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Potassium Behavior with Clay Minerals Composition under Soil Ecosystem: it's Adequacy for Maize Plants

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Abstract

Purpose: The target area for the study is one of the agricultural areas of importance in Egypt. It is a suitable area for studying the origin and distribution patterns of clay minerals. Therefore, the focal aims of this study were: (1) to examine the clay minerals' origins in semi-arid regions of Egypt. (2) The behavioral pattern of K in clay minerals in ecological changes, (3) the reflection of K-behavior in soil on the maize plant's nutrient content under soil systems.

Methodology: Evaluation of water samples were: Evaluate the pH and EC, soluble ions, sodium adsorption ratio (SAR), soluble sodium percentage (SSP), sodium to calcium activity ratio (SCAR), residual sodium bicarbonate (RSBC), and residual sodium carbonate (RSC). Also, Evaluation of soil samples were: Evaluate the particle size distribution, OM content, soil pH, Gypsum, $CaCO_3$ content, cation exchange capacity (CEC), exchangeable sodium percentage (ESP), EC, soluble ions, Soil available K, exchangeable K, and total K. Separation of the clay fraction: preparation of soil samples for mineralogical analysis. Qualitative clay mineralogical analysis: X- ray diffactograms were obtained for some selected clay samples using Philips equipment pw (1140/90). Evaluation of plant samples were: Evaluate the N, P, and K concentrations. Statistical analysis: SPSS (v. 20) was used to determine the descriptive statistics and correlation analysis.

Findings: Achieving study aims, a series of methodological steps were implemented to study soil and water properties, and their reflection on maize plants. The irrigation water results analysis showed no problems. The soil properties were also distinguished by the results: common features of this type of soil are a depth of greater than 120 cm, a slightly well-drained clay texture, and poor OM content. The $CaCO_3$ content increases with depth. The available N, P, K were (slight to moderate, very low, and good) respectively. The EC values range from non-saline to moderate saline. As indicated, the X-ray diffraction patterns of the clay fractures are separated from those features. It appears from the analysis that the mineral composition of the clay fracture at both areas is dominated by montmorillonite, kaolinite, and then hydrated mica. Based on the studied soil characteristics, there was a reflection on the maize plant grown, which showed the following: A strong positive correlation between the soluble K content and K in maize plants at the age of 30 days. The multiple correlations were significantly positive between the N and P content available to the grain of maize plants. The results exposed a negative correlation between the available K and K content of maize plants at 45 days of age. Also, there was a significant negative correlation between the exchangeable K and K content in maize plants at 60 days of age.

Contribution to theory, practice and policy: The results presented the significant relationships between the evaluation of the physical and chemical properties of the soil, the content of available nutrients, as well as the type of soil minerals, and their reflections and contributions on the elements contained in the different parts of the maize plants (stems and grains), according to the state of the maize plants age.

Keywords: *K- behavior, clay mineralogy, physicochemical soil properties*, *maize*

INTRODUCTION

Currently, the challenges facing the agricultural development strategy in Egypt are managing arid and semi-arid regions. The area of Egypt is close to 1 million km^2. Egypt's physical is amid the extremely dry region extending from North Africa to West Asia, where the dry belt is, noting the scarcity of water resources. Efforts are being made through research into managing soil resources to keep up soil health and quality, enhance productivity and reduce water losses (Ahmed, 2015; El-Keblawy *et al*., 2016; Elnoby& Moustafa, 2017; Abutaha *et al*., 2019 and Maged *et al*., 2020). Based on the previous, soil managing efficiency must be improved by enhancing the soil's NPK content. Thus, helping the metabolism of nutrients in the plant, (John and Ron, 2020; Pellegrino *et al*., 2020 and Lisuma *et al*., 2020).

Potassium (K) is an essential nutrient for growing crop yields and enriching soil quality. The two K forms that are accessible to plants from the soil are exchangeable-K and soil solution K. Anywhere, K is an essential nutrient for crop production, especially in plant growth (photosynthesis, sugar transport, starch production in grains, protein synthesis) (Tilman *et al*., 1999; Zinabu, 2016 and Francis *et al*., 2020).

Clay minerals are formed due to the chemical decomposition of some rock-forming (2:1). Kaolinite $Al_2Si_2O_5\ (OH)_4$ consists of alternating Si and Al plates. *Montmorillonite* $(Na, Ca)_{0.33}(Al, Mg)_2Si_4O_{10}\ (OH)_{2.n}H_2O)$ has layers made of two Si plates and one Al plate. The bond between these layers is weak, so water easily enters the structure and separates them. *Illite* KAl4 $(Si,Al)_8O_{18}.2H_2O$ has layers made of two Si plates and one Al plate. *Illite* has layers similar to that of *Montmorillonite* but contains K^+ ions in between each layer. This property makes the clay structure stronger than *Montmorillonite*, but weaker than kaolin Clay minerals in the soil (2:1) contribute to the minerals. Common clay minerals are *Kaolinite* (1:1), *Illite* (2:1), and *Montmorillonite* availability of soil K. This is the significance of these clay layers. It depends on its ability to absorb and release K^+ from the interlayer layers, under the phenomenon of adsorption and release. Despite the contribution of mineral clay, the K interlayer of plant nutrition is often seen to be of minor importance, and it's now suspected that it may add a large part, if not the majority, of the K supply in many soils. Observing and assessing the interlayer for K dynamics is perhaps a key parameter for understanding the K soil cycle (Sardans & Peñuelas, 2015; Moterle *et al*., 2016; Paola *et al.*, 2016; Diovane *et al*., 2019, Dill, 2020 and Paolo, 2020).

Maize is one of the world's most important cereal crops, as it is the third most important cereal crop, as food for humans and livestock (Nurhanan and Wan, 2014). The optimum supply of NPK has an important role in the growth features of plants, as it contributes to the mechanisms of plant cells (Csaba *et al*., 2021). Several studies have highlighted K as a nutritive guarantor of production quality (grain weight, single grain weight, fresh corn yield). K fertilization up to 90 kg/ha showed improved growth and maize yield under semi-arid climates (Li Yang *et al*., 2021).

MATERIAL AND METHODS

1. Studied area explanation:

Location: The study area covers the governorates of Gharbia and Menoufia (Fig. 1), which follow the central Nile Delta region. The area is about 450 km^2 (44320 hectares). The climatic conditions prevail in the Mediterranean region (moderately dry summers and moderately cold and humid winters). The region produces crops such as maize, wheat, potatoes and green beans, a large part of which is exported. The agricultural land is irrigated by the waters of the Damietta branch of the Nile. The sediments covering the study area are mainly alluvial deposits formed by the sedimentation processes of the Nile River. It consists of silt or clay that contains a high content of clay minerals (Ibrahim *et al.*, 1993 and Moataz & Ahmed, 2018).

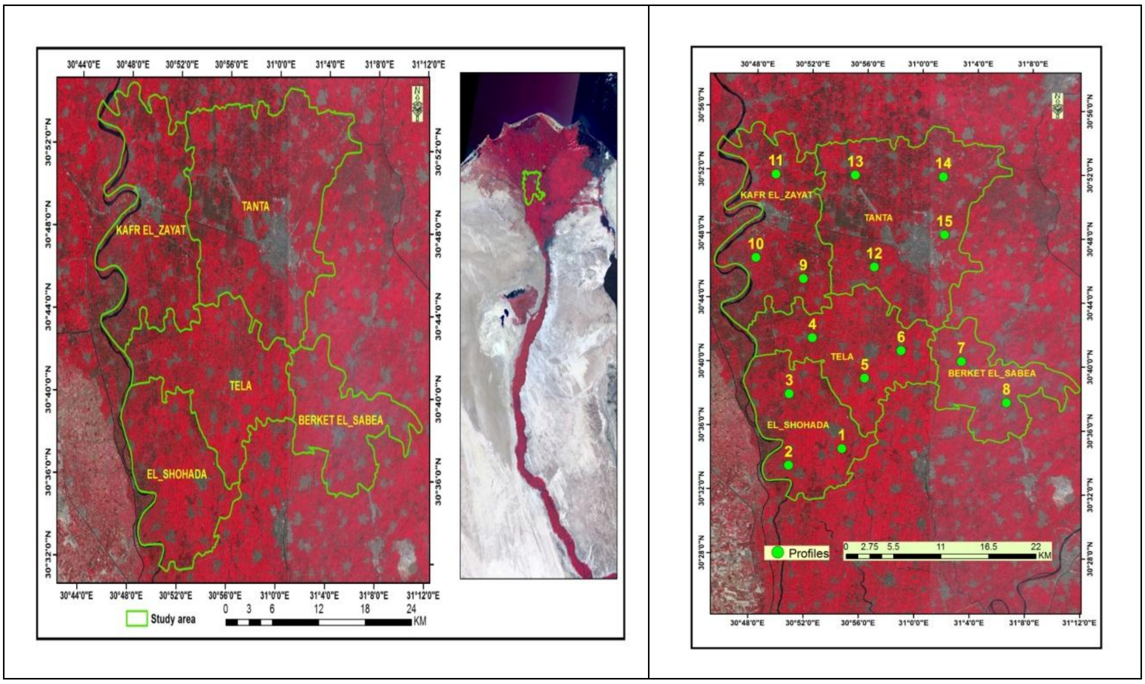


***Fig. (1)*: Map explained to the study area and the profiles represented by them.**

2. Sampling:

The fifteen samples of irrigation water were collected. Samples were taken during the season (March 2021). Polyethylene bottles fitted with a stopper (1-liter capacity) were used to provide water samples, with appropriate temperatures (<4°C). The fifteen samples soil profiles (different depths) were also collected. Also, fifteen samples of maize plants were collected. After sampling, the samples were transferred to SWERI-ARC for analysis, Table (1).

RESULTS AND DISCUSSION

Characterization of the studied irrigation water: Irrigation water quality has an imprint on agricultural soil managing; moreover, the productivity of the cultivated land is related to the soil quality and irrigation water. The measurement of the soluble ions in irrigation water samples, the most important factor of water quality on crop yield. In table 2, water pH was ranged amid 6.78 to 7.31. Based on the results, the EC_w was slight to moderate, with the ranged amid 0.97 to 2 dS/m. Where soluble salts were dominant ($NaCl$, $NaSO_4$, $CaCl_2$, $CaSO_4$), the SAR value was <10, which indicates that all the studied samples are in good condition, agree with me (Mahmoud *et* al., 2020; Abdelhafez *et al.*, 2020 and Abu-Hashim *et al.*, 2021). The SSP was safe (range between 41.15 to 63.43 mmolc L^{-1}), with a little Na accumulation, that allow soil physical properties to be broken down. In addition to, irrigation water categorized was non- sodicity water (SCAR < 5). Based on the results of irrigation water analysis, there are no problems, and the effects of Na are multiple, such as the specific nature of plant toxicity, poor soil drainage, and plant nutrition imbalance. That is the higher the Na content in the irrigation water, the higher the exchangeable Na content in the soil exchange complex, and the soil dispersal more quickly. The dispersed soil particles close the large pores of the soil, and reduce the permeability of the soil. In these conditions, the water availability of the plant is also significantly reduced.

Characterization of the studied soil:

- ***Physical characterization***: The study area is considered as a Vertisol profile is given in table (3). The dominant plants cultivated in this area are rice, maize and vegetables. The physiochemical of the soil properties are determined and shown in Table 3. The joint features of this soil type with a depth of > 120 cm, and clay texture with slightly well-drained. It's clear that the clay ratios in the layers meet the requirements of Argillic horizons, but under soil forming factors prevailing in Egypt, it is doubtful whether they exist.
- ***Chemical characterization:*** In table 3, the CEC of the soil correlates with the clay content. The exchange characteristics of the soil in this study dictate that the values of CEC are high, and are well in line with the soil texture, ranging from 23.96 to 48.66 $cmol_c\ kg^{-1}$. The absorptive capacities of soil surfaces are the effective CEC. So, this signifies the total of exchangeable cations, which soils can absorb on their surfaces. The cations such as Na^+, K^+, Mg^{2+}, Ca^{2+}, Mn^{2+}, Fe^{2+}, H^+ are usually adsorbed on (–) charged soil surfaces. At low pH, it is the permanent charges of the type 2:1 clay that absorb the replaceable cations. With soil pH, (+) charged ions are adsorbed onto charge-changing surfaces such as 1:1 clay, clay, SOM, iron oxides and oxides (Weil & Brady, 2016 and Emily *et al.*, 2020). Soil pH specifically controls the amount of (-) charges on soil surfaces with a variable charge: either through protonation or H^+ de-protonation of hydroxyl groups on soil surfaces.

The results showed that the SOM content is weak, where the values range from 0.39 to 0.94%. It is possible that the decreasing OM behavior is related to the arid climate, also, burning the remnants of the local vegetation cover, and some poor agricultural practices, such as plowing the soil, and thus breaking the soil aggregates. Including exposing the protected SOM to the influence of microorganisms, as well as wasting the underground carbon stock from the vegetation cover (Zhang *et al.*, 2018, Santana *et al*., 2019 and Aldair *et al.*, 2021).

The results indicate that these soils are slightly and moderately calcareous, where the $CaCO_3$ content varies widely from 2.70 to 5.69%. The values increase with depth. Recently, they described the impact of clay minerals on CO_3 nucleation. The presence of *montmorillonite* began in the form of *calcite* at minor saturation levels than in the form of *quartz* or *kaolinite* (Kralj and Vdović, 2000). The mica surface templated the oriented advance of *calcite*; furthermore, the heterogeneous surface performed to enhance Mg^{2+} combination into the *calcite* structure **(Xu *et al.*, 2018)**. The attendance of clay minerals promoted the construction of very high-Mg *calcite* or *protodolomite* through the maturation of the caused materials at a high (8:1) Mg: Ca molar ratio (Liu *et al.*, 2019, Liu *et al.*, 2020, and Aboukota *et al*., 2021).

- ***Elements status characterization***: In table 3, the study showed that the N content decreased with the vertical increase in soil depth, where the values ranged from 64.75 to 111.50 mg/kg (slightly to moderately). The N content in the soil depends on several factors, most notably: the confounding effects of climate, vegetation cover, and land use; also, in the case of SOM. The most important explanations for N loss in the studied soil samples were *leaching* (as a result of flood irrigation), *denitrification* (a bacterial process that converts NO_3-N to N gases which are lost in the atmosphere), and *volatilization* (as a result of climate), and the lack of recycling of crop residues.

The results of this study showed that P content ranged between 2.25 to 3.47 mg/kg (generally very low). The level of P in the soil is an important factor affecting crop production, and the quality of its content. The study indicated that the studied semi-arid soil is supplied with available K, and its content ranges between 427.37 and 488.93 mg/kg. A large proportion of K is present in the semi-arid soil system, as a mineral form followed by an inner layer, which is immutable and soluble in water. These forms are related to each other by sand and silt fracturing, and K resistance to depletion, as explained (Jordi and Josep, 2021). And add the results of analysis that the K exchangeable ranges between 0.37 to 0.72 cmol kg^{-1}.

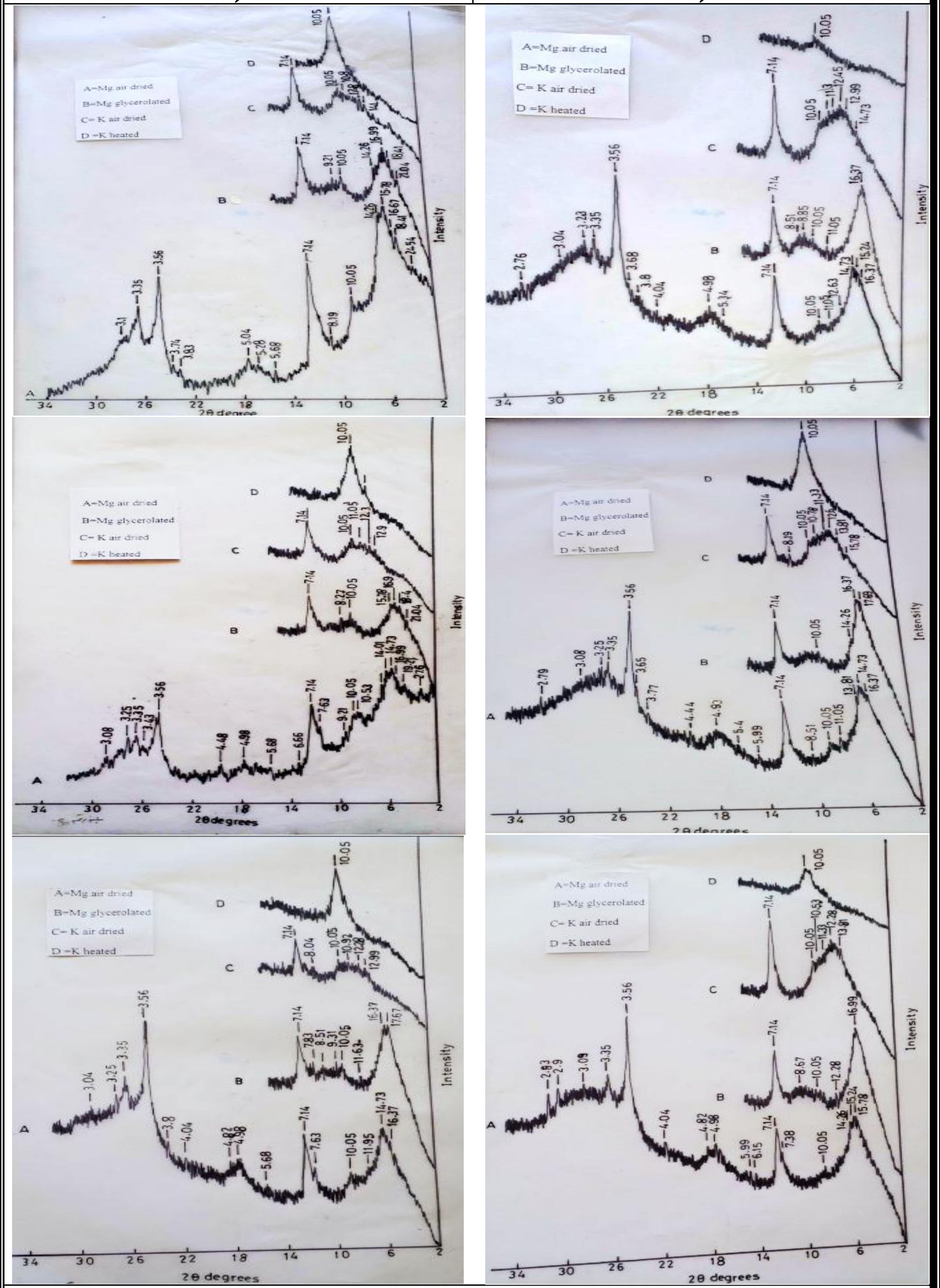
The results indicate the necessity of using OM such as animal manure and crop residues, as they improve the structural and chemical properties of the soil, and replenish nutrients such as (N, P, K, Fe, Mn, Zn, and Cu). These changes also increase the soil's water holding capacity and allow for better root penetration and aeration (Richard *et al.,* 2006 and Abdellatif *et al.,* 2021). Soil fertility Degradation is the weakening of the elemental content of dry land. As well, it includes man-made issues, the many ways soil fertility is degraded. While some physiochemical factors are involved, a significant aspect is misuse. Soil poor managing of soil and irrigation increases the pace of soil degradation (Ali *et* al., 2020 and Abu-Hashim *et al*., 2021).

- ***pH soil and soluble ions status characterization***: in table 4, as indicated by pH values that range from 7.40 to 8.36, the soil reaction ranges from slightly and moderately alkaline. Nutrient availability is hampered if the soil pH is not within the optimum level range. The relatively slightly and moderately EC values in these soils with high content of fine fractions of silt and clay are generally affected by the particle size distribution of texture. EC values vary from 1.88 to 7.54 dS m^{-1} based on soil texture, suggesting non-saline to moderate saline values. The results showed the main source of salt ions in the studied soil, it was related to the origin of the soil, semi-arid climate, and human practices, too to the lack of attention to the quality of drainage. The results indicated that the predominant salt ions on a large scale are Na^+ followed by Ca^{2+} among cations, and Cl^- followed by SO_4^{2-} among anions. With the Na accumulation, we also observed a high concentration of $Cl^-$and SO_4^{2-}in the soil by NaCl and Na_2SO_4, respectively. Previous studies have shown the adverse effects of $Cl^-$and SO_4^{2-}accumulation on soil structure. We observed a high concentration of Ca^{2+} and Mg^{2+} ions in the exchange complex, in contrast to Na^+, which accumulated significantly in the soil solution. This reflection can also be clarified by the higher obligatory capacity of divalent cations at the interchangeable sites compared to monovalent cations. (FAO, 2019 and Irakoze *et al*., 2021). ESP is an indicator of soil sodicization. When this value > 15%, the physicochemical properties of the soil and the nutrition of crops are affected. The results of the analysis showed that the values ranged from 0.88 to 22.95% (Lam and Tran, 2021).

***The* relationship mechanisms between clay minerals and soil characterization in the studied area:** X-ray diffraction study is one of the tools for defining clay and non-clay minerals. The clarification of the X-ray diffraction form on the presence of diffraction peaks characteristic of each of the crystalline species present in the sample. The intensity and sharpness of the peaks are affected by many factors, such as the content and fineness of the crystals, crystal imperfection, degree of disordering, amorphous material content, and the presence of a layer of less lattice silicate, for example, quartz. The diagnostic criteria used to identify clay minerals and added minerals are those described by (Pierre *et al*., 2008; Jin *et al*., 2018; and Nabeel *et al*., 2021). The X-ray diffraction patterns of clay fraction separated from the studied *Vertisols* indicate great similarity in the clay mineralogical composition of all studied *Vertisols*. Thus, only the mineralogical composition of the clay fractions of the *Haplotorrerts* great group will be discussed here. The X-ray diffraction patterns of the clay fractions separated from those profiles are shown in figure (2). It appears from the figures that the mineralogical composition of the clay fraction in both locations is dominated by *Montmorillonite*, followed by *Kaolinite* and then *hydrous mica*. *Chloride* is found in the clay fraction of some layers (0-35cm & 75-135cm) in profile 3. As specified by the stable diffraction pattern at 14.2Ao in all treatments. Also, the appearance of a diffraction peak at 7.12Ao in K-saturated and heated to 550oC as a second order confirms its presence. *Quartz* and *feldspar* minerals are present in a minor amount in all clay samples. In all layers of profile 12 were aboard, diffraction patterns in K-saturated air dried at 10-14Ao showed the presence of *Chloritized Montmorillonite*. K fixation transpires when K^+ ions form a surface complex with O_2 atoms in the interlayers of certain silicate clay minerals. Portions of the K held among the layers of clay, such as *smectitic* clay (*montmorillonite*), will willingly prolix back into solution as the K is depleted by reason of plant uptake or leaching. But other soil minerals, mainly vermiculite, will powerfully complex K in the interlayer, releasing it only slowly back into solution.

K is combined chemically with many minerals. There are 3 groups of K-containing minerals: 1) clay minerals, in which K is any present in the mineral composition or absorbed into clay particles; an example is *illite*. The K content varies in clay minerals: *illite* has a high content (3.5-8.3%), but *kaolinite* has a low content. 2) rock forming minerals, where K is chemically combined into the mineral structure, such as K-feldspar (*orthoclase* $KAlSi_3O_8$, *microclean* $KAlSi_3O_8$) and mica (*biotite, muscovite*). 3) It evaporates, where K is chemically extant as a salt (*KCl, carnallite KCl,* $MgCl_2 (H_2O)_6$). As reported by Atsuyuki (1983) and Al-Alawi *et al.*, (2020) The K-*montmorillonite* and K-*vermiculite* fixed great quantities of K even at 25˜ Fixed K in *moutmoriuonite* increased with the layer charge increase, which is too prejudiced significantly by the interlayer cation, the behavior in K-fixation was exact for both clays. The type of mechanical transformation with K-fixation was altered for clay. In *montmorillonite*, mainly, the type of transformation was correlated to the cationic composition of the system; in the K *homoionic* system, *montmorillonite* transformed rapidly into *iUite/montmorillonite* with about 40% stretchy layers at 300˜, and in a mixed cation structure through Ca and K, it re-joined regularly to random *illite/montmorillonites* at increasing temperature. These data specify that the cation-exchange method of a normal pore solution plays a significant role in the regular alteration. Interstratification and layers of added minerals through *kaolinite* can influence the heights of exchangeable and nonexchangeable K and Mg in soils. The K and Mg content of well-crystallized *kaolinites* are generally very low. Regardless of the parent material, the increase in weathering and high *kaolinite* clay content in part due to a superior degree of crystallization of *kaolinite* in the samples studied. The increased Cl may be due to the presence of suitable conditions for crystal development of *kaolinite* in a nearly mono-mineralic environment (Melo *et al*., 2001).

Profile 3 (0-35), (35-75) and (75-135)cm	Profile 12 (0-35), (35-85) and (85-135) cm



**** For clarification :** Fixation occurs when K is held in highly charged sites in the interlayer region of vermiculite and mica minerals. This differs from exchangeable K which is held at lower charged sites, on the surface and edges of clay minerals such as *kaolinite* and *montmorillonite*, source: **(Stuart *et al.*, 2011)**

***Fig. (2)*: X- ray diffraction pattern of the clay fraction separated layers of profiles no 3 and 12.**

The relationship between soil characterization and the macro-nutrient content of the maize plants: K is a macro nutrient needed for the proper growth and sustainable productivity of crops. Also, K increased the yields and growth of plants under drought stress conditions. Thus, the application of K has been proposed as an approach to reduce water scarcity in the maize crop (Muhammad, 2020).

The results of the analysis of macro-nutrients (NPK) in maize plants indicate that during the age stage of 30 days, the level of the nutrients is good, and gradually decreases between 45 and 60 days. The explanation for this is for the following reasons: The maize variety grown in the studied area is "Giza 10". The soil was prepared before planting, where (300 kg of $CaH_6O_9P_2$ 15.5% was added, and some farmers added 120 kg of Ca $(H_2PO_4)_2$ 37.5% + 100 kg of K_2SO_4 + H_3PO_4 with irrigation water + 15 m3 of organic fertilizer)/feddan. The planting was carried out in mid-April 2021, after harvesting the winter crops (wheat and beans), and farmers were chosen for this variety because it is resistant to late wilt disease; planting at distances of 20 to 25 cm between plants. The crop was thinned at about 3 weeks of age, leaving one plant. Fertilization was done in three batches (a batch after a week of planting-a batch at the age of 21 days after the first batch-a batch at 35 days after the second batch). The fertilization was 350 to 450 kg/feddan of NH_4NO_3 33.5%, (120 to 150 N units). The farmers indicated that recently, liquid N fertilizer was used due to "low cost, ease of use, and considered a stimulating dose for root growth, and raising the efficiency of its uptake". The fertilization program ends at flowering, based on the references of the Egyptian Ministry of Agriculture and Land Reclamation, with a production rate of 12 to 15 kg/feddan.

In table 5, the maize plant stem had N content at the age of 30 days ranged between 0.729 to 0.891 %; at the age of 45 days, between 0.721 to 0.809 %, and at the age of 60 days, between 0.522 to 0.611 %. The P content at the age of 30 days ranges between 0.125 to 0.152 %; at the age of 45 days, between 0.175 to 0.235 %, and at the age of 60 days, between 0.022 to 0.110 %. Besides, the K content at the age of 30 days ranges between 0.729 to 0.891 %; at the age of 45 days, between 0.721 to 0.809 %, and at the age of 60 days, between 0.522 to 0.611 %. The uptake of NPK in the maize plants decreases at the maturity stage, agrees with me (Csaba *et al*., 2021). Moreover, the results indicated that the maize grain content of N, P, and K were (0.819 to 0.922 %, 0.113 to 0.152 %, and 1.464 to 1.844 %), respectively.

In table 6, the statistical analysis exhibited that there is a strong significant positive correlation ($r= 0.523^{*}$) between soluble K and K content of maize plants stems at 30 days of age, which explains the plant's health for the next life stages. The multiple correlation coefficients were highly positive and significant between the available N and P content of maize grain ($r= 0.546^{*}$). When the available N percentage in the soil increased, this managed to increase the P content of the grains. In this case, the analysis showed that the content of the soil from the facilitated N increased the plant's ability to uptake the elements, which was reflected in the grain P stock. The results highlighted that there is a strong negative significant correlation between available K and K content of maize stems at 45 days of age ($r=-0.682^{**}$). Furthermore, a negative significant correlation between exchangeable K and K content of maize plants stems at 60 days of age ($r=-0.568^{*}$). In this regard, the behavior of two nutrients may be attributed to the phenomenon of antagonism, the competition between any two elements, which greatly depends on element concentration and solubility in which one element may restrict the other one. Moreover, the phenomenon of element selectivity of plant root cells must be put into consideration when discussing nutrient mobility accumulation and behavior; it was reported (aboukota, 2016).

The study showed that maize plants have NPK necessity at different growth stages. P and N must be provided to the plant immediately after germination to start the growth of stems, leaves, and buds. The present results indicate that K has full effect on the growth stages (leaves, stems, and grains). The highest K uptake occurs in the sowing stage, and the results are bright.

CONCLUSION

Recently, the new agricultural policy has focused on water and soil conservation. Reduce the negative effects, and maintain and increase production; further, support food security, within a broad perspective of sustainable development. Therefore, the research turned to an integrated study between irrigation water, soil properties, and strategic plants (maize). There is now a growing realization of the need for an integrated study of the ecosystem to maintain and increase the quality of production. To achieve this, a series of methodological steps were implemented to study the soil and water properties, and their reflection on the plants. The main results that have occurred in the study context are that the study area is irrigated by a surface irrigation system. The water properties are characterized as the results of irrigation water analysis. There are no problems. The soil properties were also characterized by the following; the joint features of this soil type with a depth of > 120 cm, and clay texture with slightly well-drained. The OM content is weak; the $CaCO_3$ content increases with depth. The case of available soil elements was (N was slightly to moderately, P was very low, and K was good content). EC values vary from non-saline to moderate saline values. X-ray diffraction patterns of the clay fractions separated from those profiles.

It appears from the analysis that the mineralogical composition of the clay fraction in both locations is dominated by Montmorillonite, followed by Kaolinite and then hydrous mica. Based on the studied soil properties, there was a reflection on the maize plant grown in the study area, which showed the following: a strong significant positive correlation between soluble K and K content of the maize plant stem at 30 days of age. The multiple correlation coefficients were highly positive and significant between the available N and P content of maize plants grain. The results highlighted that there is a strong negative significant correlation between available K and K content of maize plants stems at 45 days of age. Also, a negative significant correlation between exchangeable K and K content of maize plants stems at 60 days of age. From the above, the study added important recommendations for farmers, namely:

- It's recommended to fertilize the clay soil under study, with KNO_3 fertilizer. From the results, it was observed that the adding of KNO_3 salt reduces soil ductility, CEC, and water holding capacity within the soil structure. The optimum concentration was 5% of KNO_3, and the inclusion of KNO_3 closed some of the large pores in the soil structure, resulting in a change in the pore size distribution.
- We also recommend conducting more studies, including "cost-benefit analysis regarding the effective use of mineral fertilizers by farmers".
- The use of compounds that contain a high percentage of carbohydrates, to expand the carrier vessels in the plant.

- Attention to K fertilization before flowering and after the decade, while reducing N fertilization, so as not to cause weak vertical growth.

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Table (1): Methods and reference for analyzes of water, soil, and plant samples for the study area.

Water Analysis		• The research highlights the water characteristics used in irrigation for the study area. To find out the influences of the ecosystem. Thus, 5 samples were taken from irrigation sources, and the following was studied: pH and EC were measured in situ, and Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}, and SAR were determined in the lab and the techniques described in (APHA, 2012 & Rakotondrabe *et al.*, 2018). $$\mathbf{SAR = Na^{+} / ([Ca^{2+} + Mg^{2+}]/2)^{1/2}}$$ • Soluble sodium percentage (SSP) was calculated by the formula of (Todd, 1980). $$\mathbf{SSP = Na^{+} / (Na^{+} + K^{+} + Ca^{2+} + Mg^{2+}) \times 100}$$ • Sodium to calcium activity ratio (SCAR) and Residual sodium bicarbonate (RSBC) were calculated by the formula of (Gupta, 1990). $$\mathbf{SCAR = Na^{+} / (Ca^{2+})^{1/2}}$$ $$\mathbf{RSBC = HCO_3^{-} - Ca^{2+}\ (ion\ concentrations\ in\ mmol_c\ L^{-1})}$$ • Residual sodium carbonate (RSC) method according to (USDA, 1954). $$\mathbf{RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})}$$
Soil Analysis	**Physical**	• Particle size distribution was assessed by the *Pipette* Method by **Piper (1950).**
	Chemical	• OM was determined by the *Walkley and Black* according to the method outlined by Jackson, (1967). • Soil pH was measured in 1:2.5 soil water suspensions; (Van Reeuwijk, 1993). • Gypsum was measured according to Schoonover, (1952). • $CaCO_3$ content was measured according to Wright, (1939) where was determined by *Collins Calcimeter*. • CEC was determined according to (Bower *et al.*, 1952 and Rhoades, 1982). • ESP is calculated by the formula of (Allison *et al.*, 1954). $$\mathbf{ESP = 100(-0.0126 + 0.01475 * SAR)/1 + (-0.0126 + 0.01475 * SAR)}$$ • EC and soluble ions were measured according to (Page *et al.*, 1982 & Frankenberger, 1996). • Soil available K was determined according to Soltanpour and Workman (1985). • Evaluate the K status of these soils: exchangeable K by 1 M CH_3COONH_4 buffered at pH 7 (Jackson 1973); non-exchangeable K by 0.7 M H2S04 and hot I M $HN0_3$ (Knudsen *et al.*, 1982), and total K by method (Buckley and Cranston 1971).

Soil Mineralogy	▪ **Separation of the clay fraction:** preparation of soil samples for mineralogical analysis was carried out according to Jackson, (1975). Removal of carbonate and divalent cations was carried out by treating soil samples with *Sodium Acetate* solution (1.0 N pH= 5). Then *Organic Matter* and *Manganese Oxides* were removed by digesting the samples in *Hydrogen Peroxides* 30%. This is surveyed by free *Iron Oxide* removal which was carried out by *Sodium – Dithionite - Citrate* following the methods of (Mehra and Jachson, 1960). Clay fractions (< 2.0 µ) were separated by sedimentation and decantation method. Then air dried and kept for further clay minerals identification. ▪ **Qualitative clay mineralogical analysis:** X- ray diffactograms were obtained for some selected clay samples using Philips equipment pw (1140/90). Each oriented clay samples was subjected to X- ray after the following treatments. 1. Mg- Saturated air dried. 2. Mg- Saturated air dried + Glycol solvated. 3. K- Saturated air dried. 4. K- Saturated and heated to 550 ^oC for 2 hours. Interpretation of X- ray diffractograms was carried out according to Brown, (1961), Jackson, (1965) and Dixon and Weed, (1977)
Plant analysis	▪ Available N was determined by *Kjeldahl method* and P content assessed by the *Chlorostannous Molybdophosphoric* method in H_2SO_4 (Piper, 1944). K concentration was measured by *Atomic Absorption Spectroscopy* after *tri-acid* (HNO_3: H_2SO_4: $HClO_4$ in the ratio of 10:1:4) digestion, (Bray and Kurtz, 1945).
Statically analysis	▪ SPSS (v. 20) was used to determine the descriptive statistics and correlation analysis, and its technology has made difficult analytical tasks easier through advances in usability and data access, allowing more people to benefit from the use of quantitative techniques in making decisions (SPSS, 2015).

Table (2): Chemical characterization of irrigation water for the studied area.

Samples No.	pH	EC dS m^{-1}	Soluble ions (mg/l)								SSP	SCAR	RSBC	RSC meq/l
			Ca	Mg	K	Na	Cl	HCO_3	SO_4	SAR				
1	6.78	1.00	3.08	1.29	0.13	5.50	6.98	0.20	2.82	5.26	55.00	3.13	-2.88	-4.17
2	7.12	1.54	6.54	0.74	0.23	7.89	9.01	0.45	5.94	5.85	51.23	3.09	-6.09	-6.83
3	7.08	1.89	6.31	3.04	0.44	9.11	10.65	0.36	7.89	5.96	48.20	3.63	-5.95	-8.99
4	6.88	1.08	3.20	0.64	0.11	6.85	6.00	0.38	4.42	6.99	63.43	3.83	-2.82	-3.46

5	7.00	0.97	3.39	0.83	0.17	5.31	4.76	0.25	4.69	5.17	54.74	2.88	-3.14	-3.97
6	7.04	2.00	7.28	4.72	0.34	7.66	12.32	0.51	7.17	4.42	38.30	2.84	-6.77	-11.49
7	7.21	1.36	3.93	1.97	0.13	7.57	8.15	0.44	5.01	6.23	55.66	3.82	-3.49	-5.46
8	7.00	1.62	5.39	3.75	0.04	7.02	11.11	0.42	4.67	4.64	43.33	3.02	-4.97	-8.72
9	6.91	1.08	3.53	1.11	0.36	5.80	7.00	0.45	3.35	5.39	53.70	3.09	-3.08	-4.19
10	7.23	1.22	4.31	2.52	0.35	5.02	9.87	0.51	1.82	3.84	41.15	2.42	-3.80	-6.32
11	7.22	0.99	2.67	1.98	0.21	5.04	5.21	0.50	4.19	4.67	50.91	3.08	-2.17	-4.15
12	6.98	1.29	3.31	2.75	0.01	6.83	8.80	0.37	3.73	5.55	52.95	3.75	-2.94	-5.69
13	7.00	1.77	5.85	3.37	0.13	8.35	9.81	0.28	7.61	5.50	47.18	3.45	-5.57	-8.94
14	7.10	1.23	3.30	1.83	0.23	6.94	8.65	0.33	3.32	6.13	56.42	3.82	-2.97	-4.80
15	7.31	2.00	6.60	3.75	0.46	9.19	12.19	0.38	7.43	5.71	45.95	3.58	-6.22	-9.97

- **SSP**: concentrations of all ions are determined in mmolc / L. Water containing SSP less than 60 is safe with a little sodium accumulation that allow soil physical properties to be broken down (Fipps, 1998).
- **SAR**: concentrations of all ions have been indicated in mmolc / L. The SAR categories are, low, S1 (<10); moderate, S2 (10–18); high, S3 (18–26); and very high, S4 (>26), (USDA, 1954).
- **SCAR**: On the basis of SAR/SCAR, the irrigation water may be categorized in six categories of sodicity, non-sodicity water, S0 (<5); normal water, S1 (5-10); low sodicity water, S2 (10-20); moderate sodicity water, S3 (20-30), high sodicity water, S4 (30-40) and very high sodicity water, S5 (>40), Gupta (1990).
- **RSBC:** Depending on RSC/ RSBC ratio there are six alkalinity groups as the following: non-alkaline water, A0 (negative value); normal water, A1 (zero value); low alkaline water, A2 (2.5); moderate alkaline water, A3 (2.5-5); high alkaline water, A4 (5-10) and very high alkaline water, A5 (>10), Gupta (1990).
- **RSC:** concentrations of all ions have been expressed in mmolc L-1. RSC categories are no-hazard (<1.25), moderate hazard (1.25-2.5) and extreme hazard (>2.5), (USDA, 1954).

Table (3): physiochemical properties and element of the studied soil profiles.

Prof	Depth cm	Physical Soil Properties				Chemical Soil Properties			Available& Exchangeable Elements			
		Particle size distribution %				CEC cmolc kg-1	OM %	$CaCO_3$ %	N mg/kg	P mg/kg	K mg/kg	*$K_{exch.}$ cmol kg^{-1}
		Sand	Silt	Clay	Tex.							
1	0-35	7.25	30.98	61.77	C	33.09	0.57	2.70	89.54	2.49	441.35	0.58
	35-80	5.69	32.00	62.31	C	25.97	0.53	2.84	84.14	2.51	458.29	0.59
	80-120	10.25	35.25	54.50	C	46.79	0.44	2.90	79.97	2.53	460.93	0.58
2	0-35	6.36	33.58	60.06	C	29.03	0.94	3.91	97.58	2.47	463.16	0.55
	35-85	6.36	32.01	61.63	C	29.03	0.81	4.27	97.84	2.55	466.35	0.67
	85-125	6.33	33.21	60.46	C	28.89	0.56	4.27	83.03	2.47	458.37	0.71
3	0-35	8.24	21.25	70.51	C	37.61	0.53	3.44	111.50	2.49	469.02	0.70
	35-75	10.21	21.58	68.21	C	46.61	0.76	3.80	78.23	3.39	458.49	0.72
	75-135	7.66	21.09	71.25	C	34.97	0.63	3.59	78.27	3.38	488.93	0.54
4	0-35	10.66	30.68	58.66	C	48.66	0.54	4.79	84.38	3.38	432.41	0.50
	35-80	5.25	31.58	63.17	C	23.96	0.39	5.33	84.14	3.36	431.20	0.50
	80-145	5.98	31.74	62.28	C	27.30	0.60	5.56	74.93	3.36	431.09	0.52
5	0-35	6.25	19.74	74.01	C	28.53	0.76	3.08	91.93	3.36	427.87	0.53
	30-75	7.02	20.00	72.98	C	32.04	0.57	3.57	89.84	3.36	428.57	0.56
	75-135	10.09	31.00	58.91	C	46.06	0.44	3.65	84.28	3.40	428.50	0.46
6	0-35	9.75	31.25	59.00	C	44.51	0.47	4.27	98.07	3.40	466.95	0.46
	35-85	6.36	32.00	61.64	C	29.03	0.53	4.27	95.63	3.37	470.93	0.37
	85-125	6.85	32.23	60.92	C	31.27	0.66	5.49	92.18	3.39	473.16	0.44
7	0-35	5.32	21.33	73.35	C	24.28	0.52	4.86	95.67	3.37	468.82	0.46
	35-80	10.30	20.36	69.34	C	47.02	0.85	5.07	94.77	2.49	462.32	0.44
	80-140	5.25	20.35	74.40	C	23.96	0.82	5.69	88.43	2.35	466.31	0.56
8	0-35	5.36	22.00	72.64	C	24.47	0.89	4.44	107.19	2.47	471.17	0.53
	35-85	7.25	19.33	73.42	C	33.09	0.65	4.64	99.93	2.46	467.07	0.57
	85-135	5.44	20.02	74.54	C	24.83	0.62	5.21	97.64	2.43	468.02	0.42
9	0-35	7.00	19.36	73.64	C	31.95	0.78	3.44	87.80	2.44	457.42	0.47
	35-85	10.11	21.36	68.53	C	46.15	0.58	3.63	82.15	2.37	460.85	0.46
	85-135	8.00	20.54	71.46	C	36.52	0.57	3.66	81.28	2.39	461.13	0.60

10	0-35	8.25	31.00	60.75	C	37.66	0.68	3.32	88.06	2.39	428.17	0.58
	35-85	9.21	31.36	59.43	C	42.04	0.89	3.91	78.23	2.25	433.32	0.42
	85-145	8.00	31.00	61.00	C	36.52	0.71	4.21	76.49	2.37	433.90	0.43
11	0-35	5.98	32.36	61.66	C	27.30	0.51	4.38	83.01	2.39	429.59	0.46
	35-80	6.00	32.20	61.80	C	27.39	0.62	4.59	80.03	3.42	432.52	0.45
	80-135	6.34	31.00	62.66	C	28.94	0.77	4.73	78.23	3.47	429.70	0.59
12	0-35	7.25	31.01	61.74	C	33.09	0.51	4.74	97.80	3.45	435.33	0.54
	35-85	5.69	35.25	59.06	C	25.97	0.42	5.49	95.88	2.37	442.67	0.60
	85-135	10.25	20.25	69.50	C	46.79	0.40	5.69	64.75	2.37	439.79	0.58
13	0-35	6.36	20.10	73.54	C	29.03	0.77	4.14	70.40	2.29	429.92	0.59
	35-85	7.36	20.13	72.51	C	33.60	0.90	4.27	69.11	2.42	434.09	0.60
	85-140	7.33	18.52	74.15	C	33.46	0.90	4.27	64.77	2.41	435.55	0.59
14	0-35	8.24	33.00	58.76	C	37.61	0.66	3.59	88.06	2.43	430.98	0.53
	35-80	10.21	35.21	54.58	C	46.61	0.74	3.78	86.00	2.46	458.06	0.57
	80-135	10.66	34.65	54.69	C	48.66	0.65	3.85	78.27	2.48	458.18	0.45
15	0-35	9.25	34.54	56.21	C	42.22	0.46	4.07	96.06	2.45	446.53	0.43
	35-85	8.98	33.47	57.55	C	40.99	0.73	4.16	89.76	2.40	464.67	0.45
	85-140	6.25	34.00	59.75	C	28.53	0.66	4.21	84.38	2.43	464.43	0.46

- **Text. :**Texture; **C:** clay; **CEC**: Cation Exchangeable Capacity; **OM:** Organic Matter; **Gy**.: Gypsum.
- Texture classes of Soil Survey Staff, USDA, (2014).

***Note:** Three classes of soil contents of exchangeable K were clear as done by Berryman et al., (1984) for tropical soils: L = Low soil content of K ranging below 0.15 cmol kg^{-1}; M = Moderate soil content of K ranging between 0.15 and 0.30 cmol kg^{-1}; H = High soil content of K ranging over 0.30 cmol kg^{-1}.

Table (4): Soil salinity and alkalinity description of the studied soil profiles.

Profiles	Depth cm	pH 1:2.5	EC dS m^{-1}	Soluble ions for soil pest extract (mmolc L^{-1})							ESP %
				Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	Cl^{-}	HCO_3^{-}	SO_4^{2-}	
1	0-35	7.67	5.79	15.06	10.33	1.32	31.19	33.64	1.97	22.30	13.57
	35-80	7.74	6.38	14.70	10.75	1.30	37.05	40.00	1.20	22.61	11.61
	80-120	7.59	6.33	14.57	6.33	1.33	41.07	48.82	1.64	12.85	8.10

2	0-35	7.89	6.45	23.20	7.00	1.27	32.98	46.28	1.47	16.70	9.36
	35-85	7.94	5.91	22.72	6.96	1.53	27.84	45.20	1.57	12.28	8.76
	85-125	7.88	5.52	13.06	5.00	1.71	35.38	35.42	1.29	18.44	9.80
3	0-35	8.00	7.02	12.84	7.75	1.79	47.77	48.42	1.88	19.85	11.42
	35-75	7.81	5.87	12.66	7.33	1.48	37.18	36.12	1.83	20.70	9.79
	75-135	7.92	5.61	13.25	7.75	1.39	33.66	40.60	1.92	13.53	8.98
4	0-35	7.88	4.13	12.62	10.69	1.55	16.39	23.30	1.41	16.54	10.94
	35-80	7.85	3.81	12.96	11.11	1.57	12.41	22.86	1.63	13.56	7.88
	80-145	7.84	3.72	12.49	6.69	1.48	16.49	23.74	1.73	11.68	10.72
5	0-35	7.74	4.31	12.56	7.36	1.64	21.49	25.64	1.35	16.06	15.14
	30-75	7.40	3.29	13.15	7.32	1.56	10.82	19.92	1.01	11.92	14.09
	75-135	8.13	1.88	6.10	4.36	1.01	7.28	11.66	1.74	5.35	14.56
6	0-35	7.62	3.46	11.75	12.11	1.48	9.21	21.30	1.23	12.02	15.34
	35-85	7.84	2.77	8.44	12.69	1.45	5.07	14.92	1.45	11.28	13.67
	85-125	7.94	2.77	11.22	8.11	1.40	6.92	16.92	1.55	9.18	19.43
7	0-35	8.03	6.77	16.24	11.72	1.34	38.35	38.72	1.64	27.29	22.27
	35-80	8.06	5.42	15.22	10.52	1.35	27.14	31.18	1.67	21.38	19.27
	80-140	7.58	5.21	13.81	11.04	1.37	25.92	31.78	1.19	19.16	17.99
8	0-35	7.92	5.74	15.39	11.27	1.43	29.33	34.02	1.53	21.87	17.49
	35-85	7.53	3.38	14.70	11.48	1.34	6.30	23.40	1.14	9.28	15.12
	85-135	7.88	3.21	14.70	10.80	1.26	5.36	20.96	1.49	9.67	12.70
9	0-35	7.70	5.66	18.95	10.00	1.24	26.43	31.64	1.31	23.68	16.86
	35-85	8.29	5.01	17.80	11.20	1.31	19.81	29.82	1.90	18.41	17.47
	85-135	8.24	4.23	17.54	10.52	1.33	12.93	26.72	1.85	13.76	18.84
10	0-35	8.33	7.54	18.38	10.29	1.49	45.29	41.76	1.94	31.75	19.03

	35-85	7.82	6.54	17.84	11.67	1.51	34.42	46.44	1.43	17.58	17.51
	85-145	8.04	6.54	17.45	11.55	1.51	34.93	35.50	1.65	28.30	17.13
11	0-35	8.14	6.67	12.78	10.43	1.47	42.00	36.20	1.75	28.73	20.94
	35-80	8.23	6.16	13.00	11.23	1.42	35.93	35.84	1.84	23.90	16.61
	80-135	7.94	5.79	13.10	10.12	1.46	33.24	35.02	1.55	21.36	16.55
12	0-35	8.36	2.70	9.59	3.94	1.56	11.93	19.92	1.61	5.50	16.56
	35-85	7.59	2.48	8.94	4.52	1.47	9.89	13.96	1.42	9.45	8.80
	85-135	8.03	2.42	8.29	4.91	1.59	9.44	16.64	1.53	6.06	7.47
13	0-35	7.86	5.28	14.39	11.79	1.68	24.94	35.70	1.49	15.62	18.81
	35-85	7.96	5.51	14.17	10.66	1.66	28.64	33.40	1.46	20.28	17.42
	85-140	7.68	5.62	14.11	11.46	1.60	29.02	37.10	1.45	17.65	11.16
14	0-35	8.27	6.70	14.10	10.36	1.53	41.04	38.08	1.28	27.67	20.76
	35-80	8.22	6.01	10.33	11.18	1.46	37.15	36.52	1.35	22.26	17.71
	80-135	8.31	4.26	10.63	11.40	1.41	19.18	29.72	1.20	11.71	17.81
15	0-35	7.80	4.55	16.06	12.43	1.38	15.65	33.00	1.50	11.02	12.08
	35-85	8.02	3.53	15.74	12.46	1.31	5.81	20.96	1.55	12.81	12.42
	85-140	8.12	2.12	10.65	6.29	1.28	3.00	14.00	1.49	5.73	12.54

- No detected CO_3^{2-}
- **ESP:** Exchangeable Sodium Percentage

Table (5): macronutrients levels in maize steam and grains samples within three stages of stem growth and grain maturation stage.

Samples	Nutrients Amount (%)											
	Stem									Grain		
	N			P			K			N	P	K
	Ages Day			Ages Day			Ages Day			Ages Day		
	30	45	60	30	45	60	30	45	60	115		
1	0.774	0.731	0.583	0.140	0.198	0.105	3.261	3.550	1.280	0.858	0.122	1.630
2	0.811	0.745	0.544	0.152	0.197	0.096	3.419	3.770	1.038	0.891	0.121	1.744
3	0.837	0.766	0.561	0.136	0.183	0.022	3.321	3.548	1.329	0.909	0.119	1.553

4	0.793	0.780	0.532	0.147	0.189	0.067	3.198	3.759	1.318	0.819	0.132	1.578
5	0.891	0.756	0.547	0.131	0.237	0.081	3.321	3.889	1.561	0.861	0.127	1.667
6	0.774	0.809	0.567	0.137	0.200	0.057	3.411	3.670	1.568	0.922	0.152	1.697
7	0.825	0.745	0.581	0.130	0.181	0.110	3.343	3.760	1.259	0.887	0.118	1.684
8	0.794	0.773	0.557	0.136	0.190	0.047	3.245	3.692	1.417	0.855	0.131	1.567
9	0.881	0.756	0.610	0.143	0.227	0.074	3.201	3.594	1.447	0.908	0.122	1.489
10	0.864	0.804	0.547	0.127	0.210	0.058	3.421	3.610	1.289	0.873	0.125	1.731
11	0.729	0.794	0.574	0.125	0.175	0.032	3.199	3.768	1.351	0.883	0.116	1.464
12	0.747	0.721	0.558	0.136	0.193	0.047	3.410	3.690	1.227	0.853	0.133	1.736
13	0.841	0.782	0.605	0.142	0.187	0.083	3.540	3.578	1.189	0.897	0.117	1.844
14	0.769	0.743	0.596	0.130	0.198	0.044	3.341	3.670	1.569	0.832	0.113	1.666
15	0.800	0.760	0.522	0.137	0.186	0.061	3.229	3.547	1.393	0.849	0.124	1.565

Table (6): statistical reflection between nutrients soil content, and its content inside the *Maize* plant (stem and grains).

Correlations												
Vai.	**Stem**									**Grain**		
	N			**P**			**K**			**N**	**P**	**K**
	30 Ages Day	**45 Ages Day**	**60 Ages Day**	**30 Ages Day**	**45 Ages Day**	**60 Ages Day**	**30 Ages Day**	**45 Ages Day**	**60 Ages Day**	**115 Ages Day**		
Sol. K	-0.203	0.323	0.046	0.131	-0.335	-0.407	0.523*	0.204	-0.322	0.011	0.018	0.412
Av. N	-0.226	-0.042	-0.355	-0.061	0.011	-0.197	-0.343	0.105	0.386	-0.039	0.546*	-0.328
Av. P	-0.161	0.381	-0.265	-0.113	-0.007	-0.377	-0.236	0.379	0.410	0.054	0.46	-0.299
Av. K	-0.195	0.071	0.149	0.087	-0.209	-0.406	-0.221	-0.682**	0.325	0.249	0.265	-0.364
Ex. K	-0.002	-0.431	0.212	0.438	-0.161	-0.035	0.249	-0.262	-0.568*	0.109	-0.402	0.168

*Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Note: soluble potassium in water cannot be computed because at least one of the variables is constant.