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Management of Phosphorus Fertigation for Drip Irrigated Wheat under Sandy Calcareous Soils

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Abstract: A Field experiment was conducted out to study the effect of frequency of P fertigation and form of P fertilizer on uptake of P by wheat plant as well as the yield production under drip irrigation system. Phosphorus fertilizers forms were (water extract of super phosphate), mono-ammonium phosphate, mono-potassium phosphate, urea phosphate and phosphoric acid) and fertigation frequencies were (every 3 and 6 days. The experimental design was spilt spilt plot design. Phosphorous uptake by wheat plants during the growth period was significantly (p<0.05) affected by the frequency of P fertigation and forms of P fertilizers. High frequency of P fertigation increased the dry matter accumulation in wheat plants and produced 3455 kg fed^{-1} compared to 3300 kg fed^{-1} in the case of low frequency

Key words: Forms of phosphorus fertilizers · New reclaimed soils · Spilting P fertilizers · Wheat · P uptake · Wheat yield

INTRODUCTION

Food security in the world is challenged by increasing food demand and threatened by declining water availability [1]. Irrigation is an increasingly important practice for sustainable agriculture. Under conditions of scarce water supply and drought, good irrigation management can lead to greater economic gain by maximizing water use efficiency. Wheat is considered the main cereal crop in Egypt. The percentage of production amounted to 53.2% of total described consumption and so Egypt imports about 46.8% of its need from wheat yearly. Most of agricultural expansion in Egypt is confined in areas located in desert which resides in the arid zone where shortage of water and unfavorable soil properties and nutrients deficiencies are the most constrains facing any agricultural project proposed for such areas. These soils need a high efficient irrigation and fertilization system for maximizing the production and sustain both the environment and resources available. Production of such desert soil is fairly good whenever the nutritional and irrigation problems are solved [2, 3].

Modern irrigation and fertilization systems i.e. sprinkler and drip fertigation are promising systems for achieving such goals. Drip irrigation can reduce leaching. Drip irrigation was is also found to increase yield of corn and also reduced leaching [4]. Drip irrigation has become more popular for several crops. Abdel-Rahman [5] studied the water use efficiency of three wheat varieties as affected by irrigation rates under drip irrigation in newly reclaimed soils in Egypt he found more yield and water use efficiency as well as Shalby *et. al* [6].

In modern agricultural systems, especially under arid or semi-arid conditions, or in greenhouses where artificial substrates are used, water and nutrient are supplied simultaneously (fertigation), mainly by drip irrigation devices [7]. Fertigation technique is widely used for fertilizer application with irrigation water, through the irrigation system. Problem encountered using this technique, is the application of phosphorous fertilizer . Nutrient transport from the soil solution to the root surface takes place by two simultaneous processes: convection in the water flow (mass flow) and diffusion along the concentration gradient [8, 9]. Soil properties, crop characteristics and growing conditions affect the relative importance of each mechanism, but the general situation is that the mobile NO_3 ion supply is taken up mainly through mass flow, while for less mobile elements such as P and K, diffusion is the governing mechanism

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Phosphorus fertilizers have different solubility in irrigation water. Some of them make problems when added to the drip irrigation systems. In that respect, special care should be taken with phosphate fertilizers in alkaline and high calcium containing irrigation waters and in calcareous soils, since calcium and magnesium precipitate easily with phosphates. Therefore, it is important to use completely soluble and acidic phosphate fertilizers. This is why acidic fertilizers like mono-ammonium phosphate (MAP), mono-potassium phosphate (MKP), urea phosphate (UP) and phosphoric acid (PA) represent suitable options. The effect of application rate of drip applied phosphorus fertilizers (rate of P fertigation) consequently is very high as a result of applying the phosphorus over a very small surface area. For example to explain the effect of P fertigation if 20 Ib/acre were applied uniformly through 2500 emitters/acre, this would provide 0.008 Ib P/emitters. Phosphorus applied within 4 inches of the emitter, the concentration would be equivalent to 1000 Ib P/acre. Moreover drip irrigation alone can have an effect on phosphorus availability in soil. Bacon and Davey [13] reported elevated concentrations of extractable phosphorus in the wetted zone beneath the emitter for 6 to 23 hours after a water only irrigation cycle.

Through fertigation nutrients are applied directly into the wetted volume of soil immediately below the emitter where root activity can be concentrated and consequently fertilizer-use-efficiency can be improved over broadcast application [19].

Soil acidification below the emitters results in a significant increase of EDTA-extractable Fe, Mn, Zn and Cu [14]. Acid P fertilizers provide several advantages when applied to alkaline calcareous soils. P fertilizers enhanced the availability of Fe in localized zones of the soil [15]. High rates of P (80 kg P /ha) applied as MCP, MAP and APP reduce soil pH 0.2 and 0.3, respectively. Soil pH depression difference due to source was mainly caused by the release of H_3PO_4, reaction of MCP with basic cations and nitrification of the added ammonium in MAP and APP [16]. There is several additional benefit of using acidic fertilizers: enhancing efficiency of phosphate and micro-nutrients and decreasing losses of nitrogen by volatilization. Previous works of Baker and Papadopoulos [17, 18] indicates that phosphorus moves very little from the point of its application [17, 18]. While Mikkelsen and Jarrel [19] observed that, the use of acid phosphorus fertilizers under drip irrigation increased its movement. Increasing P movement under drip irrigation may be caused environmental pollution by phosphorus. Higgs *et al.* [20] states that agriculture is challenged to manage P such that production benefits are maximized, while adverse environmental effects are minimized. Using P fertigation with good management for irrigation system gave more P use efficiency and reduced P fertilization.

The objective of this study therefore, is to evaluate the effect of P fertigation and management for drip irrigated wheat under sandy calcareous soils.

MATERIALS AND METHODS

Soil and Plant Analysis: Soil mechanical analysis was carried out by the pipette method, according to [21]. Soil reaction (pH) was measured in 1:1 (soil: water) suspension using a glass electrode [22]. Calcium carbonate content was measured gas metrically using a volumetric calcium carbonate calcimeter [23]. Organic matter content was determined using the modified Walkely and Black method [24]. Field capacity: was estimated according to the method described by [23]. Available phosphorus was extracted by 0.5 M Sodium bicarbonate solution at pH 8.5 according to [25] and phosphorus was determined calorimetrically using the chlorostannous-phosphomolybdic acid method [22]. Field capacity was estimated according to the method described by [23]. The plant materials were digested using a wet ashing method [23[phosphorus, in the plant digest were determined as described for soil analysis .The collected data were statistically analyzed using MSTAT computer program as described by [26].

Table 1: Some soil physical and chemical properties of the experimental site

Soil Properties	Soil depth (0.0-30) cm
Physical Properties	
Particle size distribution	
Sand (%)	88.7
Silt (%)	8.0
Clay (%)	14.9
Texture	Sand
Field capacity %	14.5
Chemical properties	
$CaCO_3$ (%)	
pH (1:1suspention)	8.1
Organic matter (%)	0.6
Available Phosphorus (ppm)	4.5

Field Experiment: The field experiments was conducted during the 2003/2004 winter growing seasons at El-Ghorieb Experimental Station, Faculty of Agriculture, Assiut University, Assiut, Egypt Longitude and Latitude is 27 08 38 and 31 19 34 respectively. The soil at this site is classified as sandy calcareous soil (Typic Torripsamments). (USDA Soil taxonomy). Some soil physical and chemical properties of the experimental site are summarized in Table 1.

The experimental site was irrigated using a drip irrigation system; which has four sub-mains that separately controlled the irrigation and fertilization. Each sub-main covered an area of 16X40 meter. The in-line GR dripper laterals were installed 1 m apart. The emitters were spaced at 0.30 m apart and a flow rate of 3.8 l h^{-1} at 110-120 KPa (1.1-1.2 bar) was maintained. Each lateral was used to irrigate an experimental plot of 0.5X20 m. Five P fertilizers and two frequency of P fertigation were used. The experimental design was a split plot with four replications. The frequency of P fertigation was assigned to the main plots and forms of P fertilizers were placed in subplot.

Wheat (*Triticum asaetivum*) variety Giza 164 was sown on December 6, 2003 in rows set apart at 15 cm at the two sides of the dripper lines. After 45 and 75 days after planting plants of ½ m^2 of each plot were taken as samples .At harvesting seeds and straw of ½ m^2 of each plot were taken also as samples. The samples were rinsed and weighed (fresh), then oven dried at 70°C until constant weight, ground and stored for plant analysis. On April 26, 2004 plants were harvested and separated into seeds and straw and the dry weight of each was recorded. All usual agriculture practices except irrigation and P fertilization were carried on. All fertilization treatments were adjusted to receive the same amount of N and K_2O. Nitrogen as ammonium nitrate (33.5 % N) and K as potassium sulfate (48% K_2O) were added at rate of 120 Kg N and 60 Kg K_2O, respectively.

Form of P Fertilizers: The P fertilizers used were selected to cover two main properties of P fertilizers, solubility in irrigation water and pH of the dissolved P fertilizer.

- Mono ammonium phosphate (MAP) 12% N and 61 % P_2O_5
- Mono potassium phosphate (MKP) 34% K_2O and 52% P_2O_5
- Urea-phosphate (UP) 18% N and 44% P_2O_5
- Phosphoric acid (PA) 61% P_2O_5
- Water extract of superphosphate solution (SP ext.)

One rate of P fertilizer 60 kg P_2O_5 / fed was used and added every 3 or 6 days. The amount of each P fertilizer needed was calculated and dissolved in the same volume of water to prepare the concentrated P fertilizer solution that will be delivered with irrigation water into the irrigation system. The superphosphate solution was prepared by dissolving the fertilizer in water to get as maximum concentration of P_2O_5 as possible. The final P concentration in solution was measured and used to calculate the amount needed to prepare the superphosphate solution. Table 2 shows the concentration and the pH of the concentrated P fertilizer solution of each P fertilizer used.

Table 2: Fertilizer characteristics of the concentrated P fertilizer solution of each P fertilizer used

Fertilizer	Concentration of fertilizer (g/L)	Phosphorus (g/L)	EC (dS/ m)	pH
SP ext.		4.04	56.87	2.71
MAP	19.11	4.38	55.95	5.29
MKP	21.98	3.91	55.03	5.61
UP	25.97	4.46	55.93	1.71
H_3PO_4	18.56	4.08	63.1	1.66

RESULTS AND DISCUSSION

Effects of Forms of P Fertilizers and Frequency of P Fertigation on P Concentration and Uptake by Wheat Plants: Phosphorous uptake by wheat plants during the growth period was significantly ($p<0.05$) affected by the frequency of P fertigation (Table 3). Phosphorous uptake and concentrations in wheat plants are also significantly ($p<0.05$) affected by the forms of P fertilizers (Table 3). At the early stage of growth period (45 days after planting), wheat plants fertilized with MAP and UP taken up more P comparing to the other P sources, while at 75 days after planting and later wheat plants fertilized with UP and PA contained higher amounts of P. Phosphorous availability in root zone due to uptake of UP and PA was remarkably high. As stated by Mikkelsen and Ristimaki [19, 29] this could be attributed to the use of more acidic P fertilizers in extending P availability in the placement zone.

The main effects of P fertigation frequency on P uptake and concentration was not significant during the first period of vegetative growth (45 days after planting), however, during the second growth period (75 days after planting) P uptake significantly ($p<0.05$) increased from 11.38 to 12.99 kg P/fed due to following the low frequency of P fertigation (Table, 3). On the other hand low frequency P fertigation significantly ($p<0.05$) decreased the P uptake and concentration in straw only. Phosphorous uptake and concentrations in wheat plants during the vegetative growth period generally significantly increased due to the interaction of frequency of P fertigation and forms of P fertilizers (Table, 4). In both cases of frequency of P fertigation the differences in P uptake and P concentrations were significant ($p<0.05$), UP was superior over the other P sources. Most often, wheat plants frequently fertigated with UP taken up the greater amount of P and has higher concentration of P compared to the other forms of P fertilizers. This could be attributed to the fact that more frequent P fertigation reduced the depletion of available P in the root zone and readily replenished the amount of P taken up by wheat plants. With using the more acidic P fertilizers (phosphoric acid) sources the plants uptake more p than any other treatments after 75 day. Works by Gracia *et al.* and Ristimaki [28, 29] showed that using more acidic P fertilizers extended the laps of time in which phosphate ions being available for wheat roots.

Effect of Forms of P Fertilizers and Frequency of P Fertigation on Dry Matter Accumulation and Yield of Wheat Plants: Dry matter accumulation during the growth season and wheat yield (straw, grain and total biomass) are affected to different extend by forms of P fertilizers and the frequency of P fertigation. As shown in Table 5, The main effects of forms of P fertilizers on dry matter accumulation and wheat yields were not significant ($p>0.05$), even though MKP and UP produced the highest straw, grain yield and total biomass. Mono-potassium phosphate and UP produced 3619 and 3393 kg wheat grain fed^{-1}, respectively, compared to 3169 kg fed^{-1} produced with using the water extractable of super

Table 3: Effect of forms of P fertilizers and frequency of P fertigation on P uptake and concentrations in wheat plants

	45 days after planting			75 days after planting			At harvesting			
							Straw		Grain	
Treatments	Dry matterkg/fed	Puptake (kg/fed)	P (%)	dry matter (kg/fed)	P uptake (kg/fed)	P (%)	P uptake(kg/fed)	P(%)	P uptake(kg/fed)	P(%)
P Fertilizer										
SP ext.	1245	6.97	0.56	3402	10.98	0.32	2.53	0.08	10.33	0.33
MAP	1307	13.35	0.68	3334	11.38	0.34	2.75	0.09	9.47	0.30
MKP	1371	9.26	0.68	3434	11.77	0.35	2.52	0.08	15.33	0.42
UP	1333	10.13	0.76	3432	11.96	0.35	2.69	0.09	13.69	0.41
PA	1256	9.34	0.74	3358	12.84	0.39	2.17	0.08	14.46	0.41
$LSD_{0.05}$	Ns	1.42	.05	Ns	1.28	.04	.44	.009	1.97	.03
P Fert.Fre.@										
High(every 3 days)	1326	8.79	0.66	3386	11.38	0.34	2.78	0.08	12.56	0.40
Low(every 6 days)	1278	9.02	0.70	3397	12.99	0.36	2.28	0.08	12.73	0.41
$LSD_{0.05}$	ns	ns	ns	ns	0.38	0.009	0.17	ns	ns	ns

SP ext.= water extract of superphosphate, MAP = mono-ammonium phosphate, MKP = mono-potassium phosphate,

UP = urea phosphate and H_3PO_4 = phosphoric acid @ Frequency of P fertigation .ns = insignificant

Table 4: Effects of frequency of P fertigation and forms of P fertilizers on P uptake and concentrations in wheat plants

		45 days after planting		75 days after planting				At harvesting			
								Straw		Grain	
Treatments		Dry matterkg/fed	Puptake (kg/fed)	P (%)	dry matter (kg/fed)	P uptake (kg/fed)	P (%)	P uptake (kg/fed)	P (%)	P uptake (kg/fed)	P(%)
High freq@.											
(every 3 days)	SP ext.	1245	6.03	0.48	3415	10.36	0.30	2.89	0.080	10.41	0.39
	MAP	1287	8.62	0.66	3318	11.07	0.33	3.03	0.083	8.10	0.32
	MKP	1419	9.39	0.67	3448	11.47	0.33	2.75	0.084	17.50	0.45
	UP	1408	10.24	0.73	3378	11.16	0.33	3.04	0.091	13.50	0.44
	PA	1270	9.68	0.76	3389	12.38	0.38	2.19	0.070	13.2	0.41
Low freq@.											
(every 6 days)	SP ext.	1245	7.99	0.64	3389	11.60	0.34	2.16	0.071	10.53	0.32
	MAP	1326	9.08	0.69	3349	11.68	0.35	2.47	0.078	10.83	0.38
	MKP	1321	9.13	0.67	3419	12.05	0.35	2.28	0.072	10.08	0.40
	UP	1258	10.01	0.79	3475	12.76	0.37	2.33	0.078	13.84	0.49
	PA	1241	8.99	0.72	3354	12.83	0.38	2.15	0.076	15.64	0.48
$LSD_{0.05}$	ns	1.21	0.06	ns	ns	0.02	ns	ns	1.61	0.02	

SP ext.= water extract of superphosphate, MAP = mono-ammonium phosphate, MKP = mono-potassium phosphate,
UP = urea phosphate and H_3PO_4 = phosphoric acid @ Frequency of P fertigation ns = insignificant

Table 5: Effects of forms of P fertilizers and frequency of P fertigation on dry matter accumulation and yield of wheat plants

	Dry matter accumulation (kg fed^{-1})		Yield (kg fed^{-1})		
Treatments	45 days After planting	75 days after planting	Straw	Grain	Total
P Fertilizers					
SP ext.	1245	3402	3113	3169	6282
MAP	1307	3334	2963	3132	6094
MKP	1371	3434	3094	3619	6713
UP	1333	3432	3142	3394	6525
PA	1256	3358	2776	3525	6301
$LSD_{0.05}$	n.s	n.s	n.s	n.s	n.s
P Fert. Freq.@					
High (every 3 days)	1326	3386	3082	3455	6518
Low (every 6 days)	1278	3397	2948	3300	6248
$LSD_{0.05}$	ns	ns	ns	ns	ns

SP ext.= water extract of superphosphate, MAP = mono-ammonium phosphate, MKP = mono-potassium phosphate,
UP = urea phosphate and H_3PO_4 = phosphoric acid. ns = insignificant @ Frequency of P fertigation

Table 6: Interaction effects of frequency of P fertigation and forms of P fertilizers on dry matter accumulation and yield of wheat plants.

		Dry matter accumulation (kg fed^{-1})		Yield (kg fed^{-1})		
Treatments		45 daysAfter planting	75 days after planting	Straw	Grain	Total
High freq@.	SP ext.	1245	3415	3375	3113	6488
(every 3 days)	MAP	1287	3318	3300	2925	6225
	MKP	1419	3448	3563	3188	6750
	UP	1408	3378	3600	3225	6825
	PA	1270	3389	3338	2963	6300
Low freq@.	SP ext.	1245	3389	2963	3113	6075
(every 6 days)	MAP	1326	3349	2963	3000	5963
	MKP	1321	3419	3675	3000	6675
	UP	1258	3475	3188	3038	6225
	PA	1241	3354	3713	2588	6300
$LSD_{0.05}$		ns	ns	ns	ns	ns

SP ext.= water extract of superphosphate, MAP = mono-ammonium phosphate, MKP = mono-potassium phosphate,
UP = urea phosphate and H_3PO_4 = phosphoric acid. @ Frequency of P fertigation ns = insignificant

phosphate (SP ext). These results agreed with the main effects of UP on the soil pH and amount of available P in the root zone of wheat plants during the growth season.

The main effects of frequency of P fertigation on dry matter accumulation in wheat plants during the growth period; straw, grain and total biomass were not significant ($p>0.05$), however high frequency of P fertigation increased the dry matter accumulation in wheat plants during the early stage of the growth. These results corroborates with the main effects of frequency of P fertigation on the distribution of P availability in the root zone of wheat plants.

As shown in Table 6 the effects of interaction of frequency of P fertigation and forms of P fertilization forms on dry matter accumulation (straw, grain and total biomass) were not significant ($p>0.05$), even though high frequency of P fertigation of MKP, UP and PA produced higher grain yields compared to low frequency P fertigation. On the other hand high frequency P fertigation of UP produced higher total biomass of 6825 kg fed^{-1}compared to low frequency P fertigation 6225 kg fed^{-1}. With the used of high frequency fertigation nutrients applied more frequently at small amount, indicates that nutrients will be available for plant uptake appropriate time and amount that minimize the losses and maximum uptake efficiency. Thus high-frequency phosphorus fertigation may increase the time-averaged of P concentration in the soil solution above that expected from P solubility considerations. P is a yield-limiting factor.

High frequent P fertigation may increase yield by stimulating P-uptake by the roots and minimize the turn-over processes that may reduce the amount of available P in the root zone of wheat plants. Previous work showed that the application of phosphorus in more than one dose gave a higher mean yield than that obtained from a single application [30]. Silber *et al* [31] obtained similar results and mentioned that high frequency of fertigation improved the uptake of nutrients through two mechanisms: 1-continuous replacement of nutrients in the depletion zone at the vicinity of the root surfaces, 2: enhanced the transport of dissolved nutrients by mass flow due to the higher average of nutrients content in water in the medium. It is reported that wheat response to water and fertilizer management [32, 33] especially in newly reclaimed soils.

CONCLUSIONS

High fertigation frequency reduces the variations in nutrient concentration, thereby increasing their availability to plants and reducing their leaching beneath the root zone. We hypothesized that by applying frequent fertigations, to supply nutrients at rates that match the plant requirements throughout the potential photosynthesis cycle, we would be able to reduce the quantities of fertilizer needed to achieve optimal production. Sandy calcareous soils have a high pH values, low availability of P and micronutrients and need good management to reduce soil pH to more nutrient availability and therefore P should be added by fertigation and by using the acid forms to avoid P perception.

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