Original Research Article

Assessment of activatedcharcoal with phosphorus for promoting maize production

ABSTRACT

The most continuous farming practice is the yearly addition of phosphorus fertilizers to soils in arid and semi-arid regions that all suffer from shortages of phosphorus availability.A vital approach is rationalizing applied fertilizers and trying to benefit from their reservoir in yearly-fertilized old soils using an activated charcoal-fertilizer mixture.Thus,a field experiment was conducted at a private farm in Mushtuhur, Toukh, Qalyubia Governorate, Egypt.This trial was set up to study the effect of phosphorus (P) fertilizer sources (phosphoric acid Ph.A and super phosphate S.Ph), the P application rates (P0=control, P1=50%, P2=75% and P3=100% of P requirements), activated charcoal (A.Ch) rates (A.Ch0=control, A.Ch1=1, A.Ch2=3 and A.Ch3=5 g/hole) and the interaction between them on promoting maize growth, production and its nutrient status. Generally, adding phosphorus improved plant height, dry grains, and ash yield without a significant difference between all P rates. Phosphoric acid affects most studied parameters,mainly the biological, ear, and ash yield;it was the best compared with superphosphate. Adding the 1st rate of A.Ch improved the studied growth and yield parameterssignificantly compared withthe control. Slight enhancement was induced by the 2ndA.Chdose, and there was no significant difference between the 3rd and 4th rates in most studied parameters. These results shed light on the fact that there is no need to add P fertilizers yearly, as described by the recommendations of the Ministry of Agriculture. Different materials can move the fixed P in old clayey soil, such as A.Ch.

Keywords: Charcoal, phosphorus fertilizers, phosphoric acid, superphosphate, maize

1. INTRODUCTION

Our world faces many biotic and abiotic stresses due to climate change, which increases fertilizer application rates to combat the depression in crop yield due to these unfavorable conditions (Abou-Baker, 2023). The massive amount of applied fertilizers leads to adverse economic, environmental, and health impacts, thus forcing us to rationalize applied fertilizer amounts concurrently with the benefits of the fertilizer reservoir in yearlyfertilized old soils.One of the most essentialelements crops need, which affects their productivity, is added annual, and has availability problems under different soil conditions is phosphorus nutrient. It induces the development of plant reproductive organs, promotes root growth, and enhances crop quality and maturation through accretion, transfer,and release of energy in several cellular metabolic processes during degradation andbiosynthesis(Meyer et al.,2011;Hussein et al., 2015).It is known that 80-90% of the P applied to the soil isuseless, resulting in a considerable loss of resources. The use of P fertilizers in clay soils leads to P-fixation processes due to the increase in the specific surface area, the high level of $CaCO_{3,}$ and pH in most cases, which reduces its effectiveness. The occurrence of inert forms can be attributed to the ability of many soil constituents to bind P: clay minerals, carbonates, iron and aluminum hydroxides, and organo-mineral complexes (Gérard, 2016), which compels farmers to augment phosphorus availability for plants..

The addition of charcoal may represent a solution to the problem of the availability of nutrients, especially P, through a reduction in P sorption sites and improve the soil'sphysical and chemical properties (Stephens et al., 2005;Zhao et al., 2016).Incorporating charcoal into soils can sequester substantial quantities of carbon for periods extending to hundreds of millions of years..Charcoal has many direct benefits:1) significantly increasing soil fertility,2) reducing the amount of organic and inorganic fertilizer use,3) improving water soil relations as waterholding capacity,4) enhancing the cation exchange capacity,5) neutralizing soil pH, which is required for crop production in soils (Stephens et al., 2005). This may result from charcoal's extensive surface area, porous characteristics, and ability to hold water and nutrients.

In many regions, maize has become a staple meal for people and animals. It is also to producestarch, syrup, ethanol, and biofuels. Maize has become a staple food in many parts of the world, with the total production of maize following the sugarcane and surpassing that of rice and wheat. In 2022, the harvested area of maize in Egypt was 930 thousand ha, producing 7.5 million tonnes (FAO, 2024).

Therefore, the study aims to find out the most appropriate type of fertilizer used as a source of phosphorous with the addition of charcoal and the most responsive by the plant, as well as knowing the properrate of charcoal, which enhances the utilization of phosphorus. The second Sustainable Development Goal (SDG2),"To end hunger, achieve food security and improved nutrition and promote sustainable agriculture," issupported by the objectives of this manuscript.

2. MATERIALS AND METHODS

2.1. Charcoal activation

The activation process of traditional coal was performed chemically in the laboratory as follows:

Five hundred grams of dried and grounded coal wasmixed with a water solution of CaCl2 with $1CaCl_2$: 3water. The produced homogeneous mortar was dried at 105°C to constant weight. The resultant powder was washed with distilled water and filtered, then dried at 105 for 30 minutes.

2.2. A Field Experiment

A field experiment was conducted at a private farm (30°20′ 45.0″N and 31°14′ 19.9″E) in Mushtuhur, Toukh, Qalyubia Governorate, Egypt. View of the field location is illustrated in Fig. (1). This experiment was established to study the effect of phosphorus fertilizer source (phosphoric acid Ph.Aand super phosphateS.Ph), the P application rates (P0=control, P1=50%, P2=75% and P3=100% of P requirements = 71.4 P_2O_5/ha), activated charcoal application rates (A.Ch0=control, A.Ch1=1, A.Ch2=3 and A.Ch3 =5g/hole) and the interaction between them on promoting maize(*Zea mays* L. var. Hi Tech 2031) growth, production and its mineral status. The Ministry of Agriculture recommended the application of 714 kg of urea and 119 kg of potassium sulfate per hectare of maize. The irrigation system was flooded. According to the Ministry of Agriculture's recommendations, the other agricultural practices were uniform and constant for all experimental areas.

Soil texture was determined using the pipette method. Soil pH wasdetermined at a ratio of 1:2.5,and electrical conductivity (EC) was determined at a ratio of 1:5 (soil:distilled water) using a digital pH meter and EC meter. Soil organic matterwas determined using the Walkely-Black methodmethod.The measured characteristics of the studied soil were determined as described by Page et al. (1982) and Klute (1986) and presented in Table 1.

At the harvest stage, plant height (m), leaves area (cm^2), biological cob,dry weight of grains (t ha^{-1}), ash yield (t ha^{-1}), and moisture in grains (%) were measured. Halve gram of dried grains from each replicate were digested for analysis.Microkjeldahl analyzed nitrogen (%), P (%) was colored using the ascorbic acid technique, and K (%) was recorded using a flame photometer apparatus. NPK content (kg/ha) and available NPK ppm were determined **(**Cottenieet al., 1982).

The experimental design was a Split-Split Plot (SSP).Themain plot contains a phosphorus source, the sub-plot contains the phosphorus rates, and the sub-sub plot contains the activated charcoal rates with three replicates. The analysis of variance (ANOVA) andthe least significant difference (LSD$_{0.05}$) test were applied to compare the mean values (Anonymous, 1989).

Fig(.1)View of the field location inEgypt.

Table (1): Some characteristics of the studied soil

Soil characteristic	The value
Chemical analyses	
pH(1:2.5)	8.39
EC(dSm^{-1})	1.28
Calcium carbonate %	3.02
Organic matter %	1.43
Available N (mg kg^{-1})	56.0
Available P (mg kg^{-1})	27.36
Available P (mg kg^{-1})	365.51
Particles size distribution	
Sand %	24.8
Silt %	32.00
Clay %	43.2
Textural class	Clayey soil

3. RESULTS

Growth parameters and yield component

The studied factors affected most of the growth parameters and yield components. Fig. (2) illustratesthe early growth of maize plants as affected by some treatments in the field.

Fig. (2) The early growth of maize plants as affected by some treatments in the field.

The data of plant height (m) at the harvest stage as affected by activated charcoal rates, phosphorus fertilizer sources, and rates are shown in Table (2). Phosphoric acid is superiorto superphosphate in increasing plant height. Phosphorus addition increased plant height compared with control (P0) without significant difference.The different application ratesof A.Chdidn't show significancein its effect on plant height. As for the third interaction between P-source, P-rate, and Ch-rate,the highest value was obtained by Ph.Ax P2x Ch0, Ph.A x P2x Ch1, and Ph.A x P3x Ch2 treatments, while the lowest value resulted fromS.Ph x P0x Ch0 and S.Ph x P1x Ch1 (Table 2).

Table (2)Plant height (m) as affected by activated charcoal rates, phosphorus fertilizer sources, and rates.

P-sources	A.Ch rates	P rates				Mean
		P0	P1	P2	P3	
Ph.A	A.Ch$_0$	2.7	3.1	3.2	3.0	3.0
	A.Ch$_1$	3.0	3.1	3.2	3.0	3.1
	A.Ch$_2$	3.0	3.1	3.0	3.2	3.1
	A.Ch$_3$	3.0	3.1	3.1	3.1	3.1
Mean		2.9	3.1	3.1	3.1	3.1
S.Ph	A.Ch$_0$	2.7	2.8	2.8	2.8	2.8
	A.Ch$_1$	3.0	2.7	2.8	2.8	2.8
	A.Ch$_2$	3.0	2.8	2.9	2.9	2.9
	A.Ch$_3$	3.0	3.1	3.0	3.0	3.0
Mean		2.9	2.8	2.9	2.9	2.9
Mean	A.Ch$_0$	2.7	3.0	3.0	2.9	2.9
	A.Ch$_1$	3.0	2.9	3.0	2.9	2.9
	A.Ch$_2$	3.0	3.0	3.0	3.0	3.0
	A.Ch$_3$	3.0	3.1	3.0	3.0	3.0
Mean		2.9	3.0	3.0	3.0	
LSD0.05	P source =0.03*** P rate=ns ch rate=ns ch rate xP rate=* P source x P rate=*** P source x ch rate=** P source x ch					

	rate x P rate=0.14**

Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

Although there was no significant alteration in biological yield between P-sources, applyingPh.A improved the biological yield compared with S.Ph (Fig. 3). The biological yield was affected significantly by increasing P rates. So, the third P (P3) application rate produced the highest biological yield value.The addition of A.Ch increased the biological yield compared with A.Ch0. The first application rate A.Ch1 produced the highest response (28.6%) compared with the preceding rate. The second-rate A.Ch2 only increased the biological yield by 7.27% compared with A.Ch1. Moreover, there is no significant difference between the second and third rates of activated charcoal (Fig. 3).

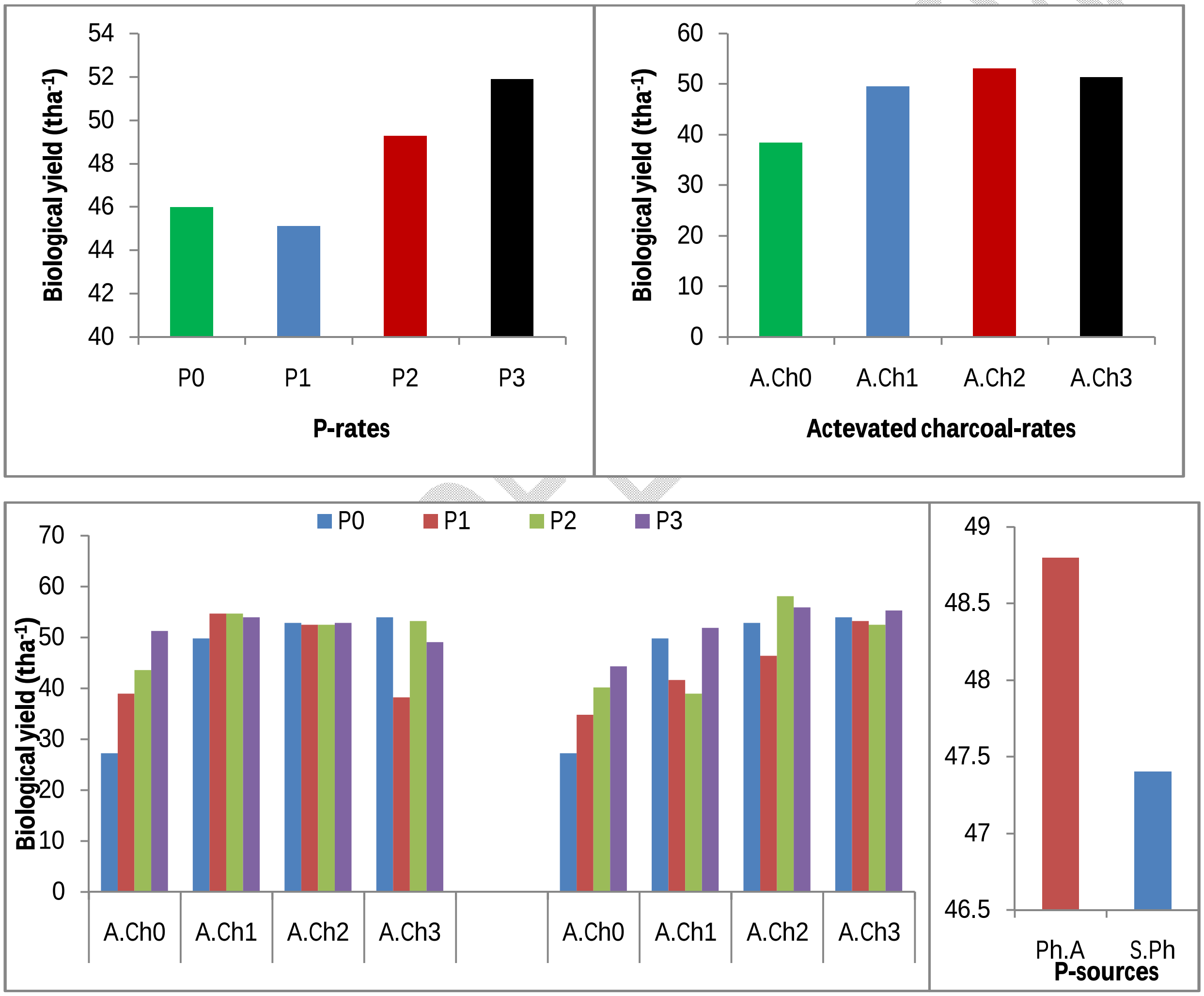

Fig. (3) Biological yield(t ha^{-1}) as affected by phosphorus fertilizer source**s,** rates,and activated charcoal rate**s.** Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

The data of ear yield (t ha^{-1}) as affected by phosphorus fertilizer sources, rates, activated charcoal rates, and the interaction between them are shown in Table (3).No significant difference appears in ear yield whenusing Ph.A compared with S.Ph.Phosphorus addition increased ear yieldcompared with control (P0) without significant difference among P rates.The A.Ch ratesaffected ear yield significantly. The highest variation appeared between A.Ch1 and A.Ch0. The response percentage of ear yield gradually decreases by increasing A.Ch rates. The difference between A.Ch2 and A.Ch3 werenot significant.Regarding the interaction among the studied factors, the highest value resulted from A.Ch3 rate without P addition (Table 3).

Table (3)Ear yield (t ha^{-1}) as affected by phosphorus fertilizer source**s,** rates,and activated charcoal rate**s.**

	A.Ch rate	P rate				Mean
		P0	P1	P2	P3	
Phosphoric acid	A.Ch$_0$	13.7	24.7	26.3	26.6	22.8
	A.Ch$_1$	28.7	29.9	28.3	26.9	28.4
	A.Ch$_2$	29.4	28.4	24.9	27.5	27.6
	A.Ch$_3$	31.4	23.6	27.5	26.5	27.3
Mean		25.8	26.7	26.8	26.9	26.5
Superphosphate	A.Ch$_0$	13.7	20.2	24.1	24.9	20.7
	A.Ch$_1$	28.7	22.6	22.6	27.3	25.3
	A.Ch$_2$	29.4	27.3	30.8	30.1	29.4
	A.Ch$_3$	31.4	30.3	30.5	29.0	30.3
Mean		25.8	25.1	27.0	27.8	26.4
Mean	A.Ch$_0$	13.7	22.5	25.2	25.7	21.8
	A.Ch$_1$	28.7	26.2	25.4	27.1	26.9
	A.Ch$_2$	29.4	27.9	27.8	28.8	28.5
	A.Ch$_3$	31.4	27.0	29.0	27.7	28.8
Mean		25.8	25.9	26.9	27.4	
LSD0.05	P source =nsP rate=ns ch rate=1.0*** ch rate xP rate=*** P source x P rate=ns P source x ch rate=*** P source x ch rate x P rate=2.6***					

Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

The outcomes in Table (4) revealed no significant differences between Ph.A and S.Ph or among the different P rates in dry weight of grain yield (t ha^{-1}).Meanwhile, the values of dry grain yield were affected significantly by increasing A.Ch rates. So, the third application rate of A.Ch (A.Ch3) produced the highest value but without significant differencecompared with A.Ch2.The increase in percentages of dry grain yield by the addition of A.Ch1, A.Ch2, A.Ch3 were 29.1, 39.7, and 41.2% compared with control (A.Ch0). The A.Ch2 treatment increased the dry grain yield by only 8.2% compared with A.Ch1 whilethe first application rate A.Ch1 produced the highest response (29.1%) compared with A.Ch0. The heist value of grain yield resulted from the third interaction between Ph.A x A.Ch3 x P0, followed by Ph.A x A.Ch2 x P0, and the next is Ph.A x A.Ch2 x P1 without significant difference among them(Table 4).

The general mean values of cob weight (t ha^{-1}) showed that the addition of both P-sources (Ph.A and S.Ph) produced the same cob weight (15.1 t ha^{-1}), as shown in Table (5). P2 and P3 increased cob weight significantly compared with P0 and P1 without significant differences between them (P2 and P3) or between P0 and P1. The addition of A produced the highest cob weight.Ch3 without phosphorus application.

Table (4)Dry weight of grain yield (t ha^{-1}) as affected by phosphorus fertilizer source**s,** rates,and activated charcoal rate**s**

P-sources	A.Ch rates	P rates				Mean
		P0	P1	P2	P3	
Ph.A	A.Ch$_0$	5.04	7.90	9.75	10.32	8.25
	A.Ch$_1$	11.00	12.15	10.97	10.47	11.15
	A.Ch$_2$	12.23	12.22	9.76	10.52	11.18
	A.Ch$_3$	12.63	9.02	11.07	10.58	10.83
Mean		10.23	10.32	10.39	10.47	10.35
S.Ph	A.Ch$_0$	5.04	7.63	9.57	10.10	8.09
	A.Ch$_1$	11.00	9.20	9.02	10.58	9.95
	A.Ch$_2$	12.23	10.35	12.27	11.68	11.63
	A.Ch$_3$	12.63	12.53	12.40	11.45	12.25
Mean		10.23	9.93	10.82	10.95	10.48
Mean	A.Ch$_0$	5.04	7.76	9.66	10.21	8.17
	A.Ch$_1$	11.00	10.68	9.99	10.53	10.55
	A.Ch$_2$	12.23	11.29	11.01	11.10	11.41
	A.Ch$_3$	12.63	10.78	11.74	11.02	11.54
Mean		10.23	10.13	10.60	10.71	
LSD0.05	P source =ns P rate=ns ch rate=0.6*** ch rate xP rate=*** P source x P rate=* P source x ch rate=*** P source x ch rate x P rate= 1.0***					

Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

Table (5) Cob weight (t ha^{-1}) as affected byphosphorus fertilizer sources, rates, and activated charcoal rates

P-sources	A.Ch rates	P rates				Mean
		P0	P1	P2	P3	
Ph.A	A.Ch$_0$	8.2	13.8	15.2	15.3	13.1
	A.Ch$_1$	16.4	17.0	16.2	15.3	16.2
	A.Ch$_2$	16.4	15.0	14.0	15.7	15.3
	A.Ch$_3$	17.8	14.0	15.9	15.0	15.7
Mean		14.7	15.0	15.3	15.3	15.1
S.Ph	A.Ch$_0$	8.2	11.7	13.7	14.1	11.9
	A.Ch$_1$	16.4	12.3	13.0	15.7	14.4
	A.Ch$_2$	16.4	16.4	17.8	17.1	16.9
	A.Ch$_3$	17.8	17.1	17.0	16.5	17.1
Mean		14.7	14.4	15.4	15.9	15.1
Mean	A.Ch$_0$	8.2	12.8	14.5	14.7	12.5
	A.Ch$_1$	16.4	14.7	14.6	15.5	15.3
	A.Ch$_2$	16.4	15.7	15.9	16.4	16.1
	A.Ch$_3$	17.8	15.5	16.4	15.8	16.4
Mean		14.7	14.7	15.3	15.6	
LSD0.05	P source =ns P rate=0.7*ch rate=0.8***ch rate xP rate=*** P source x P rate=ns P source x ch rate=*** P source x ch rate x P rate=1.9**					

Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

The data of ash yield (t ha^{-1}) as affected by phosphorus fertilizer sources, rates, activated charcoal rates, and the interaction between them are shown in Table (6). Using phosphoric acid was more effective than superphosphate in increasing ash yield. No significant difference appears in ash yield whenusing different P rates.A highly significant effect was observed in ash yield by A.Ch application.The top variation appeared between A.Ch1 and A.Ch0. The increasing percentage of ash yield gradually decreases by increasing A.Ch rates compared with the preceding rate. The differencesamongA.Ch1, A.Ch2, and A.Ch3 were not significant. Concerning the interaction among the studied factors, the highest value was produced byPh.A. x A.Ch1 x P2 (Table 6).

Table (6)Ash yield(t ha^{-1}) as affected by phosphorus fertilizer sources, rates, and activated charcoal rates

P-sources	A.Ch rates	P rates				Mean
		P0	P1	P2	P3	
Ph.A	A.Ch$_0$	21.18	30.14	32.60	32.19	29.03
	A.Ch$_1$	37.93	41.82	46.74	43.87	42.59
	A.Ch$_2$	41.27	39.16	42.03	41.00	40.87
	A.Ch$_3$	43.73	28.77	41.62	33.62	36.94
Mean		36.03	34.97	40.75	37.67	37.35
S.Ph	A.Ch$_0$	21.18	25.49	25.42	25.52	24.40
	A.Ch$_1$	37.93	31.43	27.33	41.68	34.59
	A.Ch$_2$	41.27	35.53	44.55	43.05	41.10
	A.Ch$_3$	43.73	40.05	39.16	42.85	41.45
Mean		36.03	33.13	34.12	38.27	35.39
Mean	A.Ch$_0$	21.18	27.81	29.01	28.85	26.72
	A.Ch$_1$	37.93	36.63	37.04	42.78	38.59
	A.Ch$_2$	41.27	37.35	43.29	42.03	40.98
	A.Ch$_3$	43.73	34.41	40.39	38.24	39.19
Mean		36.03	34.05	37.43	37.97	
LSD0.05	P source =1.5* P rate=ns ch rate=2.8***ch rate xP rate=* P source x P rate= ** P source x ch rate=*** P source x ch rate x P rate=5.9 **					

Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

Nitrogen

The data of nitrogen concentration (%) and content (kg ha^{-1}), as affected by phosphorus sources, rates, andactivated charcoal rates, are illustrated in Fig (4). The different treatments and their interaction had no significant effect on nitrogen concentration and content except for the impact of P-rates and P-source x Ch-rates.The highest N concentration and content resulted from P0 x Ch1 and P0 x Ch3, respectively.

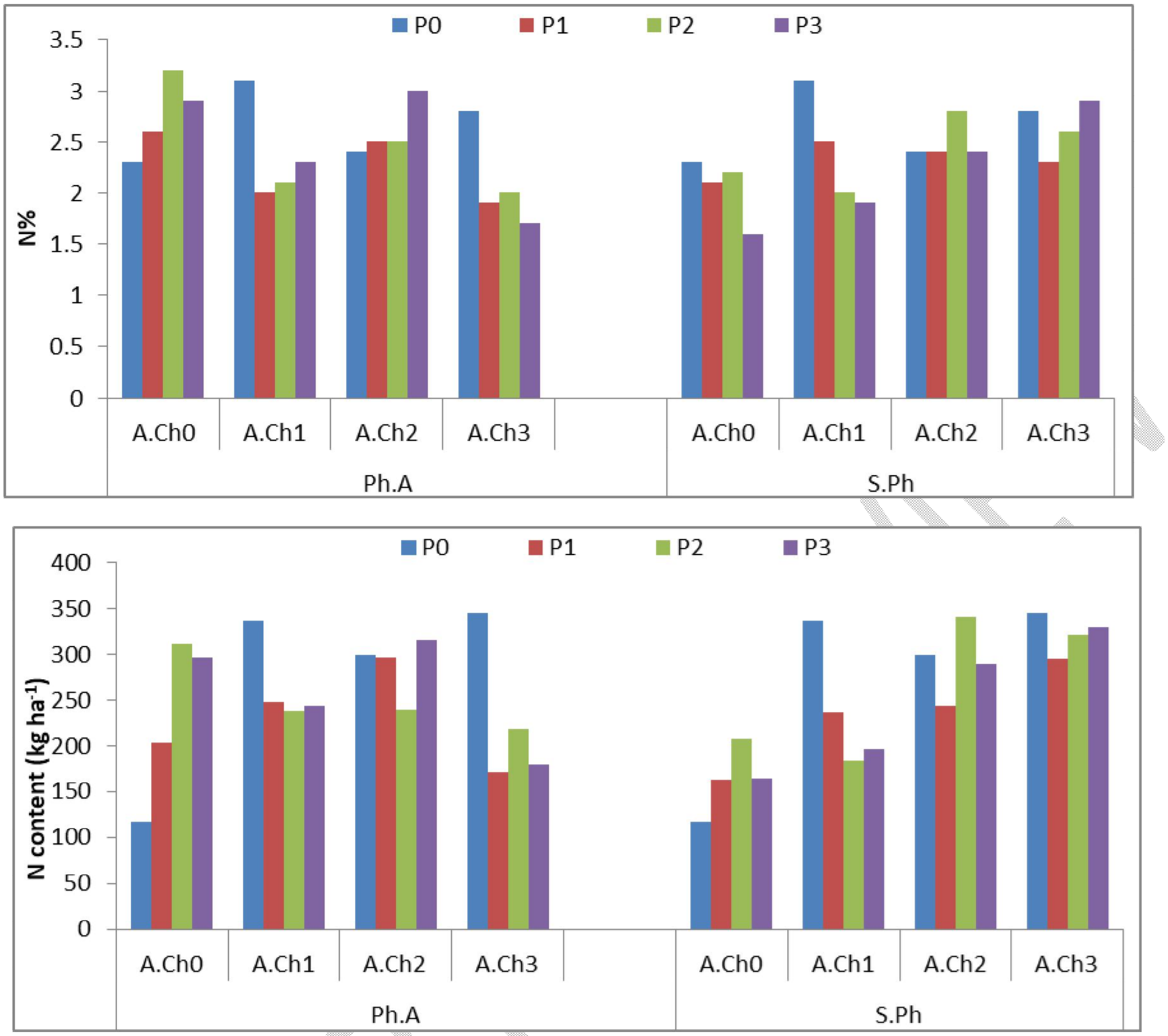

Fig. (5) Nitrogen concentration (%) and content (kg ha^{-1}) in maize grains (%) as affected by phosphorus fertilizer sources, rates, and activated charcoal rates. Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

Phosphorus

Although there was no significant variations were observed in P concentration bydifferent P-sources, A.Ch-rates, P-sources x P-rates, and P-sources x P-rates x A.Ch-rates, the effect of P-rates, A.Ch-rates x P-rates and P-sources x A.Ch-rates was significant (Fig. 6). Also P content affected significantly by all factors those affect P concentration in addition to A.Ch-rates.Like N%, the highestP concentration and content valuesresulted from A.Ch1 x P0.

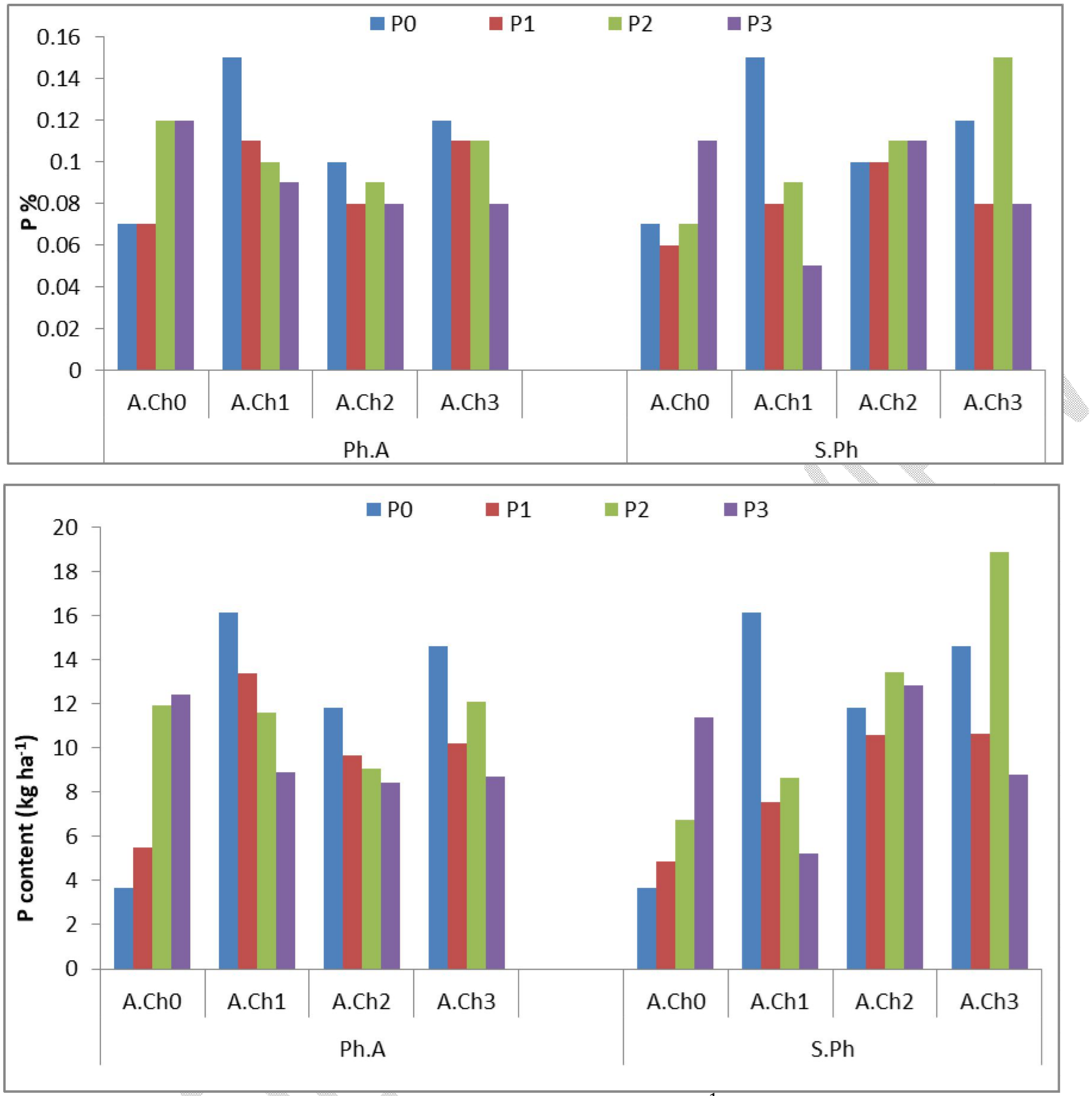

Fig. (6) Phosphorusconcentration (%) and content (kg ha^{-1}) in maize grains (%) as affected by phosphorus fertilizer sources, rates and activated charcoal rates. Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

Potassium

Except for the effect of A.Ch-rates x P-rates, all the studied factors and the interaction between them did not influence K concentration significantly (Fig. 7). Although there was a wide range in K% values where they ranged between 2.5 and 3.9%, they didn't follow a logical trend. As for K content, Ph.A was more effective than S.Ph and P2 rate was superior to the other rates but without significant difference.Regardless of the effect of P-sources and rates, the general mean of K content affected by A.Ch-rates was affected significantly and followed the order: A.Ch3> A.Ch2>A.Ch1>A.Ch0.

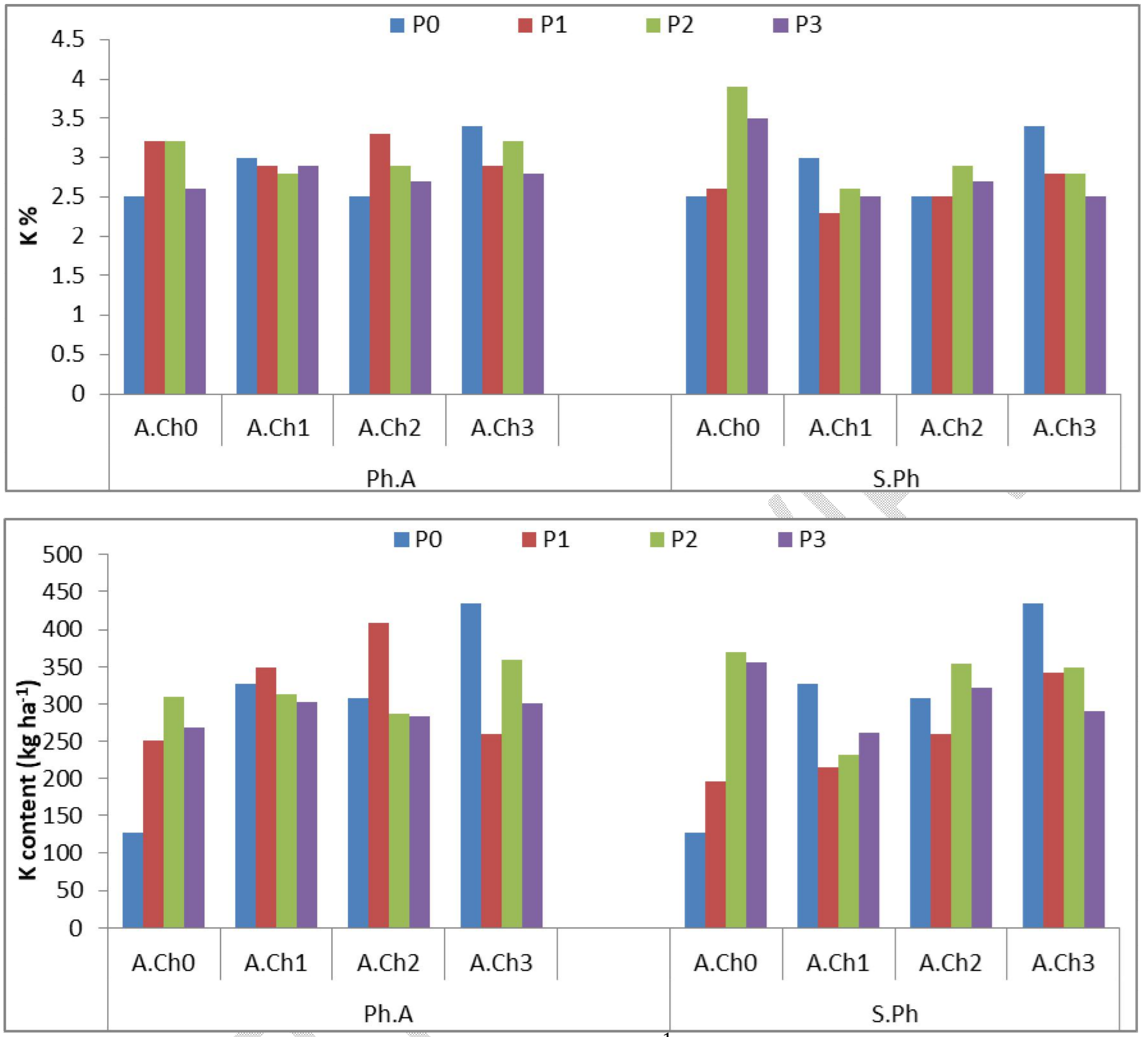

Fig. (7) Potassium concentration (%) and content (kg ha^{-1}) in maize grains (%) as affected by phosphorus fertilizer sources, rates, and activated charcoal rates. Ph.A=phosphoric acid, S.Ph= superphosphate, A.Ch= activated charcoal

4. DISCUSSION

Phosphorus element suffers from many problems in arid and semi-arid soils. P fixation by calcium can be maximized by 1) using S.Ph as a source of P. 2) mixing P fertilizers with soil, 3) increasingsoil pH, and others.Adding biochar enhances P retention in the soil (Zhao et al., 2016).

The highest value of plant height was obtained by Ph.A x P2x Ch0, Ph.A x P2x Ch1 and Ph.A x P3x Ch2 treatments, while the lowest value resulted from S.Ph x P0x Ch0 and S.Ph x P1x Ch1. The presence of Ph.A in all highest values confirms its superiority compared with S.Ph. In another study, plant height and leaves area of castorbean plants increased by adding Ph.A more than plants receiving monopotassium phosphate (Hussein et al., 2015).

The first application rate (A.Ch1) produced the highest response (28.6%) in biological yield compared with the preceding rate. The second-rate A.Ch2 only increased the biological yield by 7.27% compared with A.Ch1. Moreover no significant difference between the second and third rate of activated charcoal. This may be ascribed to the plant's response to the initial application dose, greater than the subsequent dose for all fertilizer applications, as recognized in plant nutrition science.

The addition of A produced the highest cob weight.Ch3 without phosphorus application. The cob weight increased with increasing the ear weight. Both ear weight and cob weight are positively related. Then increasing cob weight indicates good growth. However, at times, augmenting the cob weight proves to be a detrimental characteristic. This is accurate when the cob weight parameter did not correlate with ear growth and grain weight.

Although N, P, and K concentrations and content in maize grains were not affected significantly by the different Psources, spraying Ph.A increased the N and P content and decreased the K content in castorbean leaves (Hussein et al., 2015).Application of charcoal to enhancing P content in grains by adding more negatively charged surfaces to soil, increasing anion repulsion, and raising the available P in rhizosphere, thus increasing P uptake (Johan et al., 2022).Applying charcoal to soils for a long time can improve their chemical and physical characteristics. These enhancements not only lessen P fixation but also encourage the slow release of nutrients over time, increasing nutrient use efficiency to maximize crop yield (Johan et al., 2021).

The Ph.A was an applicable alternative to S.Ph as the most common P fertilizer (Hussain et al., 2011).The vast differences between S.Ph and Ph.A didn't appear as well as it was prospective because 1) The general mean values were affected by A.Ch treatments. The application of A.Ch. led to discrepancies in the logical trend of superiority of the Ph.A, 2)Calcium used in the activation process may reduce the release of phosphoric acid, 3) The liquefied P fertilizers may be less effective because the diluted P ions in the rhizosphere are easy to leachate and less reactive to the soil components than the granule P fertilizers, 4) The initial soil is fertile and has good chemical characteristics.Irrespective of A.Ch treatments (under normal conditions; A.Ch0), most of the studied parameters increased with increasing the application rates of Ph.A compared with the S.Ph rates.

On the other hand, Ph.A was even more effective than the typical commercial fertilizer because of its easy dissociation, making P available to plants, particularly in alkaline soils (Hussain et al., 2011).Meanwhile, adding A.Ch affects this main result and tends to decrease the gap between the studied P sources and rates.The efficiency of A.Ch depends on the synthesis method (Morais et al., 2023), the material used in activation, the physiochemical properties of the raw charcoal, and the interaction of the produced A.Ch. with the soil–plant–water system.

5. CONCLUSION

Under the condition of old clayey soils that are well-served and have a reservoir of many elements such as phosphorus, there is no need to add P fertilizers yearly as described by the recommendations of the Ministry of Agriculture. Different promising materials canreleasethe fixed P, such as activated charcoal. Using Ph.Anot only as a source of P but also as a material with a residual acidity-effect is the applicable method to solve the P problem under studied soil conditions.Further research is advised on phosphorus release in soils utilizing various materials, including activated charcoal, with diverse activation methods and components that improve phosphorus availability.

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