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Phosphorus Fertigation and Preplant Conventional Soil Application of Drip Irrigated Summer Squash

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Abstract: Two field experiments were conducted to evaluate squash response to the following phosphorus (P) fertigation rates and method of application: (1) 0 mg P L^{-1} irrigation water (IW) (P_0), (2) 30 mg P L^{-1} IW (P_{30}), (3) 60 P L^{-1} IW (P_{60}), (4) 90 P L^{-1} IW (P_{90}) and (5) preplant soil P application at a rate equivalent to P_{30} treatment. Squash seeds were planted for two seasons and were irrigated twice a week to replenish 80% of the class A pan evaporation. Plant and soil samples were collected and analyzed for chemical analysis. Fruit yield was determined from harvesting the middle two rows. With P fertigation, fruit yield, fruit numbers and P uptake were higher than with preplant soil application and the yield was related positively to P uptake. The P fertilizer use efficiency (PFUE) was also higher with fertigation and decreased with increasing P rates. Soil pH in the top soil decreased by the highest P rate due to the acidifying effect of phosphoric acid applied through fertigation. Being slightly soluble, P accumulated more in the top 15 cm soil and was higher with higher rates. With preplant application, P accumulated deeper in the top 30 cm. It can be concluded that the lowest fertigated P rate was adequate to achieve the highest yield and PFUE and was superior to preplant application method.

Key words: Squash, phosphorus, fertigation, preplant application

INTRODUCTION

Phosphorus is an essential plant nutrient and commonly limiting nutrient for crops grown in most calcareous soils. Plants poorly utilize P when applied conventionally through surface application especially on calcareous soils[1]. Therefore, P deficiency is widespread in plants grown in calcareous soils and the crops have generally responded to P fertilizer[2]. The recovery of P applied through conventional soil application was reported to be very low[3]. Band P application, which is considered the most efficient conventional method mainly did not result on P recovery more than 20 %[4]. The main causes for low PFUE are sorption and precipitation of P with Ca and Mg in calcareous soils[5].

Preplant conventional soil application of P has the advantage of providing the initial high P concentration in the soil solution[6] however, concentration declines during the growing season due to sorption and precipitation reaction[2]. Therefore, drip-irrigated crops, which are characterized by restricted root volumes, may suffer form P deficiency during and toward the end of the growing season[7]. A continuous P supply through fertigation (fertilization through irrigation) on the other hand, may enhance P uptake later in the season and fertigation may create a more favorable soil moisture condition that improves P mobility and availability. Fertigation resulted in higher yield quantity and quality of various vegetable crops such as tomato[8], potato[9], garlic[10]. In addition, fertigation minimizes leaching of water and nutrients from the rhizosphere, thus minimizes groundwater contamination[11] and improves fertilizer and water use efficiency[9,12,13].

Unlike N fertilizers, most commonly used P fertilizers are slightly soluble and incompatible with the irrigation water quality causing precipitation with calcium and clogging the irrigation system. Therefore, fertigation has mainly been practiced for N with little attention to P that continued to be added conventionally by soil application to the drip irrigated fields[14]. In addition, preplant P application to drip irrigated row crops practiced by most farmers will most likely become insoluble in the soil and unavailable to the plants later in the growing season. Although the use of P fertilizers in drip systems may cause clogging problems to the system, these problems can be overcome by using acidic P fertilizers especially in calcareous soils[15]. Successful P fertigation has been reported by Papadopoulos[16] who reported that the superiority of P fertigation over conventional method was through maintaining continuous higher concentration of

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P in the soil solution. Kafkafi[17] considered fertigation as an efficient method for providing and supplying available forms of immobile elements such as P, at a desirable level in the root zone. This is especially important during the very first stages where P is needed for developing a good root system. Moreover and unlike conventional band application, fertigation provides P and water at the same time that maximizes P mobility near the root system[16]. Compared to the preplant conventional soil application of triple super phosphate, it has been found that P fertigation as phosphoric acid increased the yield and nutrients uptake by tomato[15] and by potato[18]. Ristimaki and Papadopoulos[15] found that irrespective of the source, P fertigation was more effective than direct soil application. In addition, restricted root system, developed under drip irrigation, requires frequent replenishment of the nutrient in the root zone. Such requirement can be satisfied by fertigation[13,19]. On the contrary, other researchers reported that P application method (preplant conventional soil application or fertigation) had no effect on tomato yield and P uptake[20] or on potato P content[3].

Phosphorus fertigation management of squash is generally lacking and squash responses to P under semi-arid conditions are not well documented. The main objective of this study was to evaluate squash response to fertigation P rates and to both fertigation and conventional soil P application methods.

MATERIALS AND METHODS

This study was conducted in the Agricultural Center of Research and Production at Jordan University of Science and Technology. The site is located 20 km east of Irbid, 32°30° north latitude and 35°59° east longitude with an elevation of 590 m above sea level. The soil of the research site is fine-loamy, mixed, thermic, Calcic Paleargid[21].

Two field experiments were conducted in 2000 and 2001 summer growing seasons at the same location. A randomized complete block design with 4 replications of 5 treatments was used. Plot dimension was 6×6 m. Each plot contained 4 rows each 6 m long. Each row had its own irrigation line positioned near the plants with emitters spaced 40 cm apart in the irrigation line. The 5 treatments were as follow: (1) 0 mg P L^{-1} irrigation water (IW) (P_0), (2) 30 mg P L^{-1} IW (P_1), (3) 60 P L^{-1} IW (P_2), (4) 90 P L^{-1} IW (P_3) and (5) conventional soil P application at a rate equivalent to the treatment of 30 P L^{-1} IW (Ps). For the fertigation treatments, P was applied as phosphoric acid (85% and specific density of 1.7 g cm^{-3}) in irrigation water. The fifth treatment was the conventional application of P as triple super phosphate (TSP) in amount equivalent to treatment of 30 mg P L^{-1} IW as phosphoric acid. TSP was broadcasted and incorporated in the top 20 cm soil with a rototiller before planting. Nitrogen was applied uniformly to all treatments as urea at concentration of 90 mg N L^{-1} IW. The fertilizers in the fertigation treatments were injected into the IW with a fertilizer injector (Venturi). This type of injector is quite simple, relatively inexpensive and easy to install[6]. Two injectors were used: one for P fertigation treatments (rates) and the second for the uniform N application. Amounts of water and fertilizer added for both growing seasons are shown in Table 1.

Squash seeds (*Cucurbita pepo*) hybrid Ramita variety were planted at 0.4 m between plants and 1.5 m between rows. Three seeds were planted per hole, which then were thinned to one plant at the early seedling stage. Planting dates were March 14, 2000 and March 29, 2001 for the first and second summer growing seasons, respectively. Irrigation was performed to replenish 80% of the class A pan evaporation (field devise to record the amount of water evaporation in mm) twice a week.

Four composite soil samples (each composed of 3 individual samples) were taken from the site before planting. At the end of the experiment, similarly soil samples were taken between the plants (emitters) within the crop row from each plot. Soil samples were taken from depths of 0-15, 15-30 and 30-60 cm. Samples were air dried, ground and sieved through a 2 mm screen. Soil samples were analyzed for pH in 1:1 soil:water suspension[22], soluble salts were determined by measuring electrical conductivity of 1:1 soil:water extract[23], for total Kjeldahl nitrogen[24], for phosphorus by extraction with 0.5 M $NaHCO_3$[25], for $CaCO_3$ by acid neutralization method[26], for exchangeable K by extraction with 1 M NH_4OAc[27] and soil texture by hydrometer[28]. Organic matter was measured by rapid oxidation[24]. Major soil characteristics are presented in Table 2.

Fruit and above ground biomass (shoot) plant samples (from two whole plants from each plot) were collected at mid fruiting period. Plant samples were oven dried at 70°C and weighed to get the dry matter for each sample. Samples were ground to pass 2 mm sieve and stored for tissue analysis. Plant samples then were analyzed for total N using a modified micro-kjeldahl digestion procedure[24] and for total P in the dry ash digestion[29]. The fruit yield was determined from harvesting the middle two rows during the harvest period and the yield was calculated on a hectare basis. Nutrient uptake was calculated by multiplying the dry weight by the nutrient percentage concentration in shoot and fruit. Total nutrient uptake was calculated by adding the uptake

Table 1: Treatments codes and amounts of water and fertilizers added to the experiment in 2000 and 2001

Treatment codes	P concentrations mg P L^{-1}	Amount of P added Kg P ha^{-1} 2000	2001
P_0	00	00.0	00.0
P_{30}	30	47.9	44.3
P_{60}	60	95.8	88.5
P_{90}	90	143.7	132.8
Ps	Soil application as TSP	44.6	44.6
Amount of irrigation water without fertilizers (m^3 ha^{-1})		731.5	345.5
Amount of fertigation water (m^3 ha^{-1})		1596.9	1475.6
Amount of N added (Kg ha^{-1})		143.7	132.8

TSP = Triple super phosphate

Table 2: Preliminary analysis of the soil characteristics at the experimental site before starting the experiment

	Depth (cm)					
Soil parameters	0-15	15-30	30-45	45-60	60-75	75-90
PH	7.90	8.00	7.80	8.00	7.90	7.80
EC (dS m^{-1})	0.80	0.66	0.61	0.70	1.14	1.50
P (mg kg^{-1})	10.90	10.40	11.00	11.20	9.40	9.00
K	502.00	450.00	283.00	262.00	184.00	199.00
$CaCO_3$ (%)	13.50	15.20	16.90	17.30	17.30	17.20
Organic matter (%)	1.19	1.16	0.84	0.56	0.42	0.25
Sand (%)	12.70	13.70	14.00	15.30	13.40	14.10
Silt (%)	48.70	43.80	35.50	33.90	32.10	33.50
Clay (%)	38.60	42.50	50.50	50.80	54.50	52.40
Texture	SCL	SC	Clay	Clay	Clay	Clay
B. density (g cm^{-3})	1.30					

* SCL = Silty clay loam and SC = Silty clay

by shoot and fruit. Phosphorus fertilizer use efficiency (PFUE) was calculated as kg fruit yield per kg of P applied and also calculated using different method according to the following relationship:

$$\text{PFUE} = \frac{\text{P uptake by plants in the fertilized treatment- P uptake by plants in the control treatment}}{\text{amount of P applied for the fertilized treatment}} \times 100$$

Analysis of variance (ANOVA) was used to determine the effect of each treatment. When F ratio was significant a multiple mean comparison was performed using Fisher's Least Significance Test (0.05 probability level). Statistical analyses were performed with SYSTAT statistical program[30].

RESULTS AND DISCUSSION

Fruit yield and fruit number: Fertigation at a rate of 30 mg P L^{-1} IW resulted in higher fruit yield than the control (zero P) and the equivalent preplant conventional soil application treatments in both growing seasons (Table 3). Fertigation of P at higher rates (60 and 90 mg P L^{-1}) did not significantly increase the yield compared to the lowest rate (30 mg P L^{-1}) but resulted in higher yield that obtained by the control and conventional preplant soil application treatments. The response of squash yield to P fertigation rates followed a polynomial quadratic relationship where 1/3 of the variation in the population in the two seasons was accounted by this relationship. It should be indicated, that conventional application of P gave yield as low as that obtained by the control treatment and P should have been added at higher rate conventionally to increase the yield. Most of the conventionally applied P probably underwent precipitation reactions in the soil and accumulated in an unavailable form[31]. Therefore, it was reported by other researchers[32], that P should be added at rates high enough to saturate the adsorption and precipitation capacity of root zone before they can be available to plants. The higher squash yield with P fertigation compared to the conventional application method could be attributed to the more P availability to plants grown under continuous P fertigation where P fixation by the soil is lower[33]. In addition, simultaneous application of N and P with fertigation may enhance the uptake of P as compared to separate placement[9].

On the other hand, yield in the second growing season was lower than that in the first season. This could be attributed to the possible partial flower abortion and a sharp reduction in fruit set associated with the higher air temperatures prevailed in the second growing season. The lower fruit numbers obtained in the second season evidenced this. This attribution is in agreement with Stapleton *et al.*[34] who reported that extreme temperatures could influence flowering and fruit set in Cucurbitacea

Table 3: Fruit yield and fruit number of summer squash in 2000 and 2001

	Total yield t ha^{-1}		Total fruit number *1000 ha^{-1}	
Treatment codes	2000	2001	2000	2001
P_0	29.3b	19.2c	170.7	126.7d
P_{30}	38.4a	26.0a	199.7	149.4c
P_{60}	35.0ab	24.1ab	190.6	179.4a
P_{90}	34.3ab	23.2a-c	192.2	190.7b
Ps	30.6b	20.9bc	181.3	146.3c
LSD_{05} value	5.8	4.4	NS	6.4

Table 4: Total uptake of N, P and K by summer squash in 2000 and 2001

	N kg ha^{-1}		P kg ha^{-1}		K kg ha^{-1}	
Treatment codes	2000	2001	2000	2001	2000	2001
P_0	98.38	100.45	14.09b	10.20b	95.28	100.50
P_{30}	113.33	125.45	19.15a	14.75a	111.46	130.13
P_{60}	110.96	129.03	19.06a	14.90a	109.87	145.60
P_{90}	109.33	129.20	21.62a	15.70a	111.98	128.13
Ps	99.26	125.85	15.86b	14.15a	94.64	138.08
LSD value	NS	NS	2.82	3.50	NS	NS

P_0=zero P; P_{30}=30 mg P L^{-1} IW (irrigation water); P_{60}=60 mg P L^{-1}IW; P_{90}= mg P L^{-1}IW; Ps=soil application of P in amount equivalent to P_{30}. Means for each parameter within each column that have different letters are significantly different at the 0.05 level of probability. NS indicates non significant

plants. Moreover, it was reported that, floral sex expression in the Cucurbitacea is controlled by endogenous hormones, whose levels may vary in response to environmental conditions[35]. In addition, long days, high temperatures, high light intensity and low N level enhance male expression in squash crop, while the opposite conditions promote female expression[36]. Number of fruits per hectare was not affected by the treatments in the first season but increased with P application in the second season and was the highest with P fertigation treatments.

Nutrient uptake and phosphorus fertilizer use efficiency (PFUE): Nitrogen and potassium uptake was not significantly affected by the treatments in both seasons. On the other hand, P uptake similarly increased by all P fertigation rates in the first season and also similarly by all P rates regardless of method of application in the second season (Table 4).

The squash yield was correlated very well with P uptake in both seasons with correlation coefficients of 0.59 and 0.50 for the two seasons, respectively (Fig. 1). The increase in P uptake by P fertigation was found by other researchers[32,37] who attributed such increase to the maintenance of adequate soil solution P level through fertigation, which could have facilitated more P absorption. Other researchers also found similar results[38].

Phosphorus fertilizer use efficiency calculated as Kg squash fruit yield per Kg P added was in both seasons higher with P fertigation than with conventional soil application and decreased with increasing P fertigation rates (Table 5). In addition, PFUE calculated by difference method was also in both seasons higher with P fertigation being the highest for the lowest P fertigation rate (P_{30}). Similar reports were reported by other researchers[32,38] who attributed this to the continuous application of P during the growing period. Moreover, Mohammad *et al.*[9] suggested that the N applied with P in fertigation could have synergistic effect on enhancing P uptake and consequently PFUE. On the other hand, other researchers[20,39] found insignificant differences between PFUE when P applied either through fertigation or through conventional soil application. They also indicate that the TSP applied preplanting became available to plants at earlier time than fertigated treatments. Thus, roots of plants find their requirements of P earlier and consequently utilized P more efficiently[39]. Decreased PFUE with increased rates of P application has been reported by other researchers[40]. The decrease in PFUE as P rate increases could be attributed to frequent addition of high concentration of P that exceeded crop needs, thus saturation of reaction sites in the soil occurred, leading to further movement P away from the root zone[32].

It should be indicated that the lowest P fertigation rate simultaneously resulted on the highest yield level, the highest P uptake and the highest PFUE. This would have economic and environmental significance through reducing P fertilizer use, lowering production cost and minimizing the negative impact of the over fertilization and consequent nutrient imbalance on the environment. Water use efficiency expressed as kg of squash yield per one cubic meter of applied irrigation water is presented in Table 5. The highest WUE was obtained with P fertigation (P_{30}) than with preplant application (Ps). The lowest value of WUE was obtained with the zero or the highest rates of P application.

Table 5: Phosphorus fertilizer use efficiency (PFUE)and water use efficiency (WUE) by summer squash in 2000 and 2001

	PFUE	PFUE by difference method		WUE
Treatments	kg yield/kg P added	Yield dif %	Pup dif %	kg squash yield M^{-3} water applied
2000				
P_0	-	-	-	-
P_{30}	801.50a	18.99a	10.56a	-
P_{60}	365.27c	5.95b	5.19b	-
P_{90}	238.64c	3.48b	5.24b	-
Ps	685.79b	2.91b	3.97b	-
2001				
P_0	-	-	-	8.05c
P_{30}	587.31a	15.36a	10.28a	11.07a
P_{60}	272.19c	5.53b	5.31b	9.51b
P_{90}	174.69c	3.01b	4.14b	9.28bc
Ps	468.40b	3.81b	8.85b	8.88bc

Table 6: Effect of P fertigation on soil pH, EC, soil P at the end of the second growing season

		Soil depth (cm)		
Treatment codes	Soil parameters	0-15	15-30	30-60
P_0	pH	7.88a	7.97a	8.18a
P_{30}		7.75a	7.92a	8.24a
P_{60}		7.89a	7.99a	8.27a
P_{90}		7.45b	7.67b	7.91a
Ps		7.80a	8.02a	8.08a
P_0	EC (dS m^{-1})	0.41a	0.41a	0.51a
P_{30}		0.64a	0.46a	0.51a
P_{60}		0.42a	0.40a	0.53a
P_{90}		0.46a	0.41a	0.71a
Ps		0.47a	0.43a	0.66a
P_0	P (mg kg^{-1})	10.30c	7.40b	7.40a
P_{30}		18.86b	7.43b	5.14a
P_{60}		30.30a	6.30b	5.10a
P_{90}		26.90a	7.40b	6.90a
Ps		12.00c	10.3a	5.70a

P_0=zero P; P_{30}=30 mg P L^{-1} IW (irrigation water); P_{60}=60 mg P L^{-1} IW; P_{90}= mg P L^{-1} IW; Ps=soil application of P in amount equivalent to P_{30} Means for each parameter within each column that have different letters are significantly different at the 0.05 level of probability. NS indicates non significant

Soil chemical characteristics: Soil chemical characteristics at the end of the second season experiment are presented in (Table 6). The soil pH significantly decreased at the highest P fertigation rate (P_{90}) at the 0-15 and 15-30 cm soil depths as a result of the acidifying effect of the phosphoric acid. Other researchers reported that phosphoric acid applied through fertigation would decrease soil pH but temporarily because the reduced pH would probably be later buffered in calcareous soil[41]. Soil electrical conductivity (EC) at all soil depths was not affected by the treatments.

Extractable P was accumulated in the top 0-15 cm soil depth with P fertigation and was higher with higher rates. With preplant application of the whole doze of P rate, P accumulated deeper in the top 30 cm soil layer. Higher P levels in the surface soil layers are attributed to the low P mobility[31]. Also, fertigated P was applied frequently along the growing season, thus P might be added in amounts exceeded crop uptake. Consequently P accumulated in the topsoil layer. This attribution was in agreement with Imas *et al.*[42]. Addition of P in excess did not only had no effect on the yield as was found in this study, but also accumulated in the soil which can be subjected to various sorption and precipitation reactions and be converted to unavailable P to plants. This would also decrease PFUE and cause a nutrient imbalance in the soil[42]. Some researchers found comparable results (Martinez *et al.*[43] who found increase in P and K content at the center of the root zone under frequent P drip fertigation. Others found that K concentration in the soil was not significantly affected by P concentration[7]. Opposite results found that as soil extractable P increased, the concentration of exchangeable K decreased.

P movement is usually related to soil texture, where P moves deeper in sandy soils than in clay soils[42]. With drip irrigation, the rate of P applied per wetted area would be larger. This allowed the soil to become saturated at the soil surface with P so more P was able to move deeper in the soil. In addition, preplant application provided the

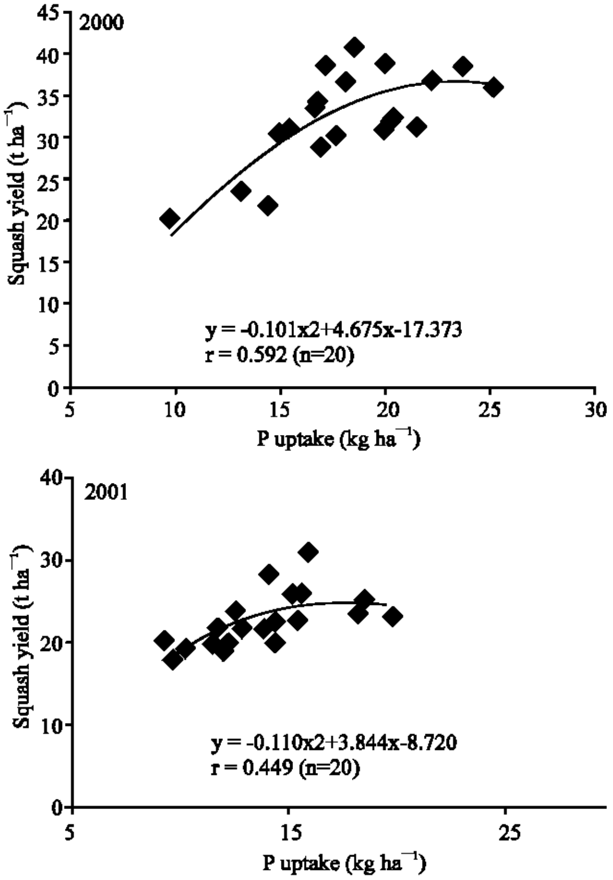

Fig. 1: Relationship between squash yield and P uptake

whole P rate in one application doze. That is why preplant application resulted in higher level of soil P in the lower soil layer (15-30 cm) compared to the fertigation treatments.

It can be concluded that fertigation was more effective in increasing squash yield than the conventional preplant application. Fertigation of P at rate of 30 mg P L^{-1} was adequate to achieve the highest yield. Higher P fertigation rates were not only not effective on the yield but also resulted in accumulation of P in the soil as unavailable forms. Consequently, decreasing farmer's income returns, creating a nutrient imbalance and contaminating the environment. Therefore, it is recommended to apply P through fertigation at a rate of 30 mg L^{-1} to the drip irrigated row crops.

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