Indian Journal of Agronomy **59** (1): 177—182 (March 2014)

Review/Overview

Pod yield and phosphorus-use efficiency in groundnut (*Arachis hypogaea*) as influenced by citric acid and its delivery methods under a semi-arid agro-ecosystem

R.S. JAT[1] AND H.N. MEENA[2]

Directorate of Groundnut Research, Junagadh, Gujarat 362 001

Received: June 2013; Revised accepted: February 2014

ABSTRACT

A field experiment was conducted during 2009–11 at Junagadh, Gujarat to find out the effect of citric acid (CA) and its delivery methods on yield, nutrient uptake and use efficiencies of phosphorus in groundnut (*Arachis hypogaea* L.). Results (mean of three years) revealed that application of citric acid at 2 kg along with farmyard manure (FYM) at 2 t/ha recorded significantly higher pod yield (2.61 t/ha), harvest index (36%) and net returns (₹38,283/ha), which were 28.6, 22.0 and 44.5% higher respectively, over FYM at 2 t/ha without citric acid. Soil available P content (18 kg P/ha) significantly increased with citric acid at 6 kg along with single super phosphate (SSP) at 250 kg/ha over control. Citric acid at 4 and 6 kg along with SSP at 250 kg/ha significantly increased P content in pod and haulm, respectively. P uptake significantly increased with citric acid at 4 kg/ha. Application of citric acid at 2 kg along with FYM 2 t/ha (17.2 kg P), citric acid at 4 kg along with SSP 250 kg/ha (17.2 kg P) and citric acid at 4 kg along with FYM 1 t/ha (8.6 kg P) recorded higher agronomic efficiency (19.5%), recovery efficiency (10.8%) and P harvest index (69%) respectively, over control plots. Application of higher levels of citric acid decreased yield, P uptake and P-use efficiencies. Thus, application of 2 kg citric acid along with FYM at 2 t/ha found appropriate in enhancing groundnut yield and net returns under semi-arid agro-ecosystem.

Key words **:** Citric acid, FYM, Groundnut, P-use efficiency, SSP, Yield

Due to P insolubility and high sorption in soils, poor phosphate supply is one of the major constraints to plant growth. In order to enhance the availability of P, plants adopt different strategies like formation of mycorrhizal associations, rhizosphere acidification which can promote the release of P from soil minerals, and the exudation of phosphatases and organic acids that solubilize the complexed P (Raghothama and Karthikeyan, 2005). Several evidences showed that addition of organic acids, especially citric and oxalic acids to soils can solubilize significant quantities of fixed P and reduce the sorption of newly applied fertilizer P (Hocking, 2001). The role of organic acids in dissolving mineral phosphate and phosphorylated minerals can be attributed due to lowering of pH which helps in the formation of stable complexes with cations such as Ca^{2+}, Mg^{2+}, Fe^{3+}, and Al^{3+}. The secondary effect appeared due to formation of unionized association compounds with Ca^{2+} thus, removing Ca^{2+} from solution and increase in soluble phosphate concentration. Effectiveness of organic acid is specific and depends on the presence of metals, pH and the extent to which the organic substances form a stable metallo-organic molecule. In soils organic acids are produced by plant roots, microorganisms or during the degradation of soil organic matter and a small amounts derive from atmospheric deposition. Organic acids exuded from the plant root may be a significant P acquisition mechanism operating in the soils (Khademi *et al*., 2009). However, their concentration in the rhizosphere is very less ranging from 10^{-2} ìM to over 80 mM (Strom *et al*., 2005).

Little information is available worldwide on the practical utility of organic acids including citric acid as a factor of crop production. Further, the effects of organic acids have mostly been studied under laboratory conditions on P solubility and availability and little is known about its field application and interactions in the rhizosphere with other nutrients, plant roots and soil microbes and their effect on plant growth and development. The soil of experimental site was alkaline calcareous having pH 8.4 and free calcium carbonate (17–21%) in the profile (0–15cm). Here both native and applied P undergoes a series of

[1]**Corresponding author Email:** rsdevgudha@yahoo.co.in
[1]Senior Scientist, Directorate of Medicinal and Aromatic Plants Research, Anand; [2]Scientist, Directorate of Groundnut Research, Junagadh

chemical reactions and tie up in highly insoluble Ca and Mg phosphates. In these soils organic acids may form complexes with Ca and Mg and simultaneously bring down the soil pH, and thus can play a significant role in releasing P in soil solution. Groundnut is selected as test crop because it is an energy rich legume crop and the major crop of this region. Being a legume crop it needs sufficient amount of nutrients particularly P for root nodulation, growth and development and high yields. Keeping in view the facts, the experiment was carried out to find out the appropriate doses and delivery methods of citric acid and its effect on pod yield, P content and uptake and P-use efficiencies in groundnut.

MATERIALS AND METHODS

An experiment was conducted at Junagadh, Gujarat (70%36'E longitude and 21%31'N latitude and at an altitude of 60 m above mean sea level). The climate of the region is semi-arid with a mean annual rainfall of 850 mm. The rainfall is mainly confined during June to September months. The monthly average temperature is minimum in January (12 °C) and maximum in May (42 °C). The experiment was conducted on a fixed site for three years from 2009 to 2011 at the research farm of Directorate of Groundnut Research, Junagadh in the summer season. The surface soils (0-15 cm) were alkaline (pH 8.2), medium black, calcareous, low (0.49%) in Walkley and Black carbon (Walkley and Black, 1934) and available N (130 kg/ha), medium in available P (10 kg/ha) and K (167 kg/ha).

Treatment consist of four methods of delivery, viz. with FYM @ 2 t and 1 t/ha, and SSP @ 250 kg and 125 kg/ha and four levels of citric acid, viz. 0, 2, 4 and 6 kg/ha. The quantity of FYM and SSP was selected to equate the recommended doses of P (17.2 kg P/ha) and its half dose (8.6 kg P/ha) to groundnut. Groundnut was sown at planting geometry of 30 × 10 cm in the month of February using seed rate of 100 kg/ha. The experiment was conducted in a split plot design with methods of delivery of citric acid in the main plots and levels of citric acid in sub-plots, and replicated thrice. The field is divided into plots of 8 × 6 m with net plots of 7 × 5 m size for harvesting. Finely-ground and sieved FYM @ 5 kg was mixed with the ground and powdered citric acid and applied evenly as per treatments in furrows. A uniform dose of 25 kg N/ha was also applied through urea. The field was left uncultivated during the *rabi* seasons and plots were maintained undisturbed till next sowing of groundnut.

Biometric observations were recorded on total dry matter accumulation and pod and haulm yield. Harvest index was calculated dividing the pod yield with biological yield. The plant samples collected at harvest, were analysed for P content, and uptake was computed by multiplying kernel and haulm yield to P contents. The composite soil samples were collected from the 0–15 cm surface soil before sowing and after the end of the experiment and were analyzed for phosphorus by Vanadomolybdophosphoric yellow colour method (Olsen *et al.*, 1954). P-use efficiencies, viz. agronomic efficiency (kg pod yield/kg P applied), apparent recovery efficiency (kg P uptake/kg P applied) and P harvest index (kg P in pods/kg P uptake) were computed using standard formulae (Mengel and Kirkby, 2001). The net returns were worked out by subtracting the total cost of cultivation from the gross return. The data were subjected to appropriate statistical analysis following the standard procedures.

RESULTS AND DISCUSSION

Yield and economic returns

Citric acid and its delivery methods significantly affected the pod and haulm yield of groundnut (Table 1). Significantly higher pod yield of 2.23 and 2.19 t/ha was recorded with citric acid at 2 kg/ha and FYM at 2 t/ha, respectively. Citric acid increased the pod yield by 15.8% at 2 kg/ha over control. Application of higher dose of citric acid (> 2 kg/ha) decreased the pod yield. Interaction between levels of citric acid and delivery methods (Table 2) showed that application of citric acid at 2 kg along with FYM at 2 t/ha recorded highest pod yield (2.61 t/ha), followed by 2 kg citric acid along with SSP at 250 kg/ha (2.24 t/ha). Citric acid at 2 kg along with FYM at 2 t/ha increased pod yield by 28.6% over FYM at 2 t/ha without citric acid. Haulm yield was the highest (4.56 and 4.55 t/ha) with citric acid at 2 kg/ha and FYM at 2 t/ha, and decreased at higher levels of citric acid.

Citric acid significantly affected the harvest index of groundnut, but there was no effect due to its delivery methods (Table 1). Application of citric acid at 2 kg/ha recorded highest harvest index (32.9%), which was 11.5% higher over the control plots. Interaction between levels of citric acid and delivery methods revealed that citric acid at 2 kg along with FYM at 2 t/ha recorded highest harvest index (36%), followed by citric acid at 4 kg applied with SSP at 125 kg/ha (33.9%) (Table 2).

Citric acid at 2 kg/ha recorded net return of ₹ 31,195/ha while FYM at 2 t/ha recorded ₹ 28,986/ha which were significantly higher than other levels when applied alone (Table 1). However, higher doses of citric acid (> 2 kg/ha) decreased the net returns. Interaction showed that net returns were highest (₹38,283/ha) with citric acid at 2 kg along with FYM at 2 t/ha, followed by citric acid at 2 kg along with SSP at 250 kg/ha (₹31,451/ha) (Table 2). Application of citric acid at 2 kg along with FYM at 2 t/ha increased net returns by 44.5% over FYM at 2 t/ha without citric acid.

Table 1. Effect of levels of citric acid and delivery methods on pod and haulm yield, harvest index and net returns (mean of 3 years)

Treatment	Pod yield (t/ha)	Haulm yield (t/ha)	Harvest index (%)	Net returns (x 10^3 ₹/ha)
Delivery methods				
FYM @ 2 t/ha	2.19	4.55	32.1	28.9
FYM @ 1 t/ha	1.97	4.39	30.7	25.2
SSP @ 250 kg/ha	2.10	4.32	32.5	28.2
SSP @ 125 kg/ha	1.95	4.27	31.0	25.7
SEm±	0.04	0.08	0.7	0.9
CD (P=0.05)	0.15	0.26	NS	3.3
Citric acid (kg/ha)				
0	1.93	4.46	29.5	25.1
2	2.23	4.56	32.9	31.2
4	2.07	4.25	32.5	27.2
6	1.98	4.27	31.4	24.6
SEm±	0.04	0.07	0.5	0.9
CD (P=0.05)	0.13	0.21	1.5	2.7

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

Table 2. Interaction effects of levels of citric acid and delivery methods on pod yield, harvest index and economic returns (mean of 3 years)

Citric acid (kg/ha)	Delivery methods			
	FYM @ 2 t/ha	FYM @ 1 t/ha	SSP @ 250 kg/ha	SSP @ 125 kg/ha
		Pod yield (t/ha)		
0	2.03	1.71	2.14	1.83
2	2.61	2.10	2.24	1.99
4	2.12	2.07	2.03	2.09
6	2.00	2.06	2.02	1.88
		SEm±	CD (P=0.05)	
Delivery methods at same level of CA	0.08	0.27		
CA at same level of delivery method	0.09	0.26		
		Harvest index (%)		
0	29.5	27.5	31.8	29.1
2	36.0	31.5	33.3	31.0
4	32.7	31.4	32.0	33.9
6	30.1	32.3	33.1	30.2
		SEm±	CD (P=0.05)	
Delivery methods at same level of CA	1.1	3.4		
CA at same level of delivery method	1.9	5.5		

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

Citric acid and its delivery along with FYM increased yield, harvest index and economic returns. This might be due to beneficial effects of FYM on soil physio-chemical and biological properties and supply of additional P; and effect of citric acid on enhanced P availability in soil and make it available for plant growth and yield. Due to these synergistic effects of FYM and citric acid on improvement in soil properties, P availability, microbial population and root nodulation might have recorded more pronounced effect on growth, yield and harvest index. The results are in close proximity to the studies carried out by earlier workers on the role of organic acids in enhancing P solubility, mobility and availability through adsorption and desorption (Hu *et al.*, 2005) and make it available for root nodulation and plant growth and development. Besides this, organic acids also exuded by plant roots in P deficient soils and consume 5–25% of the plant's photosynthetically fixed carbon (Dinkelaker *et al.*, 1989). External supply of organic acids might have saved this energy and diverted it for plant growth. Citric acid is a cheaper source of organic acid and simultaneously has increased P availability and thereby yields. Probably these reasons might have played a cumulative role in enhancing economic returns. Higher levels of citric acid have decreased yield and net returns might be due to its detrimental effects on microbial population and root nodulation.

P content, uptake and use-efficiency

Soil available P content influenced significantly with delivery methods and citric acid. Delivery of citric acid with SSP at 250 kg/ha recorded higher soil available P content in 0-15 cm soil layer (15 kg/ha). Application of increasing levels of citric acid from 2-6 kg/ha significantly increased soil P content and recorded highest (15 kg/ha) with 6 kg/ha which was 50% higher over control (Table 3). Interaction between levels of citric acid and delivery methods (Table 4) revealed that application of citric acid at 6 kg along with SSP at 250 kg/ha recorded highest soil available P contents (18 kg/ha) which was higher by 50% over SSP at 250 kg/ha without citric acid.

Citric acid at 4 kg/ha and SSP at 250 kg/ha recorded significantly higher pod P content 0.47 and 0.46% respectively (Table 3). Citric acid at 4 kg/ha increased pod P content by 20.5% over control and decreased with further increase in citric acid. However, haulm P content was recorded 0.13 and 0.12% with citric acid at 6 kg/ha and SSP at 250 kg/ha, respectively. Citric acid at 6 kg/ha increased haulm P content by 18.1% over control. Phosphorus uptake was highest (15.0 kg and 15.7 kg P/ha) with citric acid at 4 kg/ha and FYM at 2 t/ha, respectively (Table 3). Citric acid at 4 kg/ha increased the P uptake by 21.9 and 6.4% over control and citric acid at 2 kg/ha, respectively. Similarly, higher level of citric acid (6 kg/ha) decreased P uptake.

Agronomic efficiency, apparent recovery and P harvest index were calculated based on the P supplied @ 17.2 kg Ptentong with l OC over initial values (/ha through FYM (2 t/ha) and SSP (250 kg/ha), and 8.6 kg/ha supplied through FYM (1 t/ha) and SSP (125 kg/ha). Agronomic efficiency of P (19.5%) recorded highest with citric acid at

Table 3. Effect of levels of citric acid and delivery methods on P content (pod and haulm) and uptake (mean of 3 years)

Treatment	Soil P content (P kg/ha)	Pod P content (%)	Haulm P content (%)	Total P uptake (kg/ha)
Delivery methods				
FYM @ 2 t/ha	12	0.45	0.12	15.7
FYM @ 1 t/ha	10	0.37	0.11	12.2
SSP @ 250 kg/ha	15	0.46	0.13	14.9
SSP @ 125 kg/ha	11	0.40	0.11	12.2
SEm±	0.47	0.02	0.005	0.77
CD (P=0.05)	2	0.08	0.010	2.66
Citric acid (kg/ha)				
0	10	0.39	0.11	12.3
2	11	0.40	0.11	14.1
4	13	0.47	0.12	15.0
6	15	0.42	0.13	13.7
SEm±	0.25	0.02	0.004	0.53
CD (P=0.05)	0.7	0.06	0.010	1.54

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

Table 4. Interaction effects of levels of citric acid and delivery methods on soil available P content (P kg/ha) (mean of 3 years)

Citric acid (kg/ha)	Delivery methods: FYM @ 2 t/ha	FYM @ 1 t/ha	SSP @ 250 kg/ha	SSP @ 125 kg/ha
0	10	8	12	8
2	12	9	14	9
4	12	10	15	12
6	15	12	18	15
		SEm±	CD (P=0.05)	
Delivery methods at same level of CA	0.61	2.1		
CA at same level of delivery method	0.51	1.5		

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

2 kg along with FYM at 2 t/ha (17.2 kg P), followed by citric acid at 4 kg along with the same quantity of P through FYM (Fig. 1). Further, increase in citric acid (> 2 kg/ha) decreased the agronomic efficiency of P. Apparent P recovery efficiency (10.8%) was highest with citric acid at 4 kg along with SSP at 250 kg/ha (17.2 kg P), followed by citric acid at 4 kg along with FYM at 1 t/ha (8.6 kg P) (Fig. 2). Application of citric acid at 6 kg/ha decreased the

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

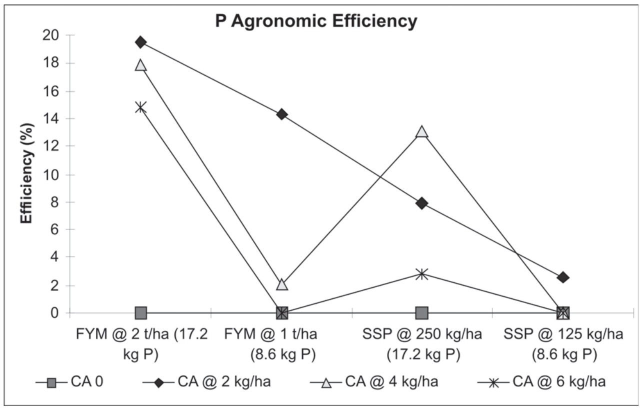

Fig. 1. Effect of levels of citric acid and delivery methods on P Agronomic efficiency

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

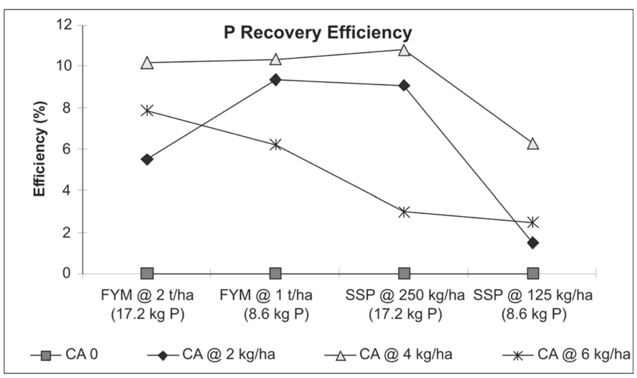

Fig. 2. Effect of levels of citric acid and delivery methods on P recovery efficiency

recovery efficiency of P. P harvest index (69%) was highest with citric acid at 4 kg along with FYM at 1 t/ha (8.6 kg P/ha), followed by citric acid at 4 kg along with SSP at 125 kg/ha (8.6 kg P) (Fig. 3).

The results are in close proximity to the studies on the role of organic acids on P solubility, mobility and availability. Citric acid form complexes with metal ions like Fe, Mn, Cu, and Zn in soil and release P, K, Ca, and Mg and thus increase their concentration in soil solution (Chen *et al*., 2002). Besides this, it reduces the sorption of newly applied P and loses from soil to water (Gardner *et al*.

FYM: Farm Yard Manure, SSP: Single Super Phosphate, CA: Citric Acid

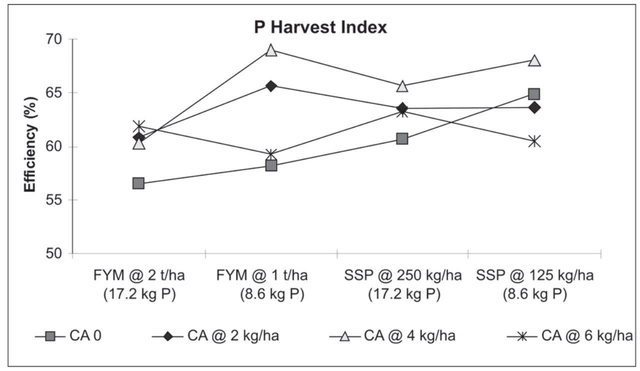

Fig. 3. Effect of levels of citric acid and delivery methods on P harvest index

1982, Hocking, 2001 and Gang *et al*., 2012). In general, organic acids are able to induce a 2–4 fold increase in mineral dissolution rate (Jones and Kochian, 1996) and 10–1000 fold increase in phosphate dissolution rates (Jones and Darrah, 1994). In calcareous soils, citric acid has capacity of complexing $CaCO_3$ and release P from the minerals such as calcium apatite which is the major form of fixed P in such soils. Thus, citric acid application increased soil P content and this might have increased pod and haulm P content. Effect of citric acid delivery along with SSP were more pronounced and recorded higher soil P content, P apparent recovery efficiency and P harvest index might be due to more soil P availability, decreased P sorption of native and applied P and plant P content (pod and haulm). Whereas, P uptake and P agronomic efficiency were higher with application of citric acid along with FYM and this might be due to the fact that FYM have improved soil physico-chemical and biological properties (Pandey *et al*., 2013), nutrient supply and yield; and citric acid increased soil P (Hocking, 2001) and thereby plant P content.

The present results revealed that application of citric acid at 2 kg along with FYM at 2 t/ha recorded remarkable increase in pod yield, harvest index and net returns by 28.6, 22.0 and 44.5% over FYM at 2 t/ha without citric acid. Also, the former treatment had highest P agronomic efficiency and harvest index. However, application of citric acid along with SSP recorded more soil P content and recovery efficiency. Thus, application of 2 kg citric acid along with FYM at 2 t/ha was remunerative in enhancing groundnut yield and net returns under this semi-arid agro-ecosystem and this technology has the potential for wide adoption.

REFERENCES

Chen, Yong-liang., Guo, Yu-qiang., Han, Shi-jie., Zou, Chun-jing., Zhou, Yu-mei and Cheng, Guo-ling. 2002. Effect of root derived organic acids on the activation of nutrients in the rhizosphere soil. *Journal of Forestry Research* **13**(2): 115–18.

Dinkelaker, B., Romheld, V. and Marschner, H. 1989. Citric-acid excretion and precipitation of calcium citrate in the rhizosphere of white lupin (*Lupinus albus* L.). *Plant Cell Environment* **12**: 285–92.

Gang, X., Hongbo, S., Rongfu, X., Nie, Y., Pei, Y., Sun, Z. and Blackwell, M.S.A. 2012. The role of root-released organic acids and anions in phosphorus transformations in a sandy loam soil from Yantai, China. *African Journal of Microbiology Research* **6**(3): 674–79.

Gardner, W.K., Parbery, D.G. and Barber, D.A. 1982. The acquisition of phosphorus by *Lupinus albus* L.II: the effect of varying phosphorus supply and soil type on some characteristics of the soil/root interface. *Plant Soil* **68**: 33–41.

Hocking, P.J. 2001. Organic acids exuded from roots in phosphorus uptake and aluminum tolerance of plants in acid soils. *Advances in Agronomy* **74**: 63–97.

Hu, H., Tang, C. and Rengel, Z. 2005. Role of phenolics and organic acids in phosphorus mobilization in calcareous and acidic soils. *Journal of Plant Nutrition* **28**: 1427–39.

Jones, D.L. and Darrah, P.R. 1994. Role of root derived organic-acids in the mobilization of nutrients from the rhizosphere. *Plant Soil* **166**: 247–57.

Jones, D.L. and Kochian, L.V. 1996. Aluminum-organic acid interactions in acid soils. 1. Effect of root-derived organic-acids on the kinetics of Al dissolution. *Plant Soil* **182**: 221–28.

Khademi, Z., Jones, D.L., Malakouti, M.J., Asadi, F. and Ardebili, M. 2009. Organic acid mediated nutrient extraction efficiency in three calcareous soils. *Australian Journal of Soil Research* **47**(2): 213–20.

Mengel, K. and Kirkby, E.A. 2001. Principles of plant nutrition. 5th Ed., *Kluwer Academic Publishers, London*.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L. 1954. Estimation of available phosphorus in soil by extraction with sodium carbonate. *USDA Conc.* 933.

Pandey, I.B., Singh, S.K. and Tiwari, S. 2013. Integrated nutrient management for sustaining the productivity of pigeonpea. *Indian Journal of Agronomy* **58**(2): 192–97.

Raghothama, K.G. and Karthikeyan, A.S. 2005. Phosphate acquisition. *Plant Soil* **274**(1): 37–49.

Strom, L., Owen, A.G., Godbold, D.L. and Jones, D.L. 2005. Organic acid behavior in a calcareous soil; implications for rhizosphere nutrient cycling. *Soil Biology and Biochemistry* **37**: 2046–54.

Walkley, A. and Black, C.A. 1934. An examination of Degtjareff methods for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29–38.