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Ameliorative Effect of Combining Different Amendments with Abu Tartur Rock Phosphate on Growth and Yield of Soybean and Maize

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ABSTRACT

The present study aims to evaluate the bioavailability of phosphorus from sedimentary rock and its effects on the growth of soybean and maize in field experiments. The field experiment was conducted to evaluate the effects of treatments on the P solubility and its relation with yield of grains and straw for both soybean and maize crops, on the sandy soil in the Nubaria area of Beheira Governorate–Egypt. Rock phosphate sample was collected from the Western Desert between El-Kharga and El-Dakhla Oases (Abu Tartur). The experiment included the following treatment: Rock phosphate + Oxalic acid +Ammonium thiosulfate; Rock phosphate +Ammonium thiosulfate. The results show that Rock phosphate + Oxalic acid had a significant impact on grain yield and straw yield while Rock phosphate + Farmyard manure(FYM) + phosphate solubilizing bacteria (PSB), Rock phosphate + Farmyard manure, and Rock phosphate + PSB had less influence on the yield characteristics of both soybeans and maize plants. The treatment of Rock phosphate + Oxalic acid + Ammonium thiosulfate recorded the highest increase in both grain yield and straw yield, as well as in the total yield (113.5, 28.0 and 53.5%), (205.5, 168.8 and 186.1%) for soybean and maize, respectively compared with rock phosphate alone, while the treatment of Rock phosphate +PSB recorded the lowest increase in all traits of the both tested crops compared to rock phosphate alone or superphosphate fertilizer.

Keywords: Rock phosphate, Organic acids, Elemental sulfur, Ammonium thiosulfate, Oxalic acid, Phosphate Solubilizing Bacteria

1. Introduction

Phosphorus (P) is an essential element for all living organisms; also phosphorus plays an important role in cell energy transfer, respiration and photosynthesis. Phosphate bonds are used for energy storage as adenosine triphosphate (ATP), which is the primary source of energy for biological processes and also serve as structural component of nucleic acids (DNA and RNA), enzymes, phosphoproteins and phospholipids (Grant *et al.,* 2001). Phosphorus is widely distributed in nature. Phosphate species are the main forms of P in the environment. A soil has an eminent reserve of total P. More than 43% of the world soils are deficient in phosphorus, but very little amount of P only 0.1% is actually available to the plants to support their growth to fulfill the requirement due to the fixation of phosphorus in the soil as insoluble phosphates (Xiao *et al.,* 2011). Therefore, phosphorus deficiency in agricultural land can drastically affect plant development and metabolism, so is one of the main factors which reduce the crop production (Wu *et al.,* 2005). Rock phosphate is one of the basic raw materials required in the manufacture such as phosphoric acid, cleaners, soaps, detergents and insecticides, food processing applications and water treatment and phosphate fertilizers such as single super phosphate, di-ammonium phosphate and nitro phosphates. Most fertilizers manufacturing processes use sulfuric acid, although some, mostly in Europe, use nitric acid (Samreen and Kausar, 2019). Rock phosphate sources in the world can be classified into five main types as follows: Metamorphic deposits, igneous

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phosphate deposits, biogenic deposits, marine phosphate deposits and phosphate deposits as a result of weathering. The world phosphate resources are distributed, according to their type, approximately as follows: 75% from sedimentary marine deposits 15–20% from igneous, metamorphic and weathered deposits and 2– 3% from biogenic sources (bird and bat guano accumulations) (Zaher and Abouzeid, 2007). The rock phosphates in Egypt their exploitation was initiated between 1908 and 1911 by foreign companies in regions the Nile Valley, Red Sea Coast and in Kharga Oases in the Western Desert. Phosphate mining and production have been surviving in the former two regions till the present, also systematic studies on phosphate reserves and production were carried out. Egypt has about 4% of the world's phosphate reserves about 1.300 billion tons and produces about 3% of the world's phosphate production in 2018 is about 4.6 million tons (U.S. Geological Survey, 2019). The rock phosphate occurrence in Egypt can be classified into three regions (Hellal *et al.,* 2019 and Mahdy, 2011). The chemical reactivity or solubility of RP is a measure of the RPs ability to release P for plant uptake. Reactivity of RP can be defined as the rate at which P in the apatite is released under favorable chemical conditions. Rock phosphates of igneous and metamorphic source are less reactive due to of their crystalline form. While the sedimentary rock deposits which have microcrystalline form are highly reactive (Kaleeswari and Subramanian, 2001). Soybean plays an important role in sustainable agriculture because it is considered the major source of protein and vegetable oil as well as an essential amendment of soil fertility. However, this species is sensitive to P deficiency (Rotaru and Sinclair, 2009). Soybean (*Glycine max L.*), a leguminous crop, is one of the most important and extensively grown crops that accounts for 30% of the world's processed vegetable oil (Graham and Vance, 2003). Legumes are especially suited for the utilization of RPs. They are compelling in dissolving RP and in engrossing its disintegration items in view of their interest for Ca and the acidifying impact of nitrogen (N) fixation in the soil close to the root framework (*rhizosphere*) (Hellal *et al.,* 2019). This effect can be utilized to improve the P nutrition of a companion crop (intercropping) or that of the subsequent crop in a rotation (Perrott, 2001).

Maize is an important crop worldwide for food, animal feed and bio-energy production (Bello *et al.,* 2010 and Randjelovic *et al.,* 2011). It is an important food crop in Africa. Maize crop provides over 30% of the dietary calories in East Africa (Salasya *et al.,* 1998). Salem et al. (2008) found that the studied soil profiles in the Nubaria area of Beheira Governorate, Egypt are classified to subgroup level as Typic Torripsamments. Salah, (2018) showed the clear evidence that the elemental S could be highly recommended as a useful and economical material to maintain the efficiency of superphosphate fertilizer in increasing growth and production of soybean plants in high pH clayey soils in Egypt after application of the elemental S with superphosphate. Mashori *et al.* (2013) recounted that the application of RP along with FYM was effective in increasing the plant height, shoot dry matter yield, P concentration and uptake in maize as SSP. It is concluded that the application of RP along with FYM can be used as an alternate source of SSP. Similarly, the combined application of RP and SSP performed better than the individual application of the two with the recommended percent of RP and SSP as 50+50. Manzoor *et al.* (2016) evaluated the effect of separate and combined use of indigenous PSB, poultry manure (PM) and compost on solubilization and mineralization of RP and their subsequent effect on growth and P accumulation of maize (*Zea mays* L.). The combined addition of PSB and organic amendments (PM, compost) with RP further increased P mineralization by releasing a maximum of 37.7 μg/g compared with separate application of RP (11.8 μg/g) and organic amendments (21.5 and 16.5 μg/g). The overall effect of PSB (as a group) with RP over RP only on maize growth showing a relative increase in shoot length 21%, shoot fresh weight 42%, shoot dry weight 24%, root length 11%, root fresh weight 59%, root dry weight 35% and chlorophyll content 32%

The objective of this study is to assess the bioavailability of phosphorus from sedimentary rock and the agronomic efficiency of RP that have a wide range of reactivity through the application of different amendments, i.e., organic acids, phosphate solubilizing bacteria, farmyard manure, sulfur, and ammonium thiosulfate, to get optimum conditions for the enhancement of maize and soybean growth in agriculture.

2. Materials and Methods

The soil sample was collected from the Production and Research Station of the National Research Centre, the Nubaria area of Beheira Governorate–Egypt, which lies to the North West of the Nile Delta of Egypt between 30° 29′ N and 30° 19′ E. Soil samples were subjected to the following analyses;

particle size distribution using standard sieving technique, Folk (1974). Soluble cations and anions, calcium carbonate concentration ($CaCO_3$%), EC (dS/m) of soil extract (1:1), and soil reaction (pH) of soil water suspension (1:2.5) were determined According to Black (1982). Available phosphorus was determined according to Olsen *et al.* (1973). Total nitrogen was determined according to Black, (1965). Extractable potassium as described by Dewis and Feritas, (1970). The geochemical distribution of certain major oxides including SiO2, Al_2O_3, CaO, MgO, Na_2O, K_2O, MnO, and Fe_2O_3 were analyzed by the X-Ray fluorescence, National Research Center and trace elements of rock phosphate samples powdered samples (100-mesh) according to Shapiro and Brannock, (1962). Active carbonates were determined according to Yaalon, (1980). The mineralogical composition of rock phosphate was determined by powder X-ray diffraction (XRD) using a Philips PW1730 diffractometer. Reactivity test using three solutions (neutral ammonium citrate NAC), 2% citric acid (CA), and 2 % formic acid (FA) to measure the solubility of rock phosphate sample according to Diamond, (1979). Some heavy metals assumed to be found in the rock phosphate sample were determined using atomic absorption spectrometry. For plant analyses, half a gram of plant samples was wet digested using 4 ml of conc. sulfuric acid (overnight) and 2 ml of 30% H_2O_2. The acid digest was analyzed for N, P, and K using the following methods: total nitrogen was determined using micro- Kjeldahel apparatus, and phosphorus was assayed using the ammonium vanadate (Cottenie *et al.,* (1982). Potassium is evaluated photometrically using a flame photometer.

A field experiment was carried out to study the effect of some treatments on the performance of the dissolution of P from rock phosphate for crop uptake. The field experiment was conducted for two successive growing seasons (May 2016 and 2017) for soybean (*Glycine max* L.) variety Giza 111 and maize (*Zea mays* L.) hydride variety three-way-cross TWC 324 under a drip irrigation system. Before sowing, soybean seeds were inoculated with a liquid solution of *Bradyrhizobium japonicum* to encourage root nodulation. The experiment was laid out in randomized complete block design with three rows 10.8 meters in length and 60cm in width provided with drip lines irrigation along each plant row which was used to maintain row to row distance of 30cm planting/ drip. The treatments were distributed as follows:

1. Control
2. RP: (Rock Phosphate),
3. **SSP:** (Superphosphate fertilizer 15.5% P_2O_5 available P)
4. RP+PSB: (Rock Phosphate+ Phosphate solubilizing bacteria)
5. RP+FYM: (Rock phosphate + Farmyard manure)
6. RP+FYM+PSB: (Rock Phosphate + Farmyard manure + Phosphate solubilizing bacteria)
7. RP+ATS: (Rock Phosphate + Ammonium thiosulfate)
8. RP+OA: (Rock Phosphate + Oxalic acid)
9. RP+OA+ATS: (Rock Phosphate + Oxalic acid + Ammonium thiosulfate)

Phosphate fertilizers from the different sources were applied at a unified rate of 30 and 45kg P_2O_5 /fad. (equal to 125kg RP and 200kg SSP /fed. for soybean and 200kg RP and 300kg SSP / fed. for maize, respectively). These amounts of P fertilizers were spread by hand on the soil surface and incorporated into the soil in one dose of pre-planting. Oxalic acid, phosphate solubilizing bacteria, and ammonium thiosulfate were applied in water-soluble form after complete germination through a drip irrigation system while RP, SSP, and FYM were applied in powder form. Extra N content in ATS was subtracted from the total required quantity by the crop to unify the N level for all treatments. Nitrogen, potassium, and phosphorus fertilizers were added according to the recommendations of the Egyptian Ministry of Agriculture (Table 1).

After harvesting, samples are air-dried and weighed. After 120 days from sowing plant shoots and grain samples were collected to determine seed yield, straw, and biological yield (kg/fed). At the end of the experiment (120 days after planting), i.e., after the final crop harvest, from each plot, 15 plants per plot were harvested to determine the total yield of each crop.

Table 1: Description of the applied NPK fertilizers to the soils with soybean and maize (after Egyptian Ministry of Agriculture**).**

Treatment	Soybean			Maize		
	Fertilizer amount (kg/fed)			Fertilizer amount (kg/fed)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	Sandy soil					
Control	20	-	60	120	-	60
RP	20	30	60	120	45	60
SSP	20	30	60	120	45	60
RP+PSB	20	30	60	120	45	60
RP+FYM	20	30	60	120	45	60
RP+FYM+PSB	20	30	60	120	45	60
RP+ATS	20	30	60	120	45	60
RP+OA	20	30	60	120	45	60
RP+OA+ATS	20	30	60	120	45	60

RP: (Rock Phosphate), **SSP:** (Superphosphate)**, RP+PSB:** (Rock Phosphate+ Phosphate solubilizing bacteria**, RP+FYM:** (Rock phosphate + Farmyard manure)**, RP+FYM+PSB**: (Rock Phosphate + Farmyard manure + Phosphate solubilizing bacteria), **RP+ATS:** (Rock Phosphate + Ammonium thiosulfate)**, RP+OA:** (Rock Phosphate + Oxalic acid)**, RP+OA+ATS: (**Rock Phosphate + Oxalic acid + Ammonium thiosulfate)

The plants were divided into the sets of shoots (grain + straw) for soybean (leaves, stems, husks, and cob cores for maize and then oven-dried at 70° C for 24 hours, weighed to determine plant biomass (grain and straw samples) and soil samples from each plot were taken to examine changes in soil pH and available P. The plant samples were analyzed for total NPK concentration. Fertilizer use efficiency (PUE) was calculated using the following equation:

PUE = (Yt-Y0) / F…………………………………………………………………………..……..(1)

Where: Yt = total yield under treatment (grain), Y0 = total yield under control, and F = applied fertilizer quantity according to Syers *et al.* (2008).

All equation variables (Kg/fed.). Crop recovery efficiency (RE) of added P by the different methods is a more common and widely used approach to estimate its efficiency using the following equation:

(RE) = (Up – U0 / Fp) × 100…………………………………………………..…………………..(2)

Where : Up = total uptake (grains + straw) under treatments (U0) = P taken up by a crop from soils and Fp = amount of the applied P (kg/fed.) and the result is expressed as a percentage according to Cassman *et al.* (1998).

Data were subjected to the analysis of variance (ANOVA) (Version 6.311, CoHort, USA, 1998-2005) appropriate to the experimental design to evaluate the effects of treatments on the P solubility. A comparison of means was carried out using the least significant difference (LSD) at a 5% probability level.

Data in Table (2) show that the particle size distribution of the studied soil, the soil texture was sandy loam, where the sand fraction was more than 80%, with low percent of clay and very low content of silt fractions. The data presented in Table (2) show that the soil salinity (EC/dS/m) is non-saline and EC values 0.22 dS/m. pH value is slightly alkaline 7.5. Organic matter content (OM) was very low as that soil is newly cultivated and organic matter content is 0.07. The Calcium carbonate content is low (5.2%). Total P% and Available P were 0.2% and 7.3 ppm respectively. Available K was 38.2 ppm.

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Table 2: Some physical and chemical characterization of the soil sample

Soil character	Nubaria soil	Soil character	Nubaria soil
Particles size distribution %		**Soluble cations meeq/L**	
Clay	15.97	Ca^{++}	0.90
Silt	3.90	Mg^{++}	0.30
Sand	80.13	Na^{+}	0.92
Texture class	Sandy loam	K^{+}	0.67
Organic matter%	0.068	**Soluble anions meeq/L**	
EC Soil paste (dS/m)	0.22	Cl^{-}	0.50
pH (1:2.5) soil: water suspension	7.5	CO^{2-}_{3}	0.00
		HCO_3^{-}	2.00
$CaCO_3$ (%)	5.2	SO_4^{2-}	0.29
Total P%	0.195		
Available P (ppm)	7.26		
Available K (ppm)	38.2		

Data in Table (3) shows some physical, chemical, and mineralogical characteristics of the Abu Tartur rock phosphate sample used in the study. Total P2O5 24%, while the available is 1.4 mg/kg. The data presented in Table (3) show that the soil salinity (EC/dS/m) of the RP sample is non-saline and EC values are 1.4 dS/m. pH value is 7.0. Calcium carbonate content is high (12.2%) while active calcium carbonate content is low (1%). Major minerals in the Abu Tartur rock phosphate sample were fluorapatite, apatite-calcite, francolite, and low quartiz content.

Table 3: Some physical, chemical, and mineralogical characteristics of the rock phosphate sample used in the study

Location	Resource Name	Total P_2O_5 (%)	Available P_2O_5 (mg/kg)	pH (1:2.5)	EC dS/m (1:2.5)	$CaCO_3$ %	Active $CaCO_3$ %	Major minerals
Western Desert	**Abu Tartur**	24	1.4	7.0	1.4	12.2	1.02	Fluroapatite Apatite-Calcite Francolite Quartiz Low

The concentrations of some heavy metals found in Abu Tartur rock phosphate sample given in Table (4), which show that zinc had high concentration followed by copper 681 and 43 mg/kg respectively.

Table 4: The concentration of some heavy metals (mg/kg) of rock phosphate sample.

Resource Name	Zn	As	Co	Pb	Cd
Abu-Tartur	681	40	43	11	3

Table (5) shows some chemical properties of farmyard manure (FYM) used in study. Table data show pH value of FYM was 7.2, O.C content was 19.5, while O.M. was 33.2% with C/N ratio 25.2 and EC value 5.8.

Table 5: Some chemical properties of the farmyard manure used in the study

O.C %	O.M. %	C/N ratio	Ph (1:10)	EC dSm^{-1} (1:10)	Total nutrients %		
					P	K	N
19.5	33.2	25.2	7.2	5.81	0.35	1.2	1.60

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The geochemical distribution of certain major oxides and trace elements may provide direct information on the depositional environment. Table 6 shows the major oxides, trace and rare elements found in collected rock phosphate sample. In general, CaO, SiO_2 beside P_2O_5 were the most oxides forms found in the structure of these raw materials. Calcium oxide values (CaO) is the high value 43.4%. Phosphate oxide P_2O_5 values show the high content of P_2O_5 (24%)

Table 6: Major oxides (%) in the rock phosphate sample.

Major oxides (%) in the rock phosphate sample											
P_2O_5	**CaO**	**Fe_2O_3**	**SiO_2**	**Al_2O_3**	**Na_2O**	**K_2O**	**MgO**	**Cl^-**	**CO_2**	**SO_3**	**F^-**
24.00	43.40	1.44	10.80	0.50	4.38	0.20	1.33	0.22	7.10	7.90	1.31

Silicate oxide (SiO_2) was the third material found in the studied RP. However, data in Table (6) show that, the low value of Fe_2O_3 and Al_2O_3 1.44% and 0.50% respectively. The MgO content is 1.33%. Data in Table (6) also, show that, low value of fluorine which is 1.31%.

3. Results and Discussion

Post-harvest change in extractable P and soil pH: Phosphorus content and soil pH after post-harvest of soybean and maize as an indicator of the efficiency of the stimulating agents (Table 7 and Figure (1 A and B). Acid-forming compounds had a good effect on decreasing soil pH at the beginning of the cultivation pH value was 8.3 for soybean and maize, but the soil reaction had changed at the roots zone blows all the acidification treatments, especially with RP+OA+ATS as soil pH was dropped to (7.2 and 7.3) following by RP+ATS were (7.3 and 7.4) then RP+OA were (7.4 and 7.5) for soybean and maize, respectively after post-harvest.

The soil used in this experiment was deficient in extractable P (7.26mg/kg). However, extractable P in soil increased when OA and ATS were added (Table 7). Across various treatments, the relative increase in extractable P due to P addition ranged between (12.1 to 117.6%) and (9.4 to 107.1%) for soybean and maize compared to control, respectively. The maximum values (19.8 and 17.6mg/kg) of extractable P contents were observed when combined with RP+ATS+OA, followed by (17.9 and 15.8mg/kg) with RP+ATS then (14.8 and13.3mg/kg) with RP+OA for soybean and maize, respectively.

Table 7: Effect of RP with different amendments on extractable P and soil pH in the roots zone of the soybean and maize after post-harvest.

Treatments	**Soil pH**		**Extractable P**	
	Soybean	**Maize**	**Soybean**	**Maize**
Control	7.5	7.5	9.1	8.5
RP	7.5	7.5	10.2	9.3
SSP	7.5	7.5	12.4	11.3
RP+PSB	7.4	7.4	10.8	10.0
RP+FYM	7.3	7.3	11.1	10.2
RP+FYM+PSB	7.2	7.2	12.1	11.4
RP+OA	7.0	7.1	14.8	13.3
RP+ATS	6.9	7.0	17.9	15.8
RP + ATS + OA	6.7	6.8	19.8	17.6
LSD 5%	**0.09**	**0.1**	**1.5**	**1.3**

RP: (Rock Phosphate), **SSP:** (Superphosphate)**, RP+PSB:** (Rock Phosphate+ Phosphate solubilizing bacteria**, RP+FYM:** (Rock phosphate + Farmyard manure)**, RP+FYM+PSB**: (Rock Phosphate + Farmyard manure + Phosphate solubilizing bacteria), **RP+ATS:** (Rock Phosphate + Ammonium thiosulfate)**, RP+OA:** (Rock Phosphate + Oxalic acid)**, RP+OA+ATS: (**Rock Phosphate + Oxalic acid + Ammonium thiosulfate)

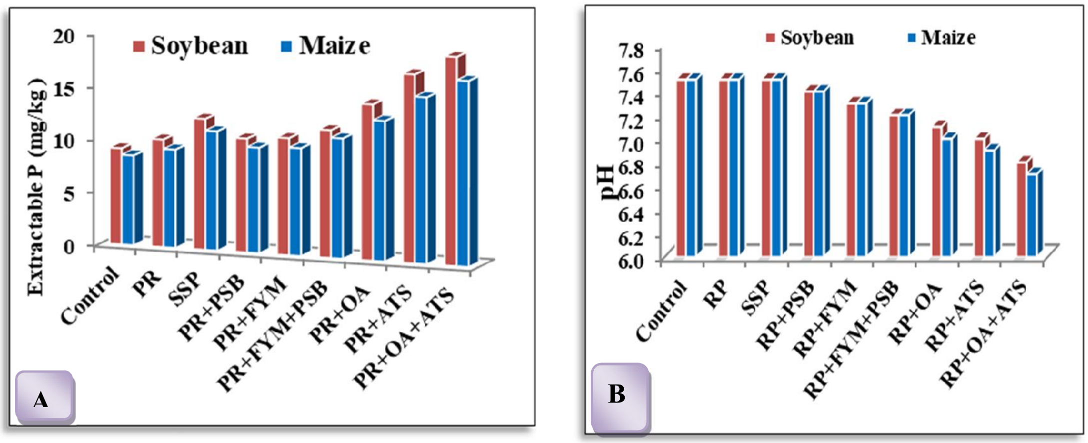

Fig. 1: Effect of RP with different stimulant agents on extractable P (A) and soil pH (B) in the root zone of soybean and maize after harvest.

So application of OA and ATS showed higher abilities on releasing P from RP with a more pronounced effect when they coupled together. This may be attributed to the carboxylic acids enhance P availability by their influences in lowering soil pH values along with chelating Ca and Mg ions and consequently increasing the availability of phosphate. It can be concluded from the previous results that the effective impact of such amendments on reducing soil pH, especially ammonium thiosulfate, and oxalic acid, and in combination with them create better conditions for phosphorus uptake and many other elements required for plant growth (Basak, 2019; Mc Callister *et al.,* (2010); He *et al.,* (2012); Zafar *et al.,* (2017). The addition of a stimulant agent to dissolve RP caused significant differences in grain yield and total dry biomass (Table 8 and Figure 2). As expected, direct application of RP produced a lower yield than any other treatment because of its low solubility and movement in the soil. The grain yield (GY) is the major objective of culturing soybean and maize and the crop yield reflects the effectiveness of different amendments and the potential of fertilization strategies opted.

As shown in Table (8) and Figures (2 and 3) the effect of the application of different amendments (PSB, FYM, OA, and ATS) with RP on the straw yield (SY), grain yield (GY), Biological yield (BY) and P use efficiency (PUE) of soybean and maize. Data in Table (8) evidence that the better yield performance with (RP+OA+ATS) can be attributed to significantly higher dry biomass for all yield components as in the case of soybean and maize. Results in Table (8) showed that the maximum significant amount of grain yield and straw yield of soybean and maize obtained when the addition of RP+ATS+OA being (1.994 and 2.813ton/fed) and (3.764 and 3.561ton/fed), RP+ATS were (1.838 and 2.877ton/fed) and (3.616 and 3.518ton/fed) then RP+OA were (1.746 and 2.777ton/fed) and (3.582 and 3.360 ton/fed), respectively and its attributes followed by RP+FYM+PSB and RP+FYM then RP+PSB had recorded the lowest effect on yield parameters of soybean and maize. The most significant increase in grain yield and straw yield of soybean and maize obvious when using RP+OA+ATS compared to SSP were (22% and 14.2%) and (11 and 11.5%) or compared to RP were (113.5% and 28%) and (205.5% and 169%), respectively. The beneficial effect of OA+ATS is related to their effect on the chemical and biological soil conditions such as reducing soil pH and chelation reaction due to releasing more phosphorus as well as several other nutrients available to plant uptake. These results agreed with Sequera and Ramiars, (2013) and Morillo *et al.,* (2007) who pointed out that partial acidification of rock phosphate with ammonium thiosulfate and sulfuric acid produces a fertilizer as efficient as the sulfuric acid for the growth of the root system in both acid and neutral soils and confirmed its efficiency in the production of dry matter and phosphorus uptake by the plant.

Harvest index (%) (HI = grain weight (kg/fed)/total dry weight at harvest (kg/fed)) was higher in soybean and maize under RP treated with OA+ATS (0.45 and 0.46) compared to SSP (0.43 and 0.44) which related to greater grain yield production (Table 8). Harvest index was affected by stimulant agents suggesting that soybean and maize crops possibly allocated increased amounts of assimilates for grain yield as translocation of nutrients during flowering and reproductive stages shifts nutrients from vegetative organs into the seed/grain of the plant (Reuter and Robinson, 1997).

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Table 8: Grain yield, straw yield and biological yield (grain yield +straw yield), P use efficiency (PUE), and harvest index (HI) in soybean and maize plants as affected by different stimulate agents (average of two years)

Treatments	Grain Yield (ton/fed)	Straw Yield(ton/fed)	Biological Yield (ton/fed)	PUE (kg yield/ kg P)	HI (%)
			Soybean		
Control	0.583	2.086	2.67	--	0.37
RP	0.934	2.198	3.13	27	0.37
SSP	1.634	2.464	4.10	81	0.43
RP+PSB	1.051	2.725	3.28	36	0.37
RP+FYM	1.207	2.147	3.45	48	0.39
RP+FYM+PSB	1.393	2.288	3.68	62	0.40
RP+OA	1.746	2.777	4.62	89	0.44
RP+ATS	1.838	2.877	4.72	97	0.44
RP + ATS + OA	1.994	2.813	4.81	109	0.45
LSD 5%	**0.171**	**0.313**	**0.404**	**3.77**	**----**
			Maize		
Control	0.959	1.015	1.97	--	0.40
RP	1.232	1.325	2.56	14	0.40
SSP	3.395	3.193	6.59	122	0.44
RP+PSB	1.652	1.353	3.01	35	0.40
RP+FYM	2.100	2.427	4.53	57	0.42
RP+FYM+PSB	2.781	2.521	5.30	91	0.43
RP+OA	3.582	3.360	6.94	131	0.45
RP+ATS	3.616	3.518	7.13	133	0.45
RP + ATS + OA	3.764	3.561	7.33	140	0.46
LSD 5%	**0.106**	**0.192**	**0.184**	**9.60**	**-----**

RP: (Rock Phosphate), **SSP:** (Superphosphate)**, RP+PSB:** (Rock Phosphate+ Phosphate solubilizing bacteria**, RP+FYM:** (Rock phosphate + Farmyard manure)**, RP+FYM+PSB**: (Rock Phosphate + Farmyard manure + Phosphate solubilizing bacteria), **RP+ATS:** (Rock Phosphate + Ammonium thiosulfate)**, RP+OA:** (Rock Phosphate + Oxalic acid)**, RP+OA+ATS: (**Rock Phosphate + Oxalic acid + Ammonium thiosulfate)

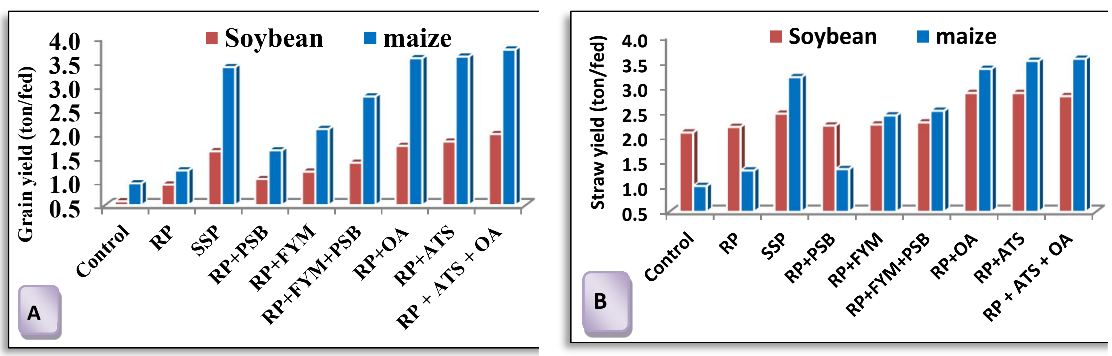

Fig. 2: Effect of different amendments on the grain yield (A) and straw yield (B) of soybean and maize plants

The P use efficiency (grain yield per unit of applied P) of the plant is the ability of the root system to acquire P from soil and accumulate it in the shoots. The response to the PUE of ATS was more prominent when ATS was combined with OA combined to ATS+RP or OA+RP and all other treatments while PUE was low under the following order RP+PSB < RP+FYM < RP+FYM+PSB in soybean and maize however, main showed the highest values for PUE (Figure 3). The PUE recorded for the treatments RP+ATS+OA were (109 and 140 kg grain yield/kg P), RP+ATS were (97 and 133 kg grain yield/kg P) and RP+OA were (89 and 131 kg grain yield/kg P) were statistically higher than all amendments, and RP only or SSP in soybean and maize, respectively (Table 8 and Figure 4).

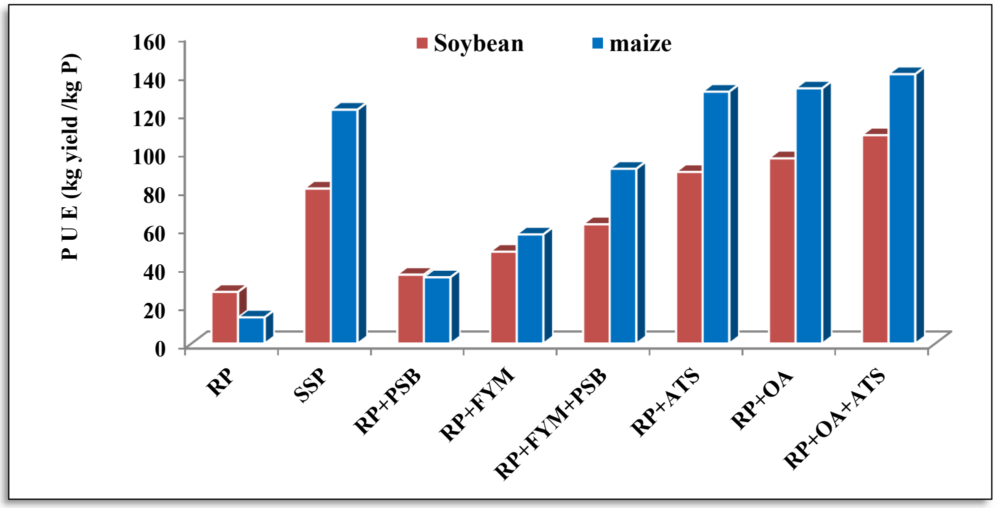

Fig. 3: Effect of different amendments on P use efficiency (PUE) of the soybean and maize plants

Therefore, holds a lot of promise as an efficient alternative to conventional P fertilizers, especially regarding its effectiveness for the PUE of RP. By averaging across the treatment, PUE in the treatments receiving RP+ATS+OA followed by RP+ATS then RP+OA increased to (34.0% and 73.1%), (19.2% and 64%) and (10.4% and 62%) in soybean and maize, respectively compared to the SSP treatment. Our results were in agreement with Fernández *et al.,* (2009); Gastal and Lemaire, (2002) and Fageria and Baligar, (1997). They explain that maize (a C4 plant) clearly showed higher P utilization efficiency than soybean and sunflower (both C3), either expressed as biomass or grain produced per unit of absorbed P. This result shows that the apparent improvement in yield increase is reflected positively in the efficiency of stimulate agents used to achieve the best results in light of the steady increase in the prices of energy and fertilizer required for production at present. Total uptake and recovery of NPK by soybean and maize (grain and straw) plants was significantly affected by stimulant agents added to RP (Table 9 and Figures 4 and 5). Oxalic acid coupled with ATS recorded the highest nutrient uptake and recovery due to higher biomass production and concentration of nutrients over SSP and RP or control treatments. The positive effect of OA+ATS on nutrients uptake and recovery of (NPK) properly due to a more uniform distribution of stimulant agents in the soil profile, which would diminish the potential effects of lower P diffusion or shallower root system or both on P acquisition efficiency. The highest N, P, and K uptake by grain yield (GY) were recorded with the treatment of RP+ATS+OA (68.6, 6.9, and 23.1kg/fed) and (49.7, 7.88, and 15.4kg/fed) in soybean and maize crops, respectively compared to control or all amendments, while the lowest N, P and K uptake by grain yield (GY) were recorded with the treatment of RP only (26.0, 2.8 and 10.2 kg/fed) and (12.5, 1.77 and 3.7 kg/fed) in soybean and maize crops, respectively compared to control or all amendments (Table 9 Figure 4). The better N, P, and K uptake performance with (OA+ATS) can be attributed to significantly higher dry biomass and content for all yield components as in the case of soybean and maize crops (Figure 6). The beneficial effect of OA+ATS is related to their effect on the chemical and biological soil conditions such as reducing soil pH and releasing more phosphorus as well as several other nutrients available to plant uptake. The convective use of OA+ATS produced the best results of N, P, and K uptake by grain yield as in the case of soybean and maize crops increased by (24.4, 27.0 and 28.0 %) and (20.5, 23.4, and 66.0%) compared to SSP, respectively.

The cumulative recovery of P and K under different amendments for soybean plants were maximal at (40.3% and 26.6%) for RP+ATS+OA, (35.6% and 23%) for RP+ATS and (31.8% and 23.6%) for RP+OA, respectively, and for maize plants the cumulative recovery of N, P, and K under different amendments were maximal at (57%, 43%, and 58.8%) for RP+ATS+OA, (55%, 40%, and 57.7%) for RP+ATS and (52 %, 37% and 53.7%) for RP+OA, respectively, while values were lowest as observed when used RP+PSB followed by RP+FYM then RP+FYM+PSB (Table 9 and Figure 5). Data in Table (9) and Figure (5) appearance that the maize plants recover more P than soybean under all treatments, however, this crop species has a higher ability to deal with phosphorus in the soil more efficiently than any other plants which may relate to the specific crop effect (Fernández *et al.* (2009). In addition, it seems that the availability of nutrients evenly with frequent fertigation was responsible for the improvement of nutrient uptake and recovery in the root zone coupled with better nutrient diffusion primarily because of lower pH value in the soil resulting from ATS (Wu *et al.,* 2017; Akande *et al.,* 2010).

The N:P ratios in grains and straw total uptake were higher in (RP+ATS), but mainly in the (RP+ATS+OA) which gave the best ratio. This corresponded to a lower N:P ratio by soybean and maize (8.50 and 5.25) vs. (9.06 and 5.69), respectively in SSP corresponding to a relatively higher P uptake than N uptake indicating the enhancing effect of such compounds on absorption of phosphorus (Table 9). Increases in N and P uptake by soybean and maize plants likely contributed to the large increase in grain, biomass, since fruit is a major nutrient sink Güsewell, (2004). Phosphorus stress early in the growing season can restrict crop growth, which can carry through to reduce final crop yield. Deficiencies during early growth generally have a greater negative influence on crop productivity than P restrictions imposed later in growth. However, plants respond to P application by adaptations the ability to access and accumulate P early in the season is a crucial factor including modification of rhizosphere pH, and diversion of P resources to available form, which may increase root proliferation in high-P regions to optimize high yield production (Grant *et al.,* 2001). This may explain the reason behind the positive effect of oxalic acid (OA) coupled with ATS on the yield production of soybean and maize crops.

Table 9: Nutrients (NPK) uptake, recovery by the grain yield (GY), straw yield (SY) by soybean and maize and N:P ratio by RP fertilization with different stimulant agents (average of two years)

Treatment	N uptake (kg/fed)		P uptake (kg/fed)		K uptake (kg/fed)		N recovery %	P recovery %	K recovery %	N:P
	GY	SY	GY	SY	GY	SY				
					Soybean					
Control	16.3	5.58	1.6	1.0	6.4	5.4	--	--	2.3	9.71
RP	26.0	9.14	2.8	1.6	10.2	8.6	--	7.1	4.7	9.35
SSP	55.1	13.57	5.4	3.1	18.1	13.6	--	26.7	11.6	9.06
RP+PSB	27.7	10.26	3.1	1.7	10.8	9.2	--	9.6	11.8	9.01
RP+FYM	35.1	11.72	3.3	2.2	12.9	10.3	--	12.9	21.0	9.58
RP+FYM+PSB	42.0	12.77	4.0	2.7	14.9	11.8	--	19.3	11.3	9.28
RP+OA	60.6	13.82	6.1	3.3	19.4	15.8	--	31.8	23.6	8.76
RP+ATS	64.5	14.55	6.5	3.8	21.3	16.9	--	35.6	23.0	8.53
RP + ATS + OA	68.6	15.30	6.9	4.0	23.1	17.1	--	40.3	26.6	8.50
LSD 5%	1.77	2.48	0.226	0.396	0.385	0.651	--	--	--	--
					Maize					
Control	9.4	6.1	1.35	1.22	2.9	7.1	8	--	10.1	6.02
RP	12.5	8.2	1.77	1.72	3.7	9.3	12	2	15.3	5.94
SSP	41.2	22.3	6.38	4.79	13.1	23.9	48	31	58.0	5.69
RP+PSB	12.6	8.7	1.80	1.76	3.8	9.5	13	2.0	23.4	5.96
RP+FYM	24.3	16.0	3.88	2.91	7.4	17.0	29	15	30.0	5.93
RP+FYM+PSB	29.6	17.1	4.38	3.78	8.3	17.6	34	20	39.5	5.72
RP+OA	45.1	23.2	6.84	5.71	14.0	25.2	52	37	53.7	5.44
RP+ATS	47.2	24.6	7.17	6.33	14.7	26.4	55	40	57.7	5.32
RP + ATS + OA	49.7	25.3	7.88	6.41	15.4	26.7	57	43	58.8	5.25
LSD 5%	1.395	1.179	0.403	0.484	0.345	0.484	--	--	--	--

RP: (Rock Phosphate), **SSP:** (Superphosphate)**, RP+PSB:** (Rock Phosphate+ Phosphate solubilizing bacteria**, RP+FYM:** (Rock phosphate + Farmyard manure)**, RP+FYM+PSB**: (Rock Phosphate + Farmyard manure + Phosphate solubilizing bacteria), **RP+ATS:** (Rock Phosphate + Ammonium thiosulfate)**, RP+OA:** (Rock Phosphate + Oxalic acid)**, RP+OA+ATS: (**Rock Phosphate + Oxalic acid + Ammonium thiosulfate)

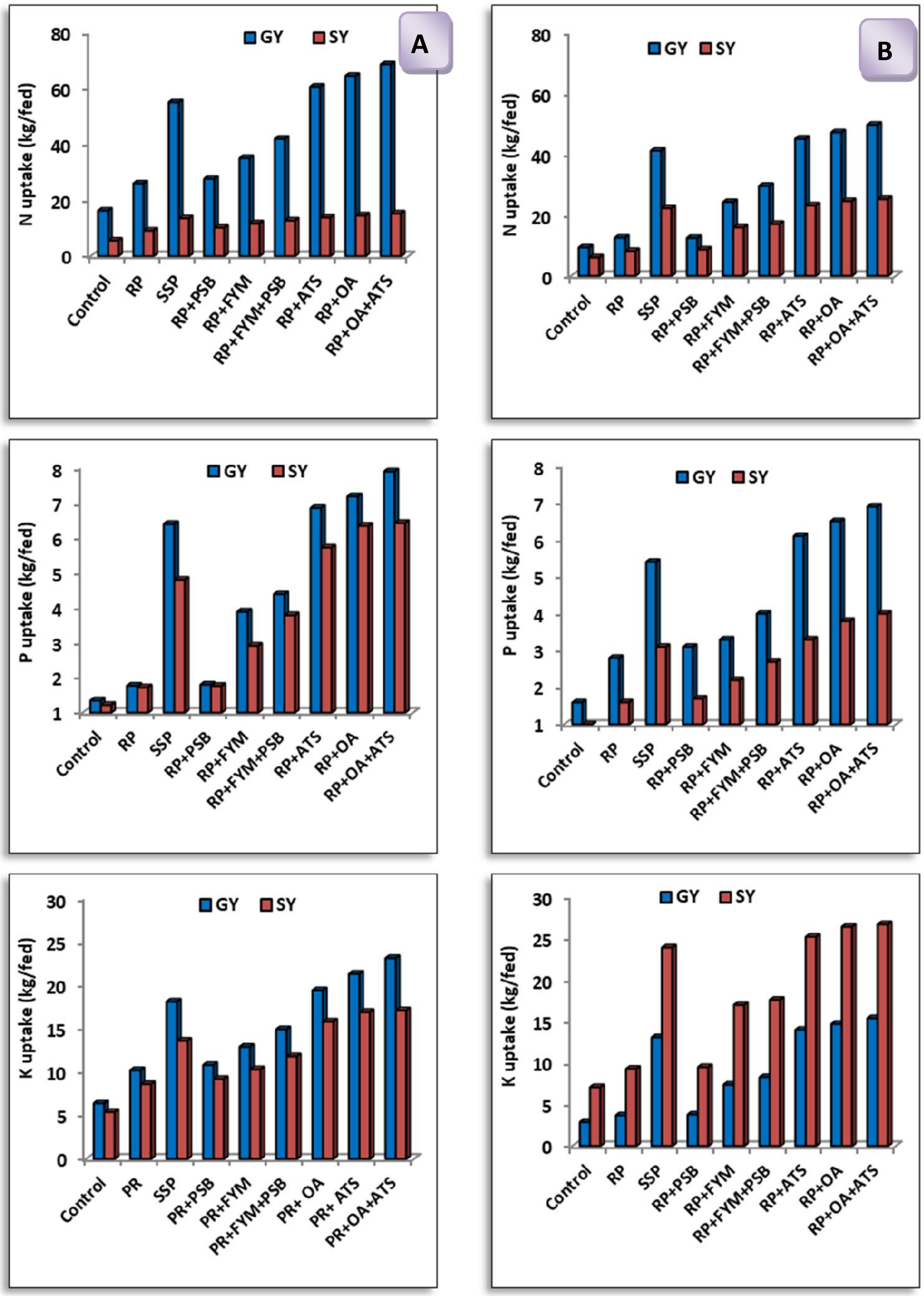

Fig. 4: Nutrients (NPK) uptake of grain yield (GY) and straw yield (SY) under effect of different stimulation agents by soybean (A) and maize (B).

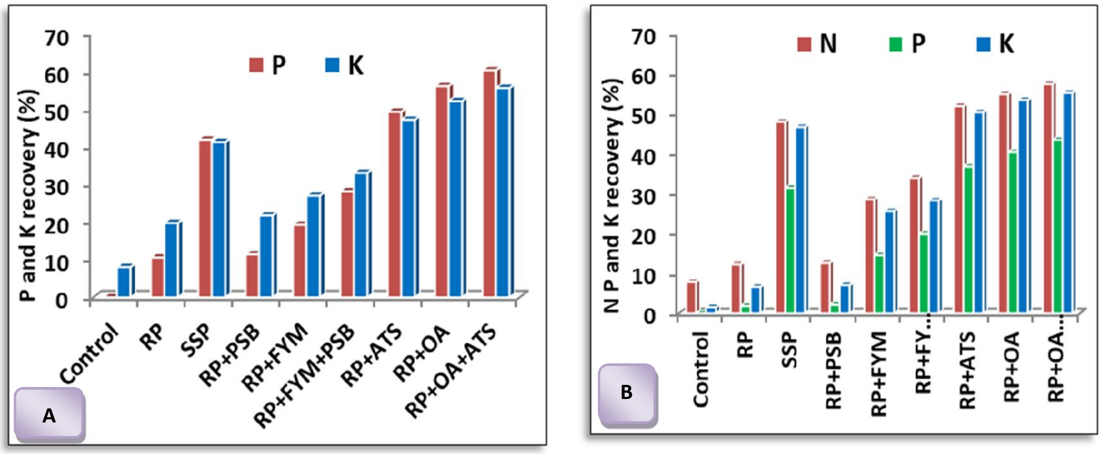

Fig. 5: Effect of different amendments on P and K recovery by soybean (A) and NPK recovery by maize plants (B)

Finally, organic acids have the potential to increase P release from RPs, particularly oxalic acid due to the acidic effect and chelation reactions with the metal associated with P, resulting in available P form suitable for plant uptake. Integration of oxalic acid and ammonium thiosulfate mixed with rock phosphate enhanced yield and all yield parameters of soybean and maize. The conjunctive use of OA and ATS represents many unique features such as ease of addition, corresponding to automation, and increases crop yield, which compensates for or even exceeds the increase in costs.

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