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Fruit Yield, Nutrient Availability and Fertilizer Recovery of Eggplants under Fertigation of Acid Forming Fertilizer Compounds

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ABSTRACT

Most soils in arid and semi-arid regions are alkaline, which may leads to poor nutrients uptake by crops and consequently poor yield production. However, maximum uptake of nutrients is often done at neutral or slightly acid soils while when soil reaction is more than seven, it causes decreased in most plant nutrients availability. The main objective of this work was to evaluate the effect of injection orthophosphoric acid (OP) coupled with different forms of nitrogen; urea (UR), ammonium sulphate (AS) and ammonium nitrate (AN) through drip irrigation on soil reaction, nutrients status in the root zone and yield of eggplants grown on sandy soil. Application of OP coupled with different forms of N significantly decreased soil reaction and the reduction was greater when N was applied as ammonium rather than urea. Ammonium distribution was restricted to a small soil volume around the water source because of relatively quick nitrification and slow transport due to adsorption on sol particles. On the other hand, nitrate accumulated with time at the boundary of the wetted area which proves that nitrate movement in the soil is directly proportional to the water movement. Phosphorus was delivered to a greater soil volume when applied as OP than SP, which should result in more plant available P in the root zone. Potassium was relatively higher adjacent to the water source, as it is highly adsorbed by the soil, preventing their movement further down the soil profile. Soil acidification in the root zone significantly increased the levels of available Fe, Mn and Zn but had little effect on levels of Cu. The highest N uptake was noted under the acidified water irrigation while the least was under normal water irrigation. Similarly the N and P recovery under acidified water was higher compared to normal water, irrespective of the N form tested. Fertigation of acid forming fertilizers resulted in 12% yield increase over normal water; however there is no significant effect among N forms on yield performance. These results suggested that enhancing root zone acidification attributable to applications of acidified water and nitrogen fertilizer containing ammonium can increase nutrient availability and uptake by crops particularly in arid and semi-regions.

Key words: Soil acidification, soil reaction, N distribution, P distraction nutrient availability, N uptake, N recovery, eggplants.

Introduction

Most of the alkaline soils are found in the desert environments throughout the world where evaporation concentrates the salts received from more elevated locations in surface water, ground water, or irrigation water. The prime minerals in irrigation water are chloride, sulfate, bicarbonate, sodium, calcium and magnesium which may accumulate in the soil and cause problems. In alkaline soil many crops exhibit symptoms of nutritional deficiencies which are often attributed to the failure of the plant to absorb or assimilate some of the nutrient elements, so that unbalanced nutrition may cause sub-optimal performance of the crop. In such cases plants may be unable to absorb the nutrients because of undesirable conditions of soil like high pH and antagonistic relations between soil and nutrient elements. However, acidification of water can correct the nutritional deficiency symptoms and improves the uniformity of pH in the field and growth of the plants (He, *et al.,* 1999). Moreover, acidification of the water slowdown the rise in pH of alkaline soil and creates a more uniform growing environment for the crop.

Application of acid forming N fertilizers such as urea, ammonium nitrate and ammonium sulphate has been reported to decrease soil pH (Neilsen *et al.,* 1994; Bouman *et al.,* 1995; He, *et al.,* 1999). The major mechanism of soil acidification by nitrogen fertilization is related to H^+ ion release through nitrification of NH_4^+−N and the subsequent leaching of $N0_3^-$−N. Another advantage is NH_4^+−N retention in soil particles due to its electrical load, in addition to it being absorbed by the plant with an energetic cost lower than $N0_3^-$-N ion (Douma *et al.,* 2005). Its absorption also produces a decrease in the pH of rhizosphere, which increases absorption of other ions such as $H_2PO_4^-$ (Havlin *et al.,* 2005). The most important consequence of soil

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acidification was the depletion of exchangeable Ca, Mg and K and an increase in Mn solubility (Neilsen *et al.,* 1994; Bouman *et al.,* 1995; Tachibana *et al.,* 1995). Soil pH influences the amount and plant availability of various macro and micro nutrients (Alva *et al.,* 1995) which, in turn, could affect the fruit yield, quality and leaching loss of nutrients.

Among the various irrigation methods used for water application, drip method seems to be the most efficient for water application worldwide. Applying plant nutrients through irrigation water (termed as fertigation) particularly with the drip system is a most efficient way of nutrient application. Fertigation allows an accurate and uniform application of fertilizers to the wetted area where most active roots are concentrated. Therefore, it is possible to dispense adequate nutrient quantity at an appropriate concentration to meet the crop demand during a growing season (Battilani and Solimando, 2006). Therefore, it is possible to dispense adequate nutrient quantity at an appropriate concentration to meet the crop demand during a growing season. Nitrogen is the nutrient element most commonly applied through drip systems and it is often injected as urea, ammonium sulphate or ammonium nitrate. The cumulative effect of fertilizer application could also be important for example, soil acidity was increased with increasing application of N fertilizer (Bouman *et al.,* 1995) and its cumulative effects caused by continual fertigation with ammonium-containing or forming fertilizers has been reported to decrease soil pH (Neilson *et al.,* 1994; Bouman *et al.,* 1995). It seems reasonable that some type of acidification agent would make available the insoluble nutrients present in the soil or delay precipitation of those nutrients added as fertilizers (Basile *et al.,* 1993). The temporary reduction in soil pH induced the highest nutrient concentration and uptake for most of the elements (Van *et al.,* 2008; Ghehsareh and Samadi, 2012).

Most of the area of our country has arid climate and because of lacking precipitation, almost of the cultured area needs irrigation. Moreover, in most areas of Egypt, water resources consist of high amounts of Ca, Mg and bicarbonate and water reaction is alkaline. The main objective of the present study was to determine the effect of injection OP coupled with different forms of nitrogen on soil reaction, nutrients status in the root zone and yield performance of drip irrigated eggplants grown on sandy soil.

Materials and Methods

Site and soil description

The field experiment was conducted at private farm located at Nubaria province west of Nile Delta of Egypt during the early summer (Mars-June) growing season of 2012. The research field is situated in an arid climate region at an altitude of 27 m above mean sea level and is intersected by latitude of 30°30N and longitude of 30°20E. The soil of the experimental site was deep, well-drained sandy profile which was classified as an (*Entisol-Typic Torripsamments*) composing of 85.5% sand (2.0–0.02 mm), 11.7% silt (0.02–0.002) 2.8% clay (less than 0.002 mm) and 0.4% organic matter in the topsoil (0-80 cm depth) with an alkaline pH of 8.2, EC of 0.85 dS m^{-1}, $CaCO_3$ 1.5%. The average soil water content at field capacity from surface soil layer down to 80 cm depth at 20 cm intervals was 0.18 (v/v) and the permanent wilting point for the corresponding depths was 0.08 (v/v), respectively. Average available N, P and K from surface soil layer down to 60 cm depth at 20 cm intervals was 12, 4 and 35 mg kg^{-1} soil, respectively before the initiation of the experiment.

Experimental design and treatments

The experimental treatments included drip fertigation of acidified water performed by using orthophosphoric acid (OP) which injected directly into the dripping system coupled with three forms of N fertilizers; urea (UR) ammonium sulphate (AS) and ammonium nitrate (AN) equivalent to 320 kg N ha^{-1}. Non acidified water was maintained as a control treatment and supplied with calcium nitrate (CN), which was injected at the same rate in the other N treatments. The injected OP (85%) with irrigation was performed at weekly intervals (50 liter per week) accordingly; the applied phosphorus rate was about 180 kg P ha^{-1} as OP. In control treatment super phosphate (SP) was broadcast directly under the drippers at the same rate of other treatments. The total amount of N was injected directly into the main line of drip system in water-soluble form using venturi-tube injector. The OP and N fertilizer was applied at weekly intervals in 12 equal doses starting one week after transplanting and stopped 30 days prior to the end of the crop period. All treatments were supplemented with a uniform dose of 240 kg K ha^{-1} as potassium sulphate prior to planting.

The four treatments were replicated three times in a randomized block design and were applied to three rows per plot (4×10 m). Seedlings of eggplants plants (black moon var.) were cultivated in one-row beds at 1 m apart at 40 cm on the early Mars 2012. Before cultivation of eggplants, drip tubing (twin-wall GR, 15 mm inner diameter, 40 cm dripper spacing delivering 2.5 liter h^{-1} at operating pressure 100 kPa) were placed on soil surface besides each plant row at the center of the soil beds. Crop water requirement was scheduled based on evapotranspiration replenishment on a daily basis by using Penman-Monteith's formula (Allen *et al.,* 1998). Irrigation frequency was running every other day for a period needed to deliver crop water requirements (ET). The ET value during the irrigation differential period was 686 mm and the total actual amount of irrigation water was 472 mm applied during the whole growing season.

To determine water and available NPK distribution for each treatment, soil samples were taken from below the drippers at depths of 10 cm down to 60-cm along with radial line originating at the water source at distances of 5 cm up to 30 cm at the end of last fertigation cycle, using tube auger from the experimental area. Soil moisture content was determined gravimetrically at the Analytical Research Lab (National Research Center, Cairo, Egypt) and expressed as percent of dry soil. Ammonium and nitrate were extracted with 1 *M* KCl from moist soil samples and measured by the modified-Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was extracted with 0.5 *M* $NaHCO_3$ and P was measured by colorimetric ascorbic acid methodology (Eaton *et al.,* 1995). Potassium was extracted with 1 *M* ammonium acetate and K was measured by flam photometer using the method described by (Jackson, 1973). Micronutrients cations (Fe, Mn, Zn and Cu) were extracted from the soils with 0.04 *M* EDTA and concentration in extracts were measured by atomic absorption spectrophotometer.

Measurements of crop parameters

Eggplant fruits were collected periodically and at last pick of fruits all aboveground biomass in each plot were collected from 3 randomly selected plants in each plot in all the replications and weighed to determined total biomass of shoots and fruits and data were presented as ton per hectare. Shoot and fruit tissues were separated and dried at 70 ºC in a forced air oven for subsequent dry weight determination. Tissue samples were ground to pass through a 0.5 mm screen and stored for dry weight analysis, with a thoroughly mixed 5 g portion of each sample stored. Tissue material was digested using H_2SO_4 in the presence of H_2O_2 and analyzed for total Kjeldahl N (Bremner and Mulvaney, 1982) and P concentration using the methods described above. Different plant parameters were determined from 10 randomly selected plants in a row in each treatment in all the replications including total fresh fruit yield per plant, fruit number per plant and average fruit weight per plant. Seasonal N and P uptake was derived from the whole plant sample (shoots + fruits) data and as the product of the crop biomass (dry weight) and the N and P concentrations in plant materials from which the uptake per hectare was derived based on plant population. Total fresh fruit yield was recorded on at least 50 plants in a row in each treatment in all the replications and data were presented as ton per hectare. Post-harvest fertilizer recovery was calculated using the following equation:

$$\text{N recovery} = (Ft / F) \times 100$$

where Ft equals the total crop fertilizer uptake (shoots + fruits) under treatment, and F equals applied fertilizer (in units of kilogram per hectare) and data were presented as percentage.

Statistical analysis

Experimental data were subjected to the analysis of variance (ANOVA) appropriate to the experimental design to evaluate the effects of treatments on crop N and P uptake, total yield, fruit number, fruit weight, dry biomass production and N and P recovery use efficiency by the plants. CoStat (Version 6.303, CoHort, USA, 1998-2004) was used to conduct the analysis of variance. Least significant differences (LSD) were used for means separation at 5% probability level.

Results and Discussion

Soil moisture content

Wetting patterns are determined by the radial distance and the depth of the wetting front from the water source (dripper), (Fig. 1). Surface drip irrigation allows water to move faster both vertically and horizontally and produced an expected onion shaped distribution surrounding the drippers. After irrigation ceased, the wetted region exhibited a vertically elongation pattern, which extended to nearly 30 cm horizontally and 60 cm vertically directly beneath the dripper. Maximum water content was recorded between the 10 and 40 cm soil depth, and at the depth beyond 50 cm the soil was relatively dry and not suitable for plant uptake. Horizontal water movement was limited, since the flow of water from dripper was mostly directed by lower capillary forces prevailing in sandy soil. After 48 hours from irrigation start, the wetted volume in the root zone retained about 50% of filed capacity and contained which indicating the need to hold irrigation process at two days intervals max. However, the position of the wetting front is commonly used to describe the extent of soil moisture distribution under different conditions. Acid water showed no significant effect on soil water distribution under any form of nitrogen or at any time.

Soil reaction (pH)

The soil had a relatively uniform surface and subsurface layer up to 60 cm soil depth, which contained about 85% sand with very low content of $CaCO_3$, about (1.5%). Normal water with calcium nitrate fertilizer had an opposite effect on the soil pH below the dripper and resulted in maximum pH increases of 0.30 over the original soil pH value probably due to the applied Ca^{+2} displacing H^+ ions from the surface soil. The soil reaction had the maximum changes at the root zone blows all the acidification treatments but gradually approached the original soil pH as the distance from the water source (dripper) increased (Fig. 2). However, soil pH was lower by 0.8 to 1.5 units as compared to the control after three months of acidified treatments. However, the decrease in soil pH was greater below the drippers with ammonium sulphate rather than urea or ammonium nitrate. It seems that the hydrolysis of urea and subsequent nitrification must have occurred directly blow the drippers during the course of the experiment in that soil volume. As expected, ammonium sulphate generally had a greater acidifying effect than urea. The effect of such fertilizer on reducing soil pH was therefore additive to the acidifying effect of orthophosphoric acid. However, application of acid-forming N fertilizers such as UR, AS and AN has been reported to decrease soil pH (Bouman, *et al.,* 1995; Neilsen, *et al.,* 1994). Moreover, the combination between mineral acids and ammonium containing or forming fertilizers can be magnified under drip fertigation because the fertilizer application is concentrated in a relatively small volume of soil rather than being spread evenly over the soil surface. Thus, in the ammonium sulphate and ammonium nitrate treatments, soil pH values were generally at or below pH 7.0 in the soil depth 40-cm of soil immediately below the dripper.

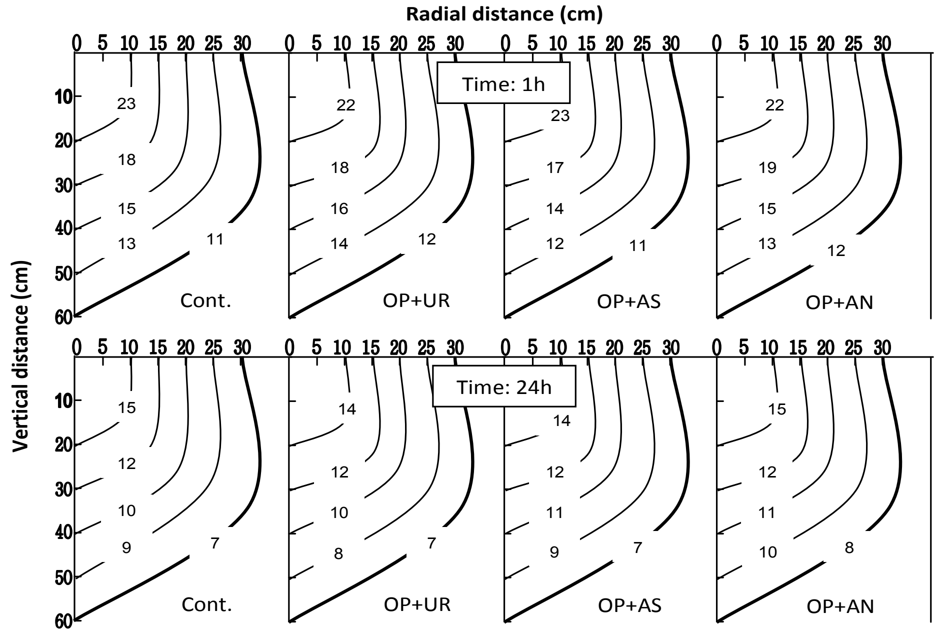

Fig. 1: Soil moisture distribution (%) in the root zone at the end (Time: 1h) and before the next (Time: 48h) of third irrigation cycle. The heavy peripheral lines are the position of the wetting fronts.

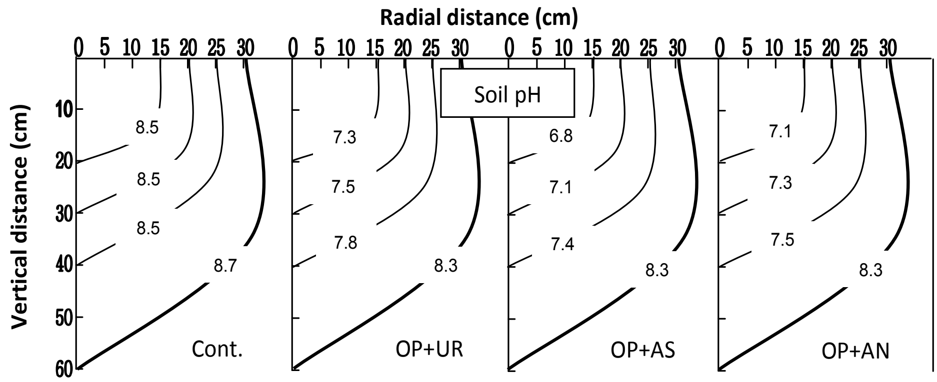

Fig. 2: Temporally changes in soil reaction (pH) as affected by fertigation of OP and different forms of nitrogen in the root zone at the end of last fertigation cycle. The heavy peripheral lines are the position of the wetting fronts.

Available nitrogen

Levels of ammonium and nitrate in the soil at the end of fertigation cycle were compared for the different applied nitrogen forms (Fig 3). Ammonium was considerably lower close to the drippers when N was applied as urea rather than ammonium sulphate or ammonium nitrate. As observed in a previous study (Hayens and Swift, 1987) the bulk of fertigated urea was converted to ammonium within 48 hour of application. They also added that the concentration of fertigated ammonium, or that originating from the hydrolysis of urea, declines slowly during the first week following application and then more rapidly over the next two weeks. For this reason ammonium concentration was found deeper in the soil profile and tended to distribute evenly within the wetted zone as it is not strongly adsorbed by soil colloids (Hayens and Swift, 1987; Hanson *et al.,* 2006). However, for this reason presumably, an appreciable amount of added urea moved away from the drippers in the urea form as shown by the measurement of ammonium at 40-cm blow and away from the drippers towards the wetting front. A great deal of urea hydrolysis and subsequent nitrification must have occurred during the course of the experiment.

Ammonium remained concentrated at the proximity of the water source (15-20 cm) when N was applied as AS or AN and beyond this distance, ammonium concentration was slightly higher over its initial value; there was only a slight movement within the soil profile because of soil adsorption and subsequent fast nitrification and/or root uptake. An unfavorable environment for nitrification resulting from the saturated zone around the source may partly account for the peak value (Haynes and Swift, 1987). Similar distribution patterns were observed for other experiments (Li *et al.,* 2003; Hanson *et al.,* 2006).

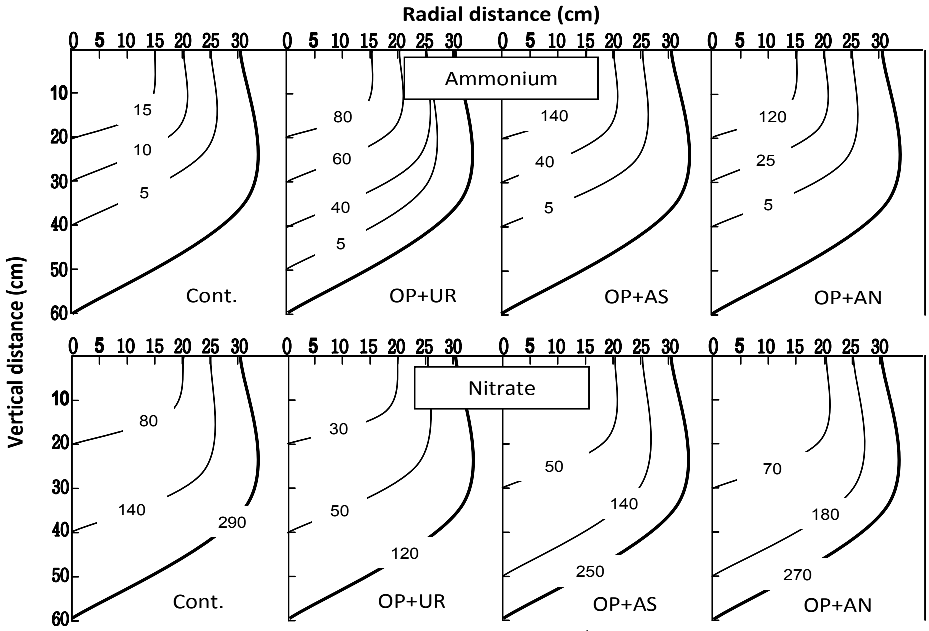

Fig. 3: Spatial distributions of ammonium and nitrate (mg kg soil^{-1}) in the root zone as affected by fertigation of OP and different forms of nitrogen at the end of last fertigation cycle. The heavy peripheral lines are the position of the wetting fronts.

On the other hand, nitrate moved continuously downward during the 90-day fertigation period, particularly when N was applied as CN and AN. As expected, high nitrate concentrations occurred near the water source due to injection, but little nitrate remained near the drip line during the growth period, because of root uptake and dispersion during downward transport. At this time, most of nitrate was distributed near the periphery of the wetted region as nitrate is not adsorbed on soil particles and also due to leaching following the fertigation. Such an effect when applying ammonium that it was not nitrified in the saturated zone immediately below the emitter; nitrification occurred in the unsaturated zone close to the edge of the wetting front. Nitrate levels and number of nitrifying bacteria were low below the dripper and higher further away (Laher and Avnimelech, 1980).

The same accumulation trend of nitrate at the boundary of the wetted volume was also observed by many authors (Mailhol *et al.,* 2001; Li, *et al.,* 2004; Hanson *et al.,* 2006). Santos *et al.,* (1997) pointed out that nitrate fate and transport is strongly dependent on the soil water content and its movement. Nitrate is very mobile and if there is sufficient water in the soil, it can move quickly through the soil profile. Careful application of nitrogen and water should be able to minimize the amount of nitrogen moving below the root zone. This is due to nitrate movement from the surface layers, a fact, which has important implication regarding the frequency of nitrate at a rate that is close to plant uptake. As also demonstrated by the laboratory study of Li, *et al.,* (2004), nitrate distributions are highly affected by the wetting patterns of the drip irrigation system and water mass flow is the major factor responsible for nitrate movement in the soil.

Available P and K

The mobility of phosphate ion in soils is of primary importance in plant nutrition. Phosphate transport in both vertical and lateral directions in control treatment was too slow for the average rate of root growth into the soil, since P fertilizers are prone to fixation at the point of application even in the sandy soil (Fig. 4). Most of the applied P may be turned to non-soluble form in a short time after its application, and the observed concentrations build up near the water source could affect root growth and create unfavorable conditions for P uptake. However, surface application of P with solid fertilizer resulted in poor utilization efficiency where most of the applied P remained close to soil surface with low available content due to adsorption and precipitation reactions. This point highlights the high P fixation capacity of the soil as well as the importance of split application of fertilizers to improve P use efficiency.

On the other hand, phosphorus was distributed to a greater soil depth when applied as orthophosphoric acid through fertigation than applied as solid fertilizer (super phosphate) and resulted in a more favorable P distribution for uptake by roots at identical rate of application. Phosphorus movement was somewhat greater with ammonium sulphate treatment than either with urea or ammonium nitrate treatments. This result suggests that the P could be utilized more efficiently by the plants and could be one of the factors for more uptake and yield.

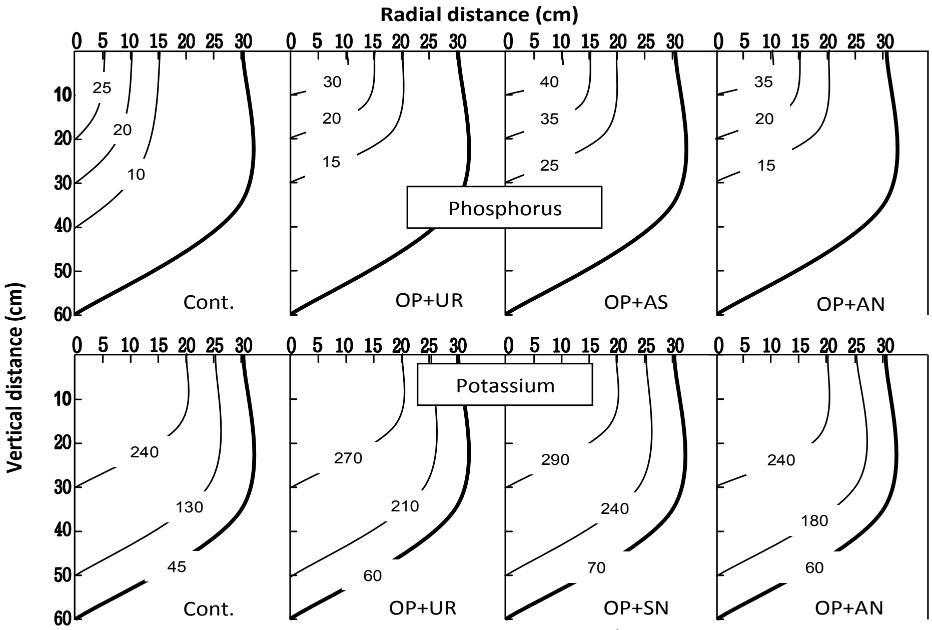

Fig. 4: Spatial distributions of phosphorus and potassium (mg kg^{-1} soil) in the root zone as affected by fertigation of OP and different forms of nitrogen at the end of last fertigation cycle. The heavy peripheral lines are the position of the wetting fronts.

Greater mobility of P beyond 30 cm depth was observed with AS is an added advantage noticed with drip fertigation. Previous reports (Silber *et al*. 2003), as well as (Bhat *et al*. 2007) revealed that drip fertigation places nutrients in active root zone besides maintaining a favorable soil water content resulting in much greater mobility of phosphorus in the root zone. The present results confirm the findings of these studies attributing greater availability of P to high frequency of drip fertigation of P in water soluble form. Kargbo *et al.,* (1991) reported that the increasing P application frequency resulted in greater P uptake, greater mass flow and mixing reaction, leading to the breakdown of regions of immobile phosphorus. Rubiez *et al.,* (1991) support the hypothesis that continuous P applications in drip irrigation systems will further increase P availability compared with other application methods. Phosphate ion, however, is highly immobile in soils and stress from P deficiency early in growth has considerable negative influence on crop production (Colomb *et al*. 2000; Grant *et al*. 2001). The present findings suggest that continuous application of P fertilizers is needed to satisfy the P fixing needs of the soil and plant requirement. In addition to this fairly direct effect, the ease of P placement in the root zone by injecting OP in drip irrigation combined with the substantial increase in soil volume to which P is distributed should make it a viable P fertilizer method. Because of its adsorption, potassium distribution around the drip line was similar to those of the ammonium (Fig. 4). However, potassium was found only immediately adjacent to the water source as K^+ is highly adsorbed by the soil, preventing its movement further down the soil profile (Fig. 4). Many studies have demonstrated that potassium distribution was limited to the most internal bulb layers, where the ion displacement was delayed due soil matrix interactions (Singh *et al.,* 2002; Rivera *et al.,* 2006).

Nutrients such as N and K are commonly applied through drip system, while P is more difficult to apply and to obtain proper distribution in soil. However, the use of orthophosphoric acid applied through surface drip irrigation resulted in a more favorable P distribution for uptake at identical rate of application. Because of the tendency of P to form insoluble precipitate with Ca and Mg commonly found in irrigation water and in the soil, the use of traditional P fertilizer in drip irrigation is not very successful. Topical application of P fertilizers through surface drip has resulted in poor distribution, where great amounts of P may remain near the soil surface, but this zone is usually not penetrated by roots because of high soil temperatures and lack of moisture, especially in arid and semi-arid regions.

Available micronutrients

Acidification of the soil below the drippers also resulted in increases in levels of available Fe, Mn and Zn but had little effect of levels of extractable Cu (Table 1). This increase was particularly pronounced when urea and ammonium sulphate was applied coupled with OP. However, a marked positive relationship was found between soil pH and the concentration of the micronutrients most commonly found in unavailable form in the soil. Such results confirm the finding of other workers (Prasad and Sinha, 1982; Graziano, 1995). Under acid conditions, Mn and Zn were relatively mobile in the soil while Fe and Cu were hardly mobile. The ability of Fe and Cu to complex strongly with soil organic matter tended to greatly reduce mobility of these elements at low pH values relative to those of Mn and Zn. However, the sequence concentration of micronutrient occurred after soil acidification could be attributed to several important factors affecting all together on the solubility of these elements in the soil.

Table 1: Effect of fertigation of OP and different forms of nitrogen on available micronutrients in the root zone (10-30 cm) at the end of last fertigation cycle.

Treatments	Micronutrients (mg kg^{-1} soil)			
	Fe	Mn	Zn	Cu
Cont.	18.6 a	23.7 a	15.4 a	2.6 a
OP+UR	46.9 b	31.7 b	18.9 b	3.2 b
OP+AS	48.2 b	32.8 b	19.4 b	3.6 b
OP+AN	52.3 b	36.5 b	18.5 b	3.8 b

Values within the column followed by different letters are significantly different based on least significant difference (P ≤ 0.05).

Eggplant yield

The response of eggplant to continuous application of acid forming fertilizer compounds versus normal water irrigation was evaluated on total yield, fruit number, fruit weight as well as N and P uptake (Table 2). Across different N form, total average yield of eggplant was significantly higher with acidified water (64.07 t ha^{-1}) over control (57.28 t ha^{-1}), which accounted for 12% yield increase. Although eggplant yield tended to be higher with ammonium nitrate than any other N form but the increase was not significantly different. Fertigation of acid forming fertilizers also brought about significant improvement in number of fruit per plant and fruit weight which mirroring the reason behind yield increase. Many field trials have shown that the form of N fertilizer has little effect on crop performance (Wang and Li, 2004; Wang, *et al.,* 2008; Kayman, 2013), because under most soil conditions applied ammonium or urea is transformed to nitrate within a period of days (Bollmann, 2006). However, in this study, N was fertigated in the form of urea or ammonium at 7 days intervals during the growing season and the obtained results had shown that significant amounts of fertigated ammonium did not remain long in soil. Thus the form of applied N had no or low significant effects on crop performance. Higher yield can be achieved, however, by maintaining relatively high nutrients content conducive to good plant growth that is achievable under acid forming fertilizer compounds.

Table 2: Eggplant yield, total dry biomass, fruit number and fruit weight as affected by fertigation of OP and different forms of nitrogen.

Main effect	Fruit yield (t ha^{-1})	Shoot DW (t ha^{-1})	Dry biomass (t ha^{-1})	Plant yield (kg plant^{-1})	Fruit number (plant^{-1})	Fruit weight (g plant^{-1})
Cont.	57.28 a	5.60 a	10.18 a	2.291 b	32.76 a	69.94 a
OP+UR	63.49 b	6.21 b	11.29 b	2.540 b	34.23 b	74.19 b
OP+AS	63.86 b	6.24 b	11.35 b	2.554 b	34.38 b	74.30 b
OP+AN	64.85 b	6.34 b	11.53 b	2.594 b	34.85 b	74.43 b

Values within the column followed by different letters are significantly different based on least significant difference (P ≤ 0.05).

The highest N and P uptake was noted under the fertigation of OP will all N forms; whereas, it was the least under normal water with calcium nitrate likely a result from the better nutrient status in the plant root zone. (Table 3). The N and P uptake under acid forming fertilizers was 15 and 27% higher compared to control treatment, however the difference across N forms was not statistically significant. Moreover, the percentage of N and P recovery was about 62 and 22% (versus 54 and 17% in control), respectively irrespective of the N treatments. Under fertigation process, the form in which N was applied (ammonium or nitrate) have not significant effects on crop growth, fruit yield and uptake of nutrients because the N can be transferred in the soil to another form during the growing season. However, when injection of OP coupled with urea or ammonium fertilizers is to be practiced in alkaline soil repeatedly, over several seasons, and then acidification in the root zone will be developed and resulted in greater crop production.

Table 3: Nitrogen and phosphorus uptake and percentage of fertilizer recovery by eggplants as affected by fertigation of OP and different forms of nitrogen.

Treatments	N uptake (kg N ha^{-1})			P uptake (kg P ha^{-1})			Fertilizer recovery (%)	
	Fruit	Shoot	Total	Fruit	Shoot	Total	N	P
Cont.	80 a	104 a	184 a	11 a	20 a	31 a	54 a	17 a
OP+UR	94 b	115 b	209 b	14 b	25 b	39 b	62 b	22 b
OP+AS	95 b	116 b	210 b	14 b	25 b	39 b	62 b	22 b
OP+AN	97 b	117 b	214 b	15 b	25 b	40 b	63 b	22 b

Values within the column followed by different letters are significantly different based on least significant difference ($P \leq 0.05$).

Conclusion

The results of the present investigation indicated that the adoption of drip fertigation with acid forming fertilizers is a good management technique to use for alkaline soils to counteract climatic and soil constraints and to satisfy the nutrient demand of vegetable crops such as eggplants. The better performance of acid forming fertilizer compounds through fertigation was attributed to maintenance of favorable soil nutrient status in the root zone, which in turn helped the plants to utilize nutrients more efficiently from the limited wetted area. Significant amounts of P, K and micronutrients (Fe, Mn, Zn) were detected in the root zone of eggplants as the soil was acidified under the different acid forming fertilizer compounds.

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