Agronomic Effectiveness of a New Formula of Phosphate Fertilizer II – Residual Agronomic Effectiveness

N. M. Muhawish* Soil & water Sci. Dept. College of Agric. Univ. of Tikrit I. B. Razaq Soil & water Resources Center Agric. & Food Tech.Res. Directorate Ministry of Sci. & Tech.

Abstract

A field experiment was conducted using wheat (Triticum aestivum var. Tamouz /2) as a test crop to evaluate the residual effect of heavy single application of three sources of P fertilizers viz: TSP, PR and M5 (a new formula consisted of PR + elemental sulphur of which 20% of S was added as H₂SO₄) which applied once in the first year at four rates (0, 86, 172, and 344 kg P.ha⁻¹) on wheat grain yield and P uptake. Results showed that a maximum grain yield was achieved by M5 and there was a significant increase caused by M5 and PR over TSP. Increasing P rate increased grain yield but it did not reach the maximum at the highest rate of application. The second rate of M5 gave a grain yield which was near the grain yield obtained by the fourth rate of PR and the third rate of TSP. The increase in wheat straw yield using M5 was significant (p=0.05) compared with PR and TSP. The fourth rate of P differed significantly with the first and second rate concerning wheat straw yield. The increase in P uptake was significant in the case of M5 compared with TSP and PR. The same trend was observed in the effect of P rate on P uptake as for wheat straw yield. NaHCO₃ extractable P (Olsen P) followed the order: TSP >M5 > PR and the differences were significant. Increasing rate of P applied affect significantly the NaHCO₃ extracted P at the third and fourth rate compared with the first and second rate. Residual agronomic effectiveness (RAE) on the basis of wheat grain yield was 247% and 175% for M5 and PR respectively compared with the standard (TSP 100%). RAE on the basis of P uptake was 185% and 74% for M5 and PR, respectively compared with the standard (TSP 100%). Results revealed the superiority of M5 for its residual effects on grain yield, wheat straw yield, P uptake and RAE compared with TSP and PR.

Keywords: Agronomic effectiveness- Phosphate fertilizer- Phosphate rock- Triple super phosphate- residual effect

* Corresponding auther

Introduction

Phosphorus (P) is an essential element in crop production, and its deficiency severely restricts crop yields. Despite the wide distribution of this element in nature, its deficiency is widespread because most of the forms in which it occurs are poorly available to crops (Khasawneh et al., 1980). When the phosphate fertilizer well soluble in water is added to soil, 15 - 20 % of P is taken up by plants and the rest either chemically fixed with soil compounds and colloids or transformed into organic forms in microorganisms bodies (immobilized) or adsorbed onto soil colloids and minerals (Prasad & Power, 1997). The residual quantity which must have a role could be available to plant depending on soil characteristics, microorganism's activity and the dominant chemical reactions (Engelstad, 1985).

Chardon & Van Faassen (1999) stated that the phosphorus sorption capacity (PSC) of soil can indeed be very large, but it is not unlimited. The fact that rate of reversion of plant available phosphorus to less soluble and ultimately unavailable forms tends to decline with time is often overlooked (Havlin et al., 1999). In fact, a small portion of soil capacity to adsorb P arise from $CaCO_3$ where most of adsorption is attributed to hydrous ferrous oxides, and that the activity of P is less on soils where calcium activity is high and having a large amount of Ca saturated clay (Tisdale et al., 1985).

Two strategies were followed to deal with this situation, the first is high input strategy where there is a high primary investment followed by an essential residual effect for many years, the second is low input strategy which based on P application as bands to saturate fixing capacity in a small volume of soil (Khasawneh et al., 1980).

Cooke (1975) mentioned that the residual effect of one single dressing of P is usually much smaller than the direct effect the year before, it may be too small to measure accurately in experiments and can usually be ignored in planning, but the cumulative residual effects of many annual dressings are large and can not be ignored, they may be sufficient for normal yields of crops without applying fresh fertilizers. Rehman et al. (2006) found that the residual effect of phosphorus applied to wheat on sorghum fodder was quite significant in improving the fresh and dry matter yields. Normally, whenever more phosphate fertilizer is added a more plant response is takeplace regardless of P content of soil because the fresh fertilizer applied is instantly available and it has a positive chemical effect on soil characteristics and nutrient availability.

The constraint of low phosphorus can be removed at least partly, by application of phosphate rock (PR) (Zapata & Axmann, 1995). Phosphate rock, which is a slow release phosphate fertilizer, is cheaper than triple super phosphate (TSP) and has a longer residual effect (Hu et al., 1997). The problem of phosphate rock is its low solubility. Various ways (chemical, biological, and biochemical) of enhancing the solubility of PR exist, but these need to be properly evaluated (Armiger & Fried, 1957; Chien & Hammond, 1978). Direct application of finely ground PR, including local phosphate deposits were possible, may be one of the cheapest ways to supply P to crops (Cooke, 1956). Phosphate rock besides, tend to have stronger residual effects than triple super phosphate, and even phosphate rock of low reactivity may have good P supplying capacity with time (Doll et al., 1957).

Zapata & Roy (2004) mentioned that the most important index used to express the agronomic performance of PR relative to water soluble fertilizers is called the relative agronomic effectiveness (RAE) of a given P test fertilizers. This is determined by expressing as a percentage the ratio of the response of the test fertilizers (treatment – control) to the response of the standard fertilizers (Engelstadet al., 1974) when both are applied at the same rate :

 $Y_{F} - Y_{C}$ RAE = -----* 100

-----(eq. 1)

 $Y_R - Y_C$

Where:

- Y_F = average yield or P uptake obtained on all rates of applications of one of the tested fertilizers
- Y_R = average yield or P uptake obtained on all rates of application of the Reference fertilizers (TSP)
- Y_C = yield obtained in treatments without P additions

Based on the RAE equation different coefficients can be caculated for crop yield or dry matter production, P uptake, chemical extraction, or L values (Zapata & Roy, 2004). Different ways (chemical, biological, physical) were used to improve the agronomic effectiveness of PRs, one of the physical ways was the phosphate rock elemental sulphur assemblage (co granulating with sulphur) which, in some times, been inoculated with sulphur oxidizing bacteria to oxidize S to H₂SO₄, which in turn react with PR to release P (Engelstad,1985). According to the above mentioned information the methods for evaluating the agronomic effectiveness of phosphate rock should take into account not only the immediate effect on P availability but also their residual long – term benefits (Zapata & Roy, 2004). The objective of the following experiment (part II) was to evaluate the residual effect of heavy single application of three sources of P fertilizers TSP, PR and our new formula M5 (Razaq et al., 2002) on wheat yield and P uptake, and compare their agronomic effectiveness.

Materials & Methods

A field experiment was conducted to grow wheat (<u>Triticum aestivum</u> var. Tamouz /2) in the same plots which were planted to corn in the first part of this study, with the same layout and design of experiment (Muhawish & Razaq, 2008). Wheat was planted from Dec. 2006 – end of May 2007. Plot dimensions were 2.0 x 2.5 m. Nitrogen was broadcasted as urea according to fertilizer recommendation of wheat which compensate to 200 kg urea. ha⁻¹, upon land preparation and 200 kg urea . ha⁻¹ at tillering stage. The P sources were three (TSP, PR and M5) applied once at four rates (0, 86, 172, 344 kg P. ha⁻¹) prior to corn seeding (see part I of this study). No P fertilizer was added in this part of study. Wheat seed (var. Tamouz / 2) were planted on rows, 15 cm was left between one row and another, with a seeding rate of 120 kg. ha⁻¹. Plots were irrigated individually according to plant need. Soil samples from each plot were taken after harvest to determine available P (Olsen P). Available P was determined after extraction with 0.5 M _{NaHCO3} (Olsen P). P uptake by grain and straw was determined by Watanabe & Olsen (1965) after wet digestion of plant material using HNO₃, H₂SO₄, and HCLO₄ acids (Jackson, 1958). Grain yield and dry weight were measured for each treatment. Total P uptake by the whole plant was also calculated.

Results & Discusion

Grain yield

The effect of rate and source of applied P on grain yield is shown in table 1 which shows a significant increase (P=0.05) achieved by the new formula (M5). There was also an increase in grain yield caused by PR over TSP but this increase was not differed significantly with M5. These results agree with the results of Medhi & De Datta (1997) which revealed that there was a promising effect of residual P from applied P sources in increasing rice grain yield. TSP gave the lowest grain yield (3374 kg. ha⁻¹) compared with PR and M5 (3881 and 4398 kg. ha⁻¹)

¹), respectively. The grain yield increased with P rate and reached the highest at the rate 344 (kg P. ha⁻¹), which did not differ significantly with the rate 172 kg P. ha⁻¹, and the two rates differed significantly with the rate 0 and 86 kg P.ha⁻¹. The table also shows that the second rate of M5 gave a grain yield which was near the grain yield obtained by the fourth rate of PR and the third rate of TSP. It is obvious that grain yield did not reach the maximum yield at the fourth rate (344 kg P.ha⁻¹) for TSP and M5 which allow using higher rates of application. It was also shown that when the same rate of P fertilizer was applied, the residual effect of PR was better in the second and the third rate than that of TSP while for the fourth rate the residual effect of TSP was better which is in accord with Hu et al. (1997).

P rate	Grain yield				
$(\text{Kg P }.\text{ha}^{-1})$	(kg.ha ⁻¹)				
	TSP PR M5 Mean*				
0	2165	3140	2590	2632 C	
86	3137	4247	3730	3705 B	
172	3877	4363	5453	4564 A	
344	4317	3775	5817	4636 A	
Mean*	3374 B	3881 A	4398 A		

Table 1 Effect of rate and source of applied P on grain yield of wheat.

* Means with the same letter are not significantly different with T test (p = 0.05)

LSD $_{0.05}$ for Fertilizer = 715.89

LSD $_{0.05}$ for P level = 826.64

Wheat Straw

Table 2 showed that there was a significant increase (p=0.05) in wheat straw yield achieved by the new formula M5 over TSP and PR. Wheat straw yields for TSP and PR did not differ significantly, although it was higher in the case of TSP (6170 kg .ha⁻¹) than for PR (5903 kg .ha⁻¹). Increasing rate of P applied as a single application in the former season significantly increased wheat straw yields. These results agree with the results of Halvorson (1989) which showed a multiple – year responses of irrigated wheat to a single application of P fertilizers. The fourth rate did not differ significantly (p=0.05) with the third rate and there was a significant increase in the third rate over the second rate which in turn differed significantly with the first rate (control). Table 2 also shows that the second rate of M5 gave a straw yield which was near that obtained by the fourth rate of TSP and PR. These results agree with Zapata & Axmann (1995) who have shown that some PRs are often as effective or nearly as effective as water soluble P fertilizers and with Rehman et al.(2006) who concluded that the residual effect of P added to wheat (first year) on sorghum fodder (second year) was quite significant in improving fresh and dry matter yields. Results of table 2 disagree with results of Ramilison (2001) who showed that during the first two years, phosphate rock fertilizers applied alone have no effect.

P rate (Kg P .ha ⁻¹)	Wheat straw (kg.ha ⁻¹)				
	TSP	TSP PR M5 Mean ³			
0	3810	5730	5970	5170 C	
86	5940	5660	6790	6130 BC	
172	7000	5500	8550	7017 AB	
344	7930	6720	8370	7673 A	
Mean*	6170 B	5903 B	7420 A		

Table 2 Effect of rate and source of applied P on wheat straw yield.

* Means with the same letter are not significantly different with T test (p = 0.05)

LSD $_{0.01}$ for Fertilizer = 994.57

LSD $_{0.01}$ for P level = 1148.4

P Uptake

The effect of rate and source of applied P on amount of P uptake is shown in table 3 which shows a significant increase (p=0.05) with the new formula M5 which was superior over the two other fertilizers but there was not any significant difference between M5 and TSP. Triple super phosphate (TSP) was superior to PR but there was not any significant difference between them. These results agree with results of Medhi & De Datta (1997) who stated that P uptake increased due to residual P from fertilizer P applied, and suggested that increased P uptake increased dry matter and grain yield. Increasing P rate caused an increase in P uptake up to the third rate (172 kg P .ha⁻¹) and decreased a little in the fouth rate (but with no significant difference) as an over all effect of all fertilizers. At the highest rates of P fertilizers applied (172 and 344 kg P .ha⁻¹) the residual effect of M5 was better than that of TSP and PR, and the residual effect of all P fertilizers on P uptake increased with the increase in the amount of P applied. Table 3 also shows that the second rate (86 kg P .ha⁻¹) for M5 gave a P uptake which was near the P uptake obtained by the fourth rate of TSP and PR. Moreover, P uptake did not reach the maximum value at the fourth rate (344 kg P.ha⁻¹) for M5 which allow using higher rates of application.

Table 3 Effect of rate and source of applied P on amount of P uptake (from the whole plant of wheat)

P rate	P uptake			
$(Kg P .ha^{-1})$	$(kg.ha^{-1})$			
	TSP PR M5 Mean*			
0	5.02	6.76	5.61	5.80 C
86	7.70	8.15	9.83	8.56 B
172	12.46	9.47	13.14	11.70 A
344	9.69	9.25	14.57	11.17 AB
Mean*	8.72 AB	8.41 B	10.79 A	

* Means with the same letter are not significantly different with T test (p = 0.05)

LSD $_{0.05}$ for Fertilizer = 2.368

LSD $_{0.05}$ for P level = 2.7343

NaHCO₃ Extractable P

Table 4 explains the effect of rate and source of P on NaHCO3 extractable P (Olsen P) at the end of wheat season. TSP caused a significant difference over M5 and PR. Olsen P of the

three sources followed the order: TSP > M5 > PR. The decrease in Olsen P for PR may be due to the unsuitable conditions for this source to release P, where it is known that PRs are slow release fertilizers, which require time and water surrounding the particles in order to enable dissolution products to diffuse away from the PR particles into the soil volume (Zapata & Roy, 2004). Olsen P was also increased significantly by application, and the highest P tests were achieved by the third and fourth rate of application. These results agree with results of Khasawneh & Sample (1979) who find that concentrations of P in soil solution sufficiently high to promote maximum plant growth were obtained only with high rates of application. There was also a disagreement with Mendoza (1984) who find a significant decrease in available P which was attributed to increase in the amount of insoluble iron phosphate. The second rate of M5 caused a nearly similar effect with the fourth rate of TSP and PR, which was the same trend observed for wheat straw and P uptake. There was also a rising effect on Olsen P obtained by M5 up to the fourth rate. It is concluded that M5 is a promising fertilizer concerning Olsen P which was released slowly by M5 and quickly by TSP.

P rate (Kg P .ha ⁻¹)	NaHCO ₃ extractable P (kg.ha ⁻¹)			
_	TSP PR M5 Mean*			
0	5.5	6.7	5.6	5.9 B
86	15.7	6.7	8.9	10.4 B
172	34.2	7.2	13.2	18.2 A
344	41.3	7.0	23.9	24.1 A
Mean*	24.18 A	6.9 C	12.9 B	

Table 4. Effect of rate and source of applied P on NaHCO₃ extractable P (Olsen P) at the end of wheat season.

* Means with the same letter are not significantly different with T test (p = 0.05) LSD _{0.05} for Fertilizer = 5.6858

LSD $_{0.05}$ for P level = 6.5654

Internal Efficiency (IE)

The internal efficiency (*IE*) which is the relationship between yield of dried tops and the P concentration measured in the tops (Bolland et al.,1992), differed for the three sources of P fertilizers (table 5). The difference in values of *IE* indicates that the plants have different internal efficiency of P use curves for the different P fertilizers. That is once the P has been take up by plants, the same P concentration or P content in the plant tops were generally related to different yields when P was derived from different fertilizers. The mean value of *IE* for all the P rates was higher in the case of PR and followed the order: PR >M5 > TSP .This may be explained by the stronger residual effect which PRs have over TSP (Zapata & Axmann, 1995).

P rate	Internal Efficiency			
(kg P.ha^{-1})	TSP	PR	M5	
0	1190	1312	1526	
86	1179	1216	1070	
172	873	1041	1066	
344	1264	1135	974	
Mean*	1127	1176	1159	

Table 5. Relationship between yield of dried tops and the P uptake of the dried tops (Internal Efficiency, IE of P use) for the wheat experiment.

Yield of dried tops

P uptake

Internal Efficiency = -----(eq. 2)

Relative Agronomic Effectiveness (RAE)

Table 6 shows the relative agronomic effectiveness of various P sources. Using TSP as the standard (100%) and on the basis of wheat grain yield, RAE of the PR was 175 and there was a high increase in RAE of M5 which was 247. These results confirm again the efficiency of the industrial process of M5 which combines both the partial acidulation by H_2SO_4 which works initially to supply P, and sulphur content which works later by eliciting acid formation to enhance P availability.

Table 6.	Relative agronomic	effectiveness	of various	phosphates	depending of	n Wheat	grain
	yield and P uptake.						

P source	Grain yield	RAE*	P uptake	RAE*
TSP	3347	100	8.7	100
PR	3881	175	8.4	74
M5	4397	247	10.8	185

* After averaging the grain yield and P uptake over all rates, these values were calculated using the formula:

$$Y_{\rm F} - Y_{\rm C}$$

RAE = ------ * 100 [Engelstad et al.,1974]
 $Y_{\rm R} - Y_{\rm C}$

The results also reflex the importance of the residual effect of sources derived from PRs. On the basis of P uptake by wheat, RAE of PR was 74 and there was an increase in RAE of M5 (185) over that of TSP (100) which was the standard. The improvement in the RAE of PRs

(PR and M5) over time has been attributed to the continuation of the PR dissolution process while a low concentration is maintained in soil solution. The improvement may also result from the depletion of P from the soluble fertilizer as a result of P uptake by plants and the conversion of soluble P to less available P forms.

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الفعالية الزراعية لتركيبة جديدة من السماد الفوسفاتي II- الفعالية الزراعية المتيقية

إبراهيم بكري عبد الرزاق	نور الدين محمد مهاوش
مركز التربة والموارد المائية	قسم علوم التربة والمياه
دائرة البحوث الزراعية وتكنولوجيا الغذاء	كلية الزراعة
وزارة العلوم والتكنولوجيا	جامعة تكريت

الخلاصة

احريت تجربة حقلية لزراعة الحنطة بهدف تقييم الأثر المتبقى لإضافة منفردة ثقيلة لثلاث مصادر فوسفاتية هي : TSP و PR و MS (وهي تركيبة سمادية جديدة مكونة من الصخر الفوسفاتي والكبريت المعدني الذي أضيف 20 % منه بشكل حامض الكبريتيك) أضيفت مرة واحدة في السنة الأولى بأربعة معدلات إضافة (0 ، 86 ، 172 ، 344 كغم P. هكتار⁻¹ في حاصل الحنطة وامتصاص الفسفور. أظهرت النتائج بأن حاصل الحبوب الأقصى تحقق باستعمال M5 وكان هذاك زيادة معنوية بسبب M5 و PR مقارنة بسماد TSP. أدت زيادة معدل إضافة P الى زيادة غلة الحبوب ولكنها لم تصل إلى الحد الأقصى عند معدل الإضافة الأعلى. أعطى المعدل الثاني للأضافة حاصل حبوب مقارب لحاصل الحبوب المتحقق من المعدل الرابع لسماد PR والمعدل الثالث لسماد TSP . كانت الزيادة في حاصل قش الحنطة باستعمال M5 معنوية (P=0.05) مقارنة بسماد PR و TSP. اختلف معدل الأضافة الرابع من P معنوياً مع المعدل الأول والثاني فيما يتعلق بحاصل قش الحنطة. كانت الزيادة في امتصاص الفسفور معنوية في حالة M5 مقارنة بسماد TSP و PR ، كما لوحظ الأتجاه نفسه في تأثير معدل إضافة P في إمتصاص P كما في حالة حاصل قش الحنطة. اتبع الفسفور المستخلص بالبيكاربونات (Olsen P) الترتيب الأتي: M5 < TSP > PR وكانت الفرو قات معنوية. أثرت زيادة معدل إضافة P معنوياً في الفسفور المستخلص بالبيكاربونات في معدل الإضافة الثالث والرابع مقارنة بالأول والثاني. بلغت قيمة الفعالية الزراعية المتبقية (RAE) المحسوبة على أساس حاصل حبوب الحنطة %247 و %175 لكل من M5 و PR على التوالي مقارنة مع السماد القياسي (100% TSP). بلغت قيمة (RAE) المحسوبة على أساس الفسفور الممتص %185 و %74 لكل من M5 و PR على التوالى مقارنة بالسماد القياسي (100 % TSP). أظهرت النتائج تفوق التركيبة السمادية M5 في أثرها المتبقى في حاصل حبوب الحنطة وحاصل قش الحنطة وامتصاص P وقيم RAE مقارنة مع TSP و PR.

كلمات مفتاحية : الفعالية الزراعية – السماد الفوسفاتي – الصخر الفوسفاتي – سوبر فوسفات الثلاثي – الأثر المتبقى