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Effect of Phosphorus Application on Durum Wheat in Alkaline Sandy Soil in Arid Condition of Southern Algeria

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ABSTRACT

The present study is the part of research program on the rational fertilization of durum wheat based on the long-term trials in El-Menia situated in arid region of south eastern Algeria. This study includes only the results of three years of experimentation. Three levels of phosphorus (30, 60 and 90 kg ha^{-1} P_2O_5) from three sources Mono-Ammonium Phosphate, Single Super Phosphate and Fosfactyl were applied on durum wheat (*Triticum durum* var. Carioca) under center pivot irrigation system. The experiments were made Two-Factor Hierarchical Designs during growing seasons 2008/2009, 2009/2010 and 2010/2011. Yield components, grain and straw yields; N, P content and their uptakes by grain were measured. For most of the tests, the fertilizer source had no effect on the traits studied except for phosphorus content where single super phosphate give the best value (0.4±0.004%). Indeed, 30 and 60 kg ha^{-1} P_2O_5 give the best 1000-grain weight and grain yield regardless of the year. For straw yield, 90 and 60 kg ha^{-1} give the best average values. Nitrogen (N) uptake grains have not been influenced by the doses of phosphorus regardless of year. The P content, grain yield, number of spikes/m² and N uptake increase with increase P uptake regardless of year. While number of grains/spike, N content and straw yield increased with the phosphorus uptake by year.

Key words: Wheat, wheat yield, P fertilizer, mineral nutrition, alkaline soil

INTRODUCTION

Phosphorus is one of the major plant nutrients that directly or indirectly affect all biological process (Raghothama *et al*., 2005). Its role in increasing tillering and growth is well recognized. As a part of nucleotides (e.g., ATP), P assumes an important role in energy transfer reactions (Raghothama *et al*., 2005; Chaturvedi, 2006). It is also involved in root development and in metabolic activities especially in synthesis of protein (Tanwar and Shaktawat, 2003). In addition, concentration of phosphate in the chloroplasts determines the transport of phosphorylated sugars and synthesis of starch.

Phosphorus availability is one of the major growth limiting factors in many ecosystems around the world (Barber *et al.*, 1963). Large amounts of P fertilizers are generally required for sustainable crop production on variable charge soils because of low P availability to plants (Barrow, 1986; Lin, 1995). In sandy soil of arid area of southern east Algeria, P is influenced by various factors such as alkaline (pH>7) soil conditions and the high $CaCO_3$ content (>3%). Regular applications of ordinary superphosphate to sandy soils in laboratory leaching experiments led to a buildup of acid extractable inorganic P even though more than 80% of P in the fertilizer was lost during the leaching phase following application (Ritchie and Weaver, 1993).

Due to these interactions, nearly 80% of applied P as fertilizers may be fixed in the soil (Barrow, 1980; Holford, 1997). According to Raghothama *et al.* (2005) and Rahim *et al.* (2007), P deficiency is very common on alkaline calcareous soils. The amount of soil P removed by crops need to be replenished through the application of fertilizer P and manure to maintain soil P balance (Saleque *et al.*, 2006).

The crucial fact about P application to agricultural soils is that an insufficient dose will impede crop growth, while an overdose will be wasteful and also pose environmental threat of eutrophication (Dobermann and White, 1998) surface waters caused by increased P loading.

Therefore, the aim of present study was to assess the effect of different P fertilizers and rates on intensive irrigated winter wheat *Triticum durum* in an alkaline calcareous soil.

MATERIALS AND METHODS

Study area: Field experiments were carried out at Hadjadj Mahmoud farm located at El-Menia (southeastern Algeria) (30°57 N, 2°78 E, 397 m above sea level). This area is characterized by an arid climate, therefore very low and erratic rainfall. The minimum and maximum average annual temperature are 2°C (January) and 44°C (July), respectively. Rainfall is scarce and unevenly distributed; the average annual rainfall is 35 mm (average calculated over four years which are 2008, 2009, 2010 and 2011) (ONM., 2011).

Experimental design, treatments and crop management: A field experiments were carried out during 2008/2009, 2009/2010 and 2010/2011 growing seasons. Plots laid out in a hierarchical two-factor model design, P sources fertilizer applied at three rates 30, 60 and 90 kg P_2O_5 ha^{-1} at sowing time. The P fertilizers tested in 2008/2009 are the Single super phosphate P 20 and Fosfactyl NP 3:22, while in 2009/2010 and 2010/2011 a third fertilizer, Mono-ammonium phosphate NP 12:52, was added.

Crop was irrigated with center pivot system and receives an amount of 750 mm water during its growth cycle. For each trait, plants were sown in 1800 m^2 plots (24×75 m). The seeding rate was 200 kg ha^{-1}. The plots were fertilized with 212 kg N ha^{-1} as ammonium nitrate and urea 32, split into several provisions applied by fertirrigation.

Chemical analysis of soil, water irrigation and plant samples: The bulk sample of soil used was collected after crop harvest (winter wheat) from the upper layer of an arenosol (FAO., 2006), at depth of 0-30 cm sampled at five sampling points randomly selected along agricultural area. Soil samples were air dried, crushed, passed through a 2 mm sieve and stored for analysis. Routine analysis of the tested soil was determined according to the standard methods published by Richards (1954) and Jackson (1958). Soil pH and electrical conductivity were measured in deionized water (1:5 soil to solution ratio). The total $CaCO_3$ was analyzed by the gasometric method by using the calcimeter of Bernard. The total soil organic carbon was quantified by the Walkley-Black method (Yeomans and Bremner, 1998) and total nitrogen was determined by digestion with sulphuric acid and Kjeldahl distillation (Bremner, 1996). Phosphorus was determined colorimetrically in all extracts using Olsen method the ammonium molybdate-ascorbic (Olsen *et al*., 1954; Bowman and Cole, 1978) and exchangeable potassium analyzed by the Arnold method (Arnold and Close, 1961). Cation Exchange Capacity (CEC) was measured with ammonium acetate (1 moL L^{-1}, pH 8.7) leaching method (Metson, 1961).

At harvest, all the measurements were carried out on five square meters for each treatment. The traits studied were ears number/m² ($E \cdot m^2$), grains number/ear (NbrGr), 1000-grain weight (GW), grain yield (GrY), straw yield (StrY). Grain samples were analyzed for total N (%N DM) by Kjeldahl method and total P (%P DM) using the colorimetric ascorbic acid method. Wheat P and N uptakes were derived from the P and N concentrations and the grain and straw yields.

Statistical analysis: Data was recorded and classified using Microsoft Office Excel 2007. The significance of differences between the means was determined using analysis of variance (ANOVA) the level of significance $p<0.05$ with the software package Statistica 6.0.

RESULTS

Soil properties: Basic parameters of selected physical and chemical properties of soil samples are given in Table 1. The soil was sandy in texture, alkaline, calcareous and low in EC, very low in organic matter content, total nitrogen and phosphorus content (Table 1).

Characteristics of irrigation water: Agriculture is a major user of ground water in southern Algeria. Water is pumped from the continental interlayer (250 m deep). The water used is located in the C2S1 class (USDA., 1954) which has a good quality with low salinity risk even for sodicity (Table 2).

Components yield, grain and straw yields: Table 3 shows that there are no significant differences between fertilizers for the three tests.

Table 1: Basic parameters of selected physical and chemical properties of soil

Parameters	2008/2009	2009/2010	2010/2011
Mechanical properties			
Textural class	Sandy	Sandy	Sandy
Sand (g kg^{-1})	93.300	93.920	93.500
Silt+clay (g kg^{-1})	6.700	6.080	6.500
Physico-chemical properties			
Soil reaction (pH) (1:5 soil water extract)	8.400	8.620	8.600
Lime content (%)	8.930	13.500	1.840
Active lime (%)	6.880	7.210	-
EC (dS m^{-1}) (1:5 soil water extract)	0.170	0.175	0.114
Organic matter (%)	0.106	0.120	0.600
Total nitrogen (%)	0.080	0.065	0.010
Available P (mg kg^{-1} soil)	2.400	4.212	45.660

The effect of different levels of phosphorus differs according to the treatments and year. Indeed, the grains number/spike was not influenced by P levels whatever the year. By against, this effect is highly significant ($p \leq 0.001$) for spikes number/m^{-2} (2009/2010 and 2010/2011) and 1000-grains weight (2008/2009 and 2009/2010) and significant ($p \leq 0.05$) for grain yield (2009/2010) and highly significant ($p \leq 0.01$) for straw yield (2009/2010 and 2010/2011).

Annual comparison shows that the highest mean of spikes/m^2 (657.2) is obtained in 2009/2010, exceeding by 36.58 and 42.79% results of 2008/2009 and 2010/2011, respectively

Table 2: Chemical composition of irrigation water and electrical conductivity

Parameters	Values
pH	7.80
EC (dS m^{-1})	0.38
Ca^{2+} (mmol L^{-1})	0.77
Mg^{2+} (mmol L^{-1})	10.50
K^+ (mmol L^{-1})	0.34
Na^+ (mmol L^{-1})	1.50
Cl^- (mmol L^{-1})	2.50
SO_4^{-2} (mmol L^{-1})	25.60
HCO_3^- (mmol L^{-1})	15.30

Table 3: Effect of different rates of phosphorus application on components yield, grain and straw yields of wheat

Years	E.m^{-2}	NbrGr	GW (g)	GrY (q ha^{-1})	StrY (q ha^{-1})
2008/2009					
Fertilizers					
SSP	390.4	24.32	57.26	64.88	44.49
Fosfactyl	373.0^{ns}	24.70^{ns}	56.18^{ns}	72.28^{ns}	48.04^{ns}
Levels (kg ha^{-1})					
30	366.8	34.33	60.38^{a}	60.62	40.35
60	429.9	35.22	58.72^{a}	71.35	46.11
90	453.8^{ns}	20.06^{ns}	53.49^{b}***	72.365^{ns}	50.36^{ns}
General means	416.8	29.87	57.53	68.11	45.60
2009/2010					
Fertilizers					
SSP	667.9	23.77	42.80	67.79	79.15
Fosfactyl	651.8	24.79	42.04	68.00	83.11
MAP	655.2^{ns}	23.98^{ns}	40.74^{ns}	63.85^{ns}	70.73^{ns}
Levels (kg ha^{-1})					
30	639.4^{b}	25.38	43.35^{a}	69.26^{a}	72.18^{b}
60	672.2^{a}	23.87	43.22^{a}	69.48^{a}	79.95^{a}
90	660.1^{ab}***	23.37^{ns}	40.71^{b}***	62.58^{b}*	80.86^{a}**
General means	657.2	24.21	42.43	67.11	77.66
2010/2011					
Fertilizers					
SSP	379.7	29.13	52.82	59.18	62.53
Fosfactyl	347.7	28.27	50.45	50.48	67.24
MAP	371.7^{ns}	31.84^{ns}	50.04^{ns}	53.94^{ns}	65.20^{ns}
Levels (kg ha^{-1})					
30	358.3	29.66	49.44	53.24	58.93^{b}
60	396.0	30.19	51.03	61.09	71.67^{a}
90	374.7**	29.40^{ns}	50.55^{ns}	56.60^{ns}	61.29^{b}**
General means	376.0	29.75	50.34	56.93	63.96

,*Significant at $p \leq 0.01$ and $p \leq 0.001$, respectively, ns: Not significant, different superscript letters in a column shows significant difference

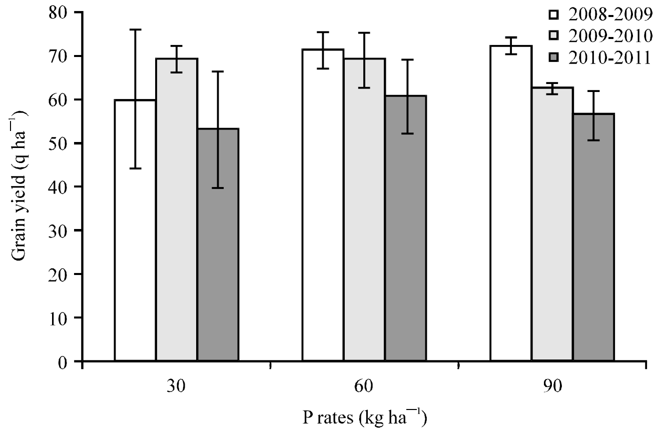

Fig. 1: Effect of P fertilization on grain yield of wheat

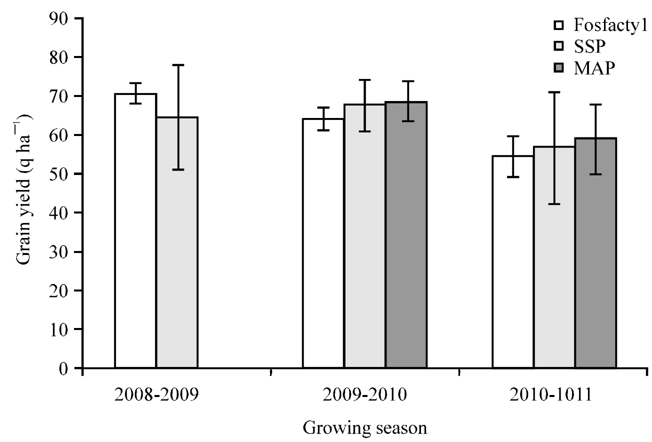

Fig. 2: Effect of P sources fertilizers on grain yield of wheat

(Table 3). The best 1000-grain weight mean was recorded in 2008/2009 with 57.53 g, exceeding 26.25 and 12.5% results achieved in 2009/2010 and 2010/2011, respectively.

The greatest mean grain yield was obtained during the 2008/2009 season (68.11 q ha^{-1}), with a gain of 1.00 and 11.18 q ha^{-1} compared to 2009/2010 and 2010/2011, respectively (Fig. 1). The highest straw yield was obtained in 2009/2010 with 77.66 q ha^{-1}, this value exceeds by 70.27 and 21.42% yields obtained in 2008/2009 and 2010/2011, respectively.

Obtained results emphasized that doses 30 and 60 kg ha^{-1} gave the best 1000-grain weight on the first two seasons and grain yield. For straw yield, levels 60 and 90 kg ha^{-1} in 2009/2010 and the level 60 kg ha^{-1} in 2010/2011 gave the best mean values (Fig. 2).

Phosphorus and nitrogen content by grains and straw and their uptakes: Grain P and N concentrations and their uptakes are presented in Table 4. Phosphorus source effect was significant ($p\leq 0.01$) only for P grain content in 2009/2010. While the rate effect showed a significant difference for N content of the grain ($p\leq 0.001$) in 2008/2009 and P content ($p\leq 0.01$) in 2010/2011. For all years, fertilizers had no significant effect on P and N uptakes. On the other side, dose effect was significant ($p\leq 0.001$) only for the P uptake.

Table 4: Effect of different rates of phosphorus application on P content, N content and their uptakes by grains wheat

Years	P DM (%)	N DM (%)	P uptake (kg ha^{-1})	N uptake (kg ha^{-1})
2008/2009				
Fertilizers				
SSP	0.73	2.14	48.53	158.7
Fosfactyl	0.75^{ns}	2.39^{ns}	52.45^{ns}	159.4^{ns}
Levels (kg ha^{-1})				
30	0.72	2.28^{b}	43.54	130.3
60	0.72	2.56^{a}	51.63	193.2
90	0.78^{ns}	1.96^{c}***	56.29^{ns}	154.0^{ns}
General means	0.74	2.27	50.49	159.04
2009/2010				
Fertilizers				
SSP	0.40^{a}	3.08	27.66	213.9
Fosfactyl	0.38^{b}	3.09	24.63	199.6
MAP	0.39^{ab}**	3.10^{ns}	26.97^{ns}	218.1^{ns}
Levels (kg ha^{-1})				
30	0.39	3.10	26.52	213.0
60	0.40	3.07	27.91	222.8
90	0.39^{ns}	3.08^{ns}	24.83^{ns}	195.7^{ns}
General mean	0.39	3.08	26.42	210.5
2010/2011				
Fertilizers				
SSP	0.65	1.88	43.29	104.2
Fosfactyl	0.71	1.75	34.22	107.3
MAP	0.62^{ns}	1.72^{ns}	33.96^{ns}	98.4^{ns}
Levels (kg ha^{-1})				
30	0.83^{a}	1.86	44.29^{a}	104.0
60	0.53^{b}	1.69	32.35^{b}	103.2
90	0.63^{b}**	1.80^{ns}	34.84^{ab}***	102.7^{ns}
General mean	0.66	1.78	37.16	103.3

***Significant at $p \leq 0.001$, ns: Not significant, Values with different superscript letters in the same column differ significantly

The best grain P content and uptake were obtained in 2008/2009 (0.74% DM, 50.49 kg P ha^{-1}), whereas N content and uptake by grains were better in 2009/2010 (3.08% DM and 210.5 kg ha^{-1}).

In 2009/2010, the source fertilizer effect was significant; SSP gave the best P content. Although the P uptake was not affected by the fertilizer source, fosfactyl gave the highest value in 2008/2009 with 52.45 kg ha^{-1}, while in 2009/2010 and 2010/2011, SSP gave the highest values with 27.66 and 43.29 kg ha^{-1}, respectively (Table 4). Level 30 kg ha^{-1} gave the best content and uptake of P by grains in 2010/2011 with 0.83% DM and 44.29 kg ha^{-1}, respectively.

Nitrogen grain uptake was not influenced by P source whatever year. Level 60 kg ha^{-1} (Table 4) gave the best N content (2.56% DM) in 2008/2009 (the only year where the level effect was significant) corresponding to a protein content 14.64% as compared to 30 and 90 kg ha^{-1} with 13.04 and 11.21%, respectively.

Correlations: Correlations between the different measured parameters shows that the P content is significantly ($p<0.05$) correlated with the nitrogen content (R = 0.404*) only in 2010/2011.

Whatever the year, P uptake is significantly correlated with the P content (R = 0.605, R = 0.481 and R = 0.787), grain yield on the two first seasons (R = 0.902, R = 0.943 and R = 0.470), spikes number/m^2 (R = 0.527, 0.389 and 0.362) and the N uptake (R = 0.672, R = 0.880 and

R = 0.589) for 2008/2009, 2009/2010 and 2010/2011, respectively. The P uptake is correlated with the NbrGr (R = 0.616 and R = 0.321, respectively 2009/2010 and 2010/2011), the N grain content (R = 0.672 in 2010/2011) and straw yield (R = 0.846 in 2008/2009). It is logical that the relationship between the P-uptake and grain yield is significant, because the P uptake derived from P content and the yield itself. These results indicate that a higher phosphorus content of grains increases their nitrogen content. The spikes number/m² and grains number/spike is proportional to the amount of P uptake. However, these two components are themselves related to grain yield. Indeed, the correlations between grain yield on one hand and spikes number/m² (R = 0.542, R = 0.410 and R = 0.784 for respectively in 2008/2009, 2009/2010 and 2010/2011) and NbrGr (R = 0.639 and R= 0.572, respectively for 2009/2010 and 2010/2011) on the other hand are positive and significant.

DISCUSSION

The result of the present study showed that for all tests, P fertilizers has no effect on the traits studied except P grain content where the SSP followed by MAP gave the best contents. Therefore, the selection of a phosphate fertilizer will be as available on the market and price. Similar results were found by Dordas (2009) which indicate that P accumulation was also affected by the fertilization regime. In contrast, under the same conditions, Mihoub and Boukhalfa-Deraoui (2014), found that P fertilizers revealed no significant effect on P content of grain.

Whatever is the year, P content, grain yield, spikes number/m² and N uptake increase when P uptake increases. While grains number/ear, N content and straw yield increase when P uptake increases according to year.

Wheat grain weight is a function of rate and duration of grain growth and is affected by photosynthate supply (Li *et al*., 2000). Regardless of the year, levels 30 and 60 kg ha^{-1} favored the best 1000-grain weights and grain yield. For straw yield, levels 90 and 60 kg ha^{-1} gave the best mean values (Fig. 3). For spikes number/m², levels 60 and 90 kg ha^{-1} gave the best values. Since there is compensation between yield components and grain yield is the final goal of this work, we can conclude that under the conditions of El-Menia, level 30 kg ha^{-1} seems adequate to produce a yield equivalent to that of 60 kg ha^{-1} and so allowing an economy of fertilizer.

Dordas (2012) in his finding, revealed that spike reduction treatment increased the pre-anthesis assimilates and contribution to grain, indicating that the dry matter remobilization from vegetative tissues were very important for grain development.

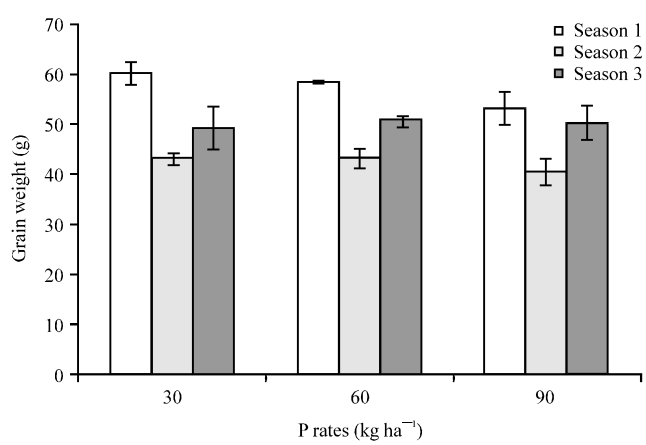

Fig. 3: Effect of P sources fertilizers on wheat grain weight

Environmental factors influence significantly the grain yield of wheat and grain protein accumulation affecting especially the gluten quantity and quality (Dupont and Altenbach, 2003; Paunescu *et al.*, 2009). Harper and Paulsen (1969) found that the deficit for each macronutrient (N, P, K, Ca, Mg and S) in wheat may decrease the activity of three enzymes, nitrate reductase, glutamic acid dehydrogenase and glutamine synthetase.

In the present study, values of 1000-grain weights obtained in 2008/2009 are better than those of both last seasons. This can be explained by the high temperatures (above 30°C) occurred during anthesis for the year 2009/2010 and during grain filling for these two seasons (2009/2010 and 2010/2011), consequently the dry matter accumulation was interrupted and the grain weight decreased. The present result is in accordance with those of Wiegand and Cuellar (1981) and Hunt *et al.* (1991) which indicate that rates of grain fill increases with temperature up to about 30°C; presumably reflecting increased enzyme activity and metabolic process (Dupont and Altenbach, 2003). According to Stone and Nicolas (1995), high temperature can be a significant factor in reducing yield and quality of wheat and drought stress reduces photosynthate production because of stomatal closure (Li *et al.*, 2000).

Nitrogen (N) grains uptake has not been influenced by different P fertilizers whatever the year. However, level 60 kg ha^{-1} (2008/2009) gave the highest N content of the grains and consequently protein content. According to Debaeke and Raffaillac (2000), the protein content should be at least 13% to avoid trace of farinaceous endosperm. However, to ensure a content exceeding this threshold while reducing costs due to use of fertilizers, we should be studied intermediate phosphorus levels between 30 and 60 kg ha^{-1} for the same dose of nitrogen used in tests.

Chintala *et al.* (2012) show that main effects like water potential, pH and N levels had significant influence on N and P concentration in plant tissue and when moisture contents increases in soil that will result in P availability to the plant roots and minimum P concentration in wheat grain and straw when no irrigation was applied (Rahim *et al.*, 2007).

Lime content and pH soil can also be limiting to plant growth as it affects the chemical reactions in the vicinity of plant roots and nutrient uptake (Elgharably *et al.*, 2010). Reactions that reduce P availability occur in all ranges of soil pH but can be very pronounced in alkaline soils (pH>7.3) and in acidic soils (pH<5.5). In our present study, pH soil was between 8.2 and 8.6 and the significant effect of dose on P content of grains was obtained only in 2010/2011 can be explained by low CaCO3 in the soil (1.84%) compared to 2008/2009 and 2009/2010 (8.93 and 13.5%, respectively).

Naseri *et al.* (2010), indicated that phosphorus deficiency is widespread in calcareous soils and it is the main factor limiting yields of annual crops in acid and alkaline soils (Fageria, 2001). The study on the behavior of P in various soil samples, characterized by different degrees of calcium concentrations, shows that the maximum of P is determined by the soil which has the maximum free $CaCO_3$ (Aslam *et al.*, 2000).

CONCLUSION

Southern Algeria is characterized by arid climate and sandy soil texture. These two factors can affect yields of crop, therefore, the choice of suitable variety, appropriate use of fertilizer and the optimal dose are the solutions for sustainable agriculture.

Results obtained on three years of experimentation showed that P content, grain yield, spikes number/m^2 and N uptake increase when P uptake increases. While grains number/spike, N content and straw yield increase when P uptake increases according to year.

Fertilizer source did not have significant effect on all measured parameters; therefore the selection of a phosphate fertilizer will be as available on the market and price.

It can be conclude that in the sandy alkaline calcareous soil, the optimal P rate is 60 kg ha^{-1} as Single Super Phosphate (SSP) in El-Menia.

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