials, respectively. Molar ratio of SiO_2/Al_2O_3 of volcanic ash was 2.08. Light minerals are mainly composed of feldspars and quartz and having a specific gravity less than 2.85 g/cm^3. Opaque, pyroxenes and amphibole heavy minerals represented about 70% of the total heavy minerals. kaolinite predominated the clay minerals followed by montmorillonite, while cholorite was detected in trace amount. Zeolite of volcanic ash has high alumina content and low Si/Al ratio (less than 4) which is considered a hydrophilic soil conditioner. The texture of volcanic ash is considered coarse with bulk density value of 1.36 g/cm^3 and total porosity value of 41.25% (65.90 % macro-pores and 34.10 % micro-pores). The electric conductivity (EC) of volcanic ash was low value (0.45) and reaction value (pH) of 5.9. There was no symptom of nutrients deficit in potato leaves or tuber as a result of using volcanic ash. Therefore, volcanic ash might be used safely to increase soil fertility and improve soil properties as soil conditioner. Moreover soil productivity might be augmented by applying volcanic ash to the soil

Keywords: Volcanic ash, soil fertility, soil conditioner, light and heavy minerals, potato crop.

INTRODUCTION

The volcanic ash (contains magmatic and non–magmatic minerals) not yet evaluate for affecting the human environment. There are two particular effects on human eco-system, one on soil, and the other on climate. Soils that contain clay minerals are thought to be generated by weathering magmatic fragments after precipitation. These clay minerals contain smectite, kaolinite, mica, etc. While non-magmatic minerals are produced during the interactions among volcanic gases, country rock and hydrothermal water (Giggenbach, 1997). Non-magmatic minerals are often regarded as magmatic volcanic ash such as Xenocrysts which derived from various depths from the mantle to the surface include quartz, feldspars, olivine, pyroxenes, amphiboles, hornnblends, garnet, alumino-silicates, carbonates, Fe-Ti oxide, and micas. Sulfide and sulfate minerals from active volcanoes are considered a vital tool to know the behavior of volcanic gas and magma (Hattori, 1997).

There is prolonged attention in estimating the heavy metal and trace element content of volcanic ash for a diversity of reasons. The inspiration stems from the aspiration to understand the geochemistry of volcanic ash in imbedded geological formations, the impact on seawater, and the possible release of toxic elements into the environment that may impact livestock grazing and water systems. Other elements, such as Zn, Cu, Cd, F, Pb, and Ba, are more willingly filtered into bodies of water and could be toxic to fish, flora, fauna, and wildlife (Smith *et al*., 1983). The presence of anhydrite ($CaSO_4$) in volcanic ash after eruption is a vital tool to understanding the opposing between the sulfur budget and excess sulfur gas emission (Luher *et al.,* 1984). In spite of trace elements form a little amount of the ash material, the amount of ash entering the ecosystem during a volcanic eruption makes even trace elements germane. While some elements create more fertile soil and aid in agriculture, other trace elements such as As, Cu, F, Mo, Ni, Pb, and Zn are prospectively toxic, when multipart with the fact that some elements are especially mobile, such as Ni, Zn, As and Mo. This can have harmful effects on the ecosystem over a huge area (Ruggieri *et al*., 2011).

This work was initiated to answer the question of could volcanic ash used as a source of elements for plants nutrition as well as if it could used as a soil conditioner to improve soil properties.

MATERIALS AND METHODS

Twenty five samples of volcanic materials (30 cm depth) from different locations around 6 km from the center of active volcano of Papandayan Mountain at Sirnajaya Village, Cisurupan, Garut District, West Java Province, Indonesia (Fig.1) were collected in January 2015. The samples were air dried, crushed and sieved at Faculty of Engineering, Cairo University. Then, all samples were mixed well to form one composite sample (≈ 60 kg) and it kept for different analyses.

Fig. 1. Satellite image of the studied area and the samples location (represented by red dot).

Location : Papandayan Mountain, Sirnajaya Village, Cisurupan, Garut District, West Java Province, Indonesia (-7.310195, 107.738063).

Altitude:2665 m Average temperature :10°C

Average rainfall :3000 mm/ year Average Humidity :70-80%

The composite volcanic ash sample was subjected to the following analysis:

Silicon was measured according to the method of Shapiro and Brannok (1956). Aluminum was determined using the method pointed by Jackson (1958). Free iron oxides were extracted by the selective dissolution method then iron was determined according to Mehra and Jackson (1960). Separation of heavy and light minerals of the sand fraction (125-63 micron) was carried out according to the procedure outlined by Brewer (1964). According to Beckhoff *et al.* (2006), X-ray diffraction (XRD) and X-Ray florournces (XRF) analysis were determined on powder sample of volcanic material (using optical emission spectrometer 8000 with effective wavelength range from 190 to 800 nm) at National Research Center, Giza, Egypt. The pH titration method was used to determine the exchangeable cation and cation exchange capacity as described by Coombs (1997).

A field trail was conducted to test the effect of volcanic ash application on some soil properties and potato crop grown in The Research Station, Fac. of Agric., Cairo University located at Wadi El-Natron region, Egypt. Some properties of both soil and the used volcanic ash were analyzed according to Page *et al*. (1982), Dewis & Freitas (1970) and Klute (1986). Calcium super-phosphate (15.5% P_2O_5) was added at a rate of 260 Kg/ acre during land preparation. Potatoes seed (Niqoula variety) obtained from a privet outlet were cut into 3 pieces, surface make germ-free then planted on 10th of October, 2015 at 80 cm away among lines and 50 cm space between tubers, then irrigated using drip irrigation system. Nitrogen fertilizer (ammonium sulphate, 20.5% N) at a rate of 240 kg/ acre was divided into three equal doses and was added at 30, 60 and 90 days after planting. After that, the field was divided into two strips (10 m width and 50 m length each) one as a control treatment and the other was treated by volcanic ash (≈ 30 kg/ strip mixed well with 30 cm soil surface). The control treatment received three doses (≈ 50 kg/ acre each) of potassium sulphate (48% K_2O) at the time of nitrogen fertilization. The mature plants were harvested on 30th January, 2016. Mean tuber weight was calculated by dividing the total tuber weight by tubers number. Leave samples were picked 80 days after planting oven dried at 70 °C for 24 hours. Determinations of N, P, K, Ca, Mg, Fe, Mn, B and Zn were carried out on the wet digestion of 0.2g plant material with sulphuric and perchloric acids was carried out by adding concentrated sulfuric acid (5ml) to the samples and the mixture was heated for 10 min. Then 0.5 ml perchloric acid was added and heating continued till a clear solution was obtained. The digested solution was quantitatively transferred to a 100 ml volumetric flask using deionized water as reported by Piper (1950).

Soil reaction (pH), salinity (EC) and soluble ions were measured in soil water extract (soil: water ratio 1: 5) according to Page *et al*. (1982). The total nitrogen content was determined by using the modified- micro-Kjeldahel method as described by Peach and Tracy (1956). Phosphorus was determined according to Jackson (1973). Potassium concentration was determined using flame photometer apparatus. Determinations of Si, Al, Na, Ti, Ba, Co, Cr, Ni, Ca, Mg, Fe, Mn, B and Zn in volcanic ash were determined using Atomic Absorption Spectrophotometer according to Piper (1950).

RESULTS AND DISCUSSION

Amorphous inorganic materials

Amorphous materials occur as a film coating on the surface of crystalline particles and play an important function in cementation and aggregations of soil particles. The initial stages of hydrolysis may form amorphous materials which may crystallize gradually to generate many new substances which migrated within the soils (Follet *et al.,* 1965 and Fitzpatrieck, 1980). The total amorphous materials in volcanic ash were about 3.5%. Free iron oxides were the upper trials component (3.2%) among amorphous inorganic materials followed by silica (0.2%) and alumina (0.096%). The iron oxides, silica and alumina represented 91.5, 6.0 and 2.5% of the total amorphous materials, respectively. The content of free iron oxides rendered to dominate igneous and metamorphic origin of parent materials. Molar ratio of SiO_2/Al_2O_3 of volcanic ash was 2.08. The lowest molar ratio of volcanic ash indicated few contributions of siliceous and alumina materials.

Light and heavy minerals of volcanic materials:

Light and heavy minerals were described to evaluate mineralogical characteristics of volcanic materials. Light minerals are mainly composed of feldspars and quartz and having a specific gravity less than 2.85 g/cm^3. The data in Table (1) shows that quartz forms 90.1% of the light minerals, while feldspars (orthoclase, plagioclase, and microcline) represented by 9.9%. They are found in igneous, metamorphic rocks, and accumulate in sedimentary environments as a result of weathering igneous and metamorphic rocks (Mason, 1966).

Table 1. Light minerals distribution in the sand fraction (0.25-0.063mm) of volcanic materials

Quartz	Feldspars (%)			
(%)	Orthoclase	Plagioclase	Microcline	Total
90.10	5.90	3.30	0.70	9.90

Data in Table (2) show that the content of opaque as heavy minerals (26%) depends mainly on the origin of parent materials which are derived from basement rocks (igneous rocks). The opaque's minerals consist essentially of iron oxides minerals such as hematite, illmenite, magnetite, and pyrite. The different among the heavy minerals was attributed to the wide variation of geologic origin of parent materials and the strength and intensity of weathering processes, such as erosion, transport and deposition which affect the relative proportion of heavy minerals in soils.

Table 2. Heavy minerals distribution in the sand fraction (0.25-0.063 mm) of volcanic materials.

Mineral			Content (%)
Opaque			26
Non-opaque	amphibole		18
	Pyroboles (pyroxene)		26
	Ubibuitous	zircon	0.08
		Tourmaline	0.04
		Rutile	0.02
	Parametamorphic	Garnet	0.03
		Staurolite	0.02
		Kyanite	0.01
		Sillimonite	0.01
		Olivine	0.01
		Epidote	0.02
		Andolosite	0.02
		Apatite	0.005
		Biotite	0.01
		Others	0.01

The non-opaque heavy minerals are represented by an assemblage that is rich in the ultra stable and Meta stable minerals of which the metamorphic minerals come from a good part. Opaque, pyroxenes and amphibole heavy minerals represented about 70% of the total heavy minerals. Zircon, tourmaline, garnet, epidote, rutile, andolosite, staurolite, kyanite, olivine, sillimonite, biotite and others are presented in little amounts. Apatite mineral was of less pronounced occurrence.

X-ray diffractogram (XRD) of the volcanic ash

X-ray diffractogram of volcanic ash illustrated that kaolinite predominated the clay minerals followed by montmorillonite, while cholorite was detected in trace amount (Fig. 2). The identified accessories minerals were mainly dominated by feldspars (plagioclase and orthoclase) followed by quartz, gypsum, aragonite, calcite, hematite, siderite, and anhydrite. Kaolnite was enhanced by hydromorphic conditions while montmorillonite occurrence confirms the contribution of water to minerals formation.

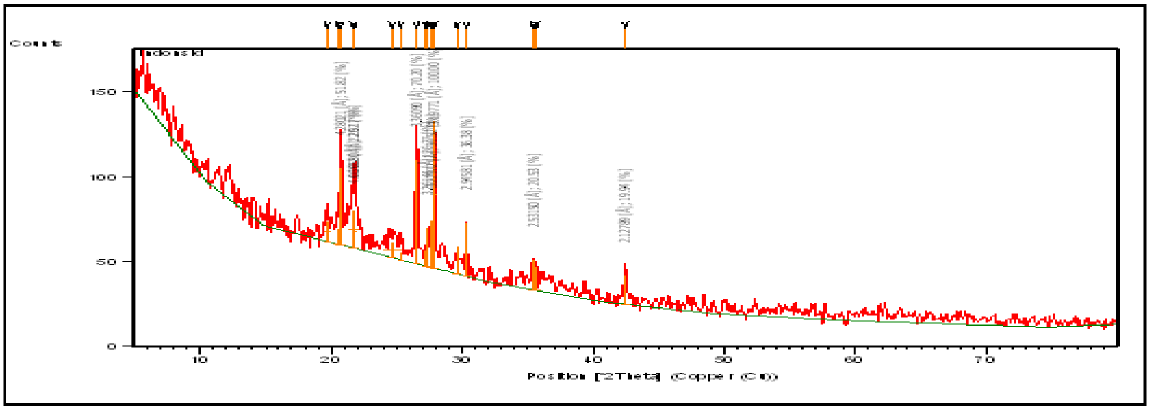

Fig. 2. X-ray diffractograms of non magmatic minerals in volcanic ash

X-ray florourntces (XRF) of the volcanic ash

X-ray florourntces (XRF) was used to distinguish whether the volcano materials contain zeolite type or not and whether it is hydrophilic or hydrophobic. The obtained results showed a high composition of silicon in volcanic ash (table 3). The ions of Fe, Al, Ca, Na, and K were the major single extra-frame work cations in the matrix of zeolite. Coombs (1997) pointed up that merely heulandite and clinoptilolite zeolites can only be differentiated on the foundation of the silica and aluminium framework. Heulandite exhibit Si/Al ratio ≤ 4 while Si/Al ratio of clinoptilolite show value > 4. All natural zeolites exhibit Si/Al ratio value more than 4 which is suitable for clinoptilolite type formation. Calcium, sodium, iron and potassium cations are the most plentiful solitary extra-framework in volcanic ash. Zeolite of volcanic ash has high alumina content and low Si/Al ratio (less than 4) which is considered a hydrophilic (Lee *et al*., 1999 and Hassan *et al.,* 2015).

Physical and chemical properties of volcanic ash

The physical properties of volcanic ash are shown in table (4) .The texture of volcanic ash is considered coarse with bulk density value of 1.36 g/cm^3. The recorded total porosity value was 41.25% with pore size distribution represented by 65.90 % macro-pores and 34.10 % micro-pores. This high porosity reflect the role of amorphous materials occur as a film coating the surface of crystalline particles and play an important function in cementation and aggregations of soil particles that could change pore space (Follet *et al.,* 1965). The field capacity (FC) and the wilting point (WP) values represented by 14.34 and 4.20%, respectively of soil moisture content (available water = 10.14%). This finding instructed that volcanic ash might be used as soil moisture retention (hydrophillic soil conditioner). In addition, hydraulic conductivity value of volcanic ash was 1.67 m/day which it is considered moderately rapid according to the classification of O°Neal (1952).

Table 3. X-ray florourntces (XRF) analysis of the volcanic ash.

Constituents (%)						
Si	Al	Ca	Na	Fe	K	Ti
29.65	14.8	7.89	4.56	21.50	1.87	0.19

Table 4. Some physical and chemical properties of volcanic ash.

Physical properties		Chemical properties	
Particle size distribution			
Coarse sand (2000-200µ)	59.75	EC dS/m (1: 5 soil : water)	0.45
Fine sand (200-20 µ)	30.15	pH (1:5) soil water suspension	5.90
Silt (20-2 µ)	6.10		
Clay < 2 µ	4.00		
Bulk density (g/ cm^3)	1.36	Soluble ions (meq./L.)	
Total porosity %	41.25	Ca	1.05
		Mg	1.69
		K	0.86
Pore size distribution (% of total porosity)		Na	0.90
Macro pores (>28.8 µ)	65.90	CO_3	0.15
Micro pores (<28.8 µ)	34.10	HCO_3	0.65
		Cl	0.90
		SO_4	3.20
Water holding capacity (WHC)	67.45	Total $CaCO_3$ (%)	0.30
Hydraulic conductivity (m/day).	1.67	Organic matter (%)	0.00
		Cation exchange capacity (meq./100g)	20.45
		Exchangeable cations (meq./100g)	
Field capacity (FC)	14.34	Ca	11.44
Wilting point (WP)	4.20	Mg	6.95
Available water (FC-WP)	10.14	Na	1.01
		K	1.05

Salinity expressed as electric conductivity (EC) of volcanic ash has low value (0.45) rendered to high intensity rainfall which leaching the basic cations from volcanic ash (Table 4). The major significant role of soil pH is on ion solubility, which in sequence affects plant growth and microbial activity. Volcanic ash reaction value (pH) was 5.9 (Table 4). In humid areas such as Indonesia, soils are liable to turn into more acidic ultimately because basic cations washed away via rainfall and replace them with hydrogen (Brady, 1990). Fine fractions (clay, silt, zeolite, and organic matter), are related closely to soils ion exchange properties (Wicklander, 1964). Volcanic ash could contribute to rise the cations exchange capacity (CEC) for surround soil attach volcano. From XRD analysis and XRF the results revealed that the volcanic materials contain clay minerals (kaolinite, montmorillonite, chlorite, and zeolite) are responsible for the quite high CEC value of volcanic materials which recorded 20.45 meq. /100g (Table 4).

Element composition of volcanic ash and soil

Data in Table (5) shows the element concentrations in both soil and volcanic ash. In general, silica and alumina represented the major components in both soil and volcanic ash since they form aluminium silicate minerals. Cations (K, Na, Ca, and Mg) concentrations were high in volcanic ash than those in soil. This might propose that addition of volcanic ash can resolve the defect of these cations in soil. Many of the elements found in volcanic ash have corresponding amount to those originate in soil. The concentrations of chromium and nickel elements in volcanic ash are lesser than those values frequently found in soil.

However, both are found at different concentrations in soil, and it is not very strange for soil to have less than 5 µg/g of Cr or Ni (Adriano, 1986). The trace elements that observed in ash are in similar to those concentrations found in soil. The concentrations of rare earth elements were similar in content to those found in crustal rock indicating there is no harmful effect from the point of environmental aspect.

Table 5. Elemental compositions of volcanic ash and soil.

Element	Soil (%)	Volcanic ash (%)
Si	45.68	48.00
Al	16.67	14.00
K	1.85	2.45
Na	2.79	3.24
Fe	10.65	9.05
P	0.34	0.13
Mg	0.45	1.13
Ca	0.33	1.50
Ti	0.49	0.63
Element	Soil (mg/g)	Volcanic ash (mg/g)
Ba	0.398	0.488
Co	0.014	0.015
Cr	0.041	0.033
Mn	0.278	0.365
Ni	0.019	0.010
Zn	0.129	0.135

Nutrients content of potato leaf and tuber

Data in Table (6) shows there was no symptom of nutrients deficit as a result of using volcanic ash. In general, the leaf nutrients content were superior in the control treatment compared to those in volcanic ash treatment .In the same sequence, all nutrient levels of potato leaves were within acceptable range for healthy plants growth.

Table 6. Some nutrients content in potato leaves under different treatments.

Treatments	Nutrients content percentage							Nutrients content (mg/ kg)			
	N	P	Ca	K	Mg	Na	SO4	Cu	Fe	Mn	Zn
Control	4.29	0.69	1.04	3.46	0.55	0.01	1.30.	12	95	83	37
Volcanic ash	2.08	0.50	1.57	3.06	0.37	0.03	1.65	9	84	61	23

The leave samples were picked 80 days after planting (80 DAP)

In general, tuber nutrients content were relatively higher in the control treatment than those in volcanic ash treatment (Table 7). It can be noticed that mixing volcanic ash with soil increased calcium level that seems to encourage tuber growth and yield. Walworth and Muniz (1983) found that calcium content of 0.02- 0.04 % is considered to be sufficient for the potato tubers. This might be attributed to the direct availability of calcium in volcanic ash which encourages the tubers to absorb it directly from soil solution (Olsen *et al.,* 1996 and Davies, 1998).

Control treatment realized a positive effect on growth traits since stem and leaves were larger, darker and thicker than those in volcanic ash treatment. Leaves dry mass were higher in control treatment than that in volcanic ash treatment by one and half fold. These findings indicated that the leaf dry mass positively responded to mineral fertilizer application (Adriano, 1986). Also, the tubers and total dry mass were higher in control treatment than those in volcanic ash treatment by one and half fold. The positive increase in the total dry mass rendered to mineral fertilizers are more impact than the corresponding amount of these nutrients found in volcanic ash material (Bennet, 1993).

Table 7. Some nutrients content in potato tuber under different treatments.

Treatments	Nutrients content percentage							Nutrients content (mg/ kg)			
	N	P	Ca	K	Mg	Na	SO4	Cu	Fe	Mn	Zn
Control	1.92	0.19	0.04	2.46	0.05	0.00	0.46	9.20	53.00	13.00	27.00
Volcanic ash	1.08	0.30	0.07	3.06	0.07	0.03	0.65	11.00	46.00	41.50	34.60

The tuber samples were picked at harvesting time (115 DAP)

The useful benefit of volcanic ash

Volcanic ash is of great significance regarding soil properties since they are controlled by dominated clay minerals. Volcanic ash contains clay minerals such as kaolinite, smectite, mica, montmorillonite and others. The cation exchange capacity of infertile soils may possibly boosted by using volcanic ashes. In addition, volcanic rocks have been considered as a source of soil fertility due to their moderately fast rate of releasing their contained nutrients. Very fertile agricultural regions are habitually resulting in young volcanic areas with weathered lavas and ashes. Also, volcanic ash could consider a media to increase soil water holding capacity. Moreover, volcanic ash materials would be deliberated to be agronomical valuable in traditional agriculture without environmental hazardous effects. Therefore, volcanic ash might be used safely to increase soil fertility and improve soil properties as soil conditioner.

CONCLUSION

The employ of volcanic ash as multi-nutrient rock silicate fertilizers, low-cost, and soil conditioner for agricultural improvement is helpful mean. Whole types of rock silicate fertilizers have the capability to furnish soils with a great variety of nutrients. Therefore, volcanic ash might be used safely to increase soil fertility and improve soil properties as soil conditioner. Moreover soil productivity might be augmented by applying volcanic ash to the soil.

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أجريت تجربة حقلية بمحطة البحوث بوادي النطرون التابعة لكلية الزراعة ، جامعة القاهرة بهدف اختبار تأثير الرماد البركاني على بعض صفات التربة ونمو محصول البطاطس. أظهرت النتائج أن أكاسيد الحديد والسيليكا والألومينا تمثل ٦.٠,٩١.٥ ,٢.٥% من إجمالي المواد غير المتبلورة على الترتيب فى الرماد البركانى. وقيمة ال Molar Rotio بين أكسيد السليكون واكسيد الالومنيوم فى الرماد البركانى ٢.٠٨ .وكانت معظم المعادن الخفيفة كوارتز وفلسبار. وتمثل المعادن المعتمة والبيروكسينات والأمفيبول حوالي ٧٠٪ من إجمالي المعادن الثقيلة. وكان الكاولينيت سائداًعلى معادن الطين متبوعاً بمعدن المونتموريلونيت بينما الكلوريت تواجد بكمية قليلة. الزيوليت فى الرماد البركاني به نسبة عالية من الألومينا وكانت نسبة Si / Al منخفضة (أقل من ٤) والتي تعتبر من محسنات التربة المحبة للماء. يُعتبر نسيج الرماد البركاني خشناً ذو كثافة ظاهرية تبلغ ١.٣٦ جم / سم ٣ ومسامية كلية ٤١.٢٥٪ (٦٥.٩٪ من المسام الكبيرة و ٣٤.١٠٪ من المسام الصغيرة).كانت قيمة التوصل الكهربائية (EC) للرماد البركاني منخفض (٠.٤٥ديسيمنز/متر) وقيمة الرقم الهيدروجيني(pH) (٥.٩). وقد أظهرت النتائج أنه لا توجد أعراض نقص للعناصر الغذائية على أوراق البطاطس أو الدرنات نتيجة لاستخدام الرماد البركاني. وعلى ذلك فإنه يمكن استخدام الرماد البركاني كمحسن تربة بدرجة آمنة لزيادة خصوبة التربة وتحسين خصائصها تعظيم انتاجيتها.