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EFFECT OF PHOSPHORUS FERTILIZER PLACEMENT ON EMERGENCE AND EARLY GROWTH OF CHICKPEA (*Cicer arietinum* L.)

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Abstract: Fertilizer in close proximity to seed can hamper emergence and early growth of seedlings. This study investigates whether phosphorus fertilizer placement with or close to seed affects emergence and early growth of chickpea (*Cicer arietinum* L.) and its relationship to soil texture. In pot culture studies with sandy soil, emergence and early growth were suppressed when triple superphosphate (TSP) and di-ammonium phosphate (DAP) were in contact with seed or banded 2 cm directly below the seed; the effect of DAP was more detrimental than that of TSP. Placement of TSP at 5 cm directly below the seed did not hamper emergence in sandy soil although it still had a mild suppressive effect on early growth of chickpea. In clay soil, the recommended rate of TSP (100 kg TSP or 20 kg P ha^{-1}) had little or no effect on emergence and negligible effect on subsequent seedling growth. In fields with clay loam soil, placement of the recommended rate of TSP with chickpea seeds in rows by a minimum-till planter was also found safe. In conclusion, the effect of phosphorus fertilizer placement in close proximity to chickpea seed was soil texture specific: in sandy soil the placement had deleterious effect on emergence and early growth while in clay soil there was little or no effect.

Keywords: Seed, minimum tillage, phosphorus, seedling establishment, toxicity

Introduction

In most chickpea (*Cicer arietinum* L.) producing areas of the world, phosphorus (P) deficiency is a major yield constraint (Saxena, 1987; Waddington *et al.*, 2010). While P fertilizer is usually applied in the large-scale commercial production of chickpea (e.g. in Australia and Canada), it is less commonly applied to this crop in resource-poor small-holder farming systems (Johansen and Sahrawat, 1991). In Bangladesh, chickpea is now mainly cultivated in the High Barind Tract (HBT) under rainfed conditions relying on water stored in the soil profile, after harvest of monsoon rice (*T. aman*) (Johansen *et al.*, 2008). Phosphorus is deficient in such soils where chickpea responses to application of P fertilizer (Ali et al., 2003). P fertilization is also recommended for this crop in Bangladesh including the HBT (Miah *et al.*, 2005). The cultivation of chickpea in the HBT traditionally involved full tillage with a bullock-drawn country plough after broadcasting the seed, and fertilizer if applied. This was a slow process which has been almost replaced by the two-wheel tractor (2-WT) driven rotary tiller that has allowed chickpea to be sown over a much wider area within the

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limited sowing window available. However, such tillage (rotary) hastens drying of the surface soil and exposes seedling emergence to drought. To conserve the surface soil moisture for successful chickpea emergence and establishment, minimum tillage is thought to be an option (Johansen *et al.*, 2008; Johansen *et al.*, 2012). Based on the widespread availability of 2-WT, development and manufacture of 2-WT mounted minimum-till planters has begun (Johansen *et al.*, 2012). In this planting system, seed and P fertilizer (usually triple superphosphate, TSP) are placed together below (5-6 cm) the surface in a narrow strip of tilled soil. A concern arising from this new planting method is whether the P fertilizer could be toxic to the seed. Studies have reported a deleterious effect of P fertilizers placed with the seed during the early stages of growth in sands (wheat, Loneragan *et al.*, 1966; white lupin, (Jarvis and Bolland, 1991). Placing P fertilizer below the seed not only avoids fertilizer toxicity but increases the effectiveness of the fertilizer (Jarvis and Bolland, 1990, 1991). Crop row spacing and rate of fertilizer application can also affect the risk of toxicity. At wider row spacing there is more P fertilizer per length of row than at narrow spacing, if the rate per unit area is constant, which can induce toxicity in wider rows (Jarvis, 1992).

Literature regarding the effect of placement of P fertilizer with chickpea or other pulse crop seed in clay loam soil such as in the HBT region or in light-textured soil elsewhere in South Asia is scarce. The recommended rate of 20 kg P ha^{-1} for chickpea in Bangladesh was based on the broadcasting method (Miah *et al.*, 2005). Phosphorus fertilizer applied with the seed at this rate by minimum-till planters may pose a toxicity threat for chickpea.

This paper examines the extent to which P placed near the seed can be toxic to the germination, emergence and early seedling growth of chickpea. Pot studies were conducted with sand and clay soils using TSP and the more soluble di-ammonium phosphate (DAP) as P fertilizer sources. Field studies in the HBT were conducted to assess effects of TSP applied at different rates in rows with the seed.

Materials and methods

Pot studies: Short-term (12 and 24 days) experiments (1–4) were conducted using TSP and/or DAP as granules or as a crushed powder (by a Coffee 'n' Spice Grinder, Breville). All experiments were conducted with polyvinyl chloride (PVC) columns (30 cm height, and 15 cm diameter) and arranged separately in a completely randomized design each with three replications in 2010-11. Experiments 1 and 3 were conducted in a naturally-lit glasshouse at Murdoch University, Perth, Western Australia (WA) while Experiments 2 and 4 were in the transparent plastic shelter in Rajshahi, Bangladesh. In Experiment 1 and 3, reddish-brown, slightly acidic sandy clay loam soil (referred to as clay, Table1) from Merredin, Western Australia (WA) (Calcic Red Dermosol, Isbell, 1996) and a subsoil yellow sand were used. In Experiment 2 and 4, a typical HBT sandy clay loam soil (referred to as clay, Table 1) (Aeric Haplaquept, Brammer, 1996) was used. The soils used in these experiments were analyzed for the properties given in Table 1. In all experiments, the amount of P fertilizers (TSP or DAP) was calculated on the basis of the recommended P rate (20 kg P or 100 kg TSP or DAP ha^{-1}) and row spacing (40 or 60 or 90 cm). A control treatment without addition of TSP or DAP was included in Experiments 1 and 3. Control treatments for Experiments 2 and 4 are described below.

Table 1: Properties of soil used in pot experiments (1 to 4). Soil analyses methods after Rayment and Higginson (1992).

Soil properties	Experiments 1 and 3 (Merredin soil)	Experiments 1 and 3 (Yellow sand)	Experiments 2 and 4 (HBT soil)
Depth soil collection (cm)	0-10	20-50	0-10
Sand (%)	63.3	93.2	51.7
Silt (%)	15.9	5.8	25.2
Clay (%)	20.8	1.0	23.1
Ammonium nitrogen (mg kg^{-1})	1.0	<1.0	10.0
Nitrate nitrogen (mg kg^{-1})	25.0	<1.0	7.0
Phosphorus Colwell (mg kg^{-1})	8.0	2.0	9.0
Phosphorus Olsen (mg kg^{-1})	nm	nm	3.1
Potassium Colwell (mg kg^{-1})	327.0	22.0	68.0
Sulphur KCl 40 extraction(mg kg^{-1})	11.3	9.1	10.4
Organic Carbon (%)	1.06	0.05	0.59
EC (1:5 soil: water) (dSm^{-1})	0.16	0.02	0.08
pH ($CaCl_2$)	6.8	6.4	5.5
pH (H_2O)	7.8	6.9	6.0
Phosphorus retention index (PRI)[1]	23.0	2.4	117.0

'EC' and 'nm' refer to electrical conductivity and not measured, respectively.

[1] PRI, is a single point P sorption measure defined as the ratio: P_{ads} (µg g^{-1} soil)/P_{eq} (µg P mL^{-1}) resulting from equilibrating soil with a 10 µg P mL^{-1} solution (1 g soil in 20 mL solution) for 16 h at 23 ^{0}C, where P_{ads} is the amount of P adsorbed and P_{eq} is the equilibrium P concentration (Ritchie and Weaver, 1993). PRI is usually reported without units, as the ratio of adsorbed P over that remaining in solution.

Fertilizer amount*:* The amount of fertilizer per seed or per column was calculated based on Fig. 1 and the following considerations: in one ha of land (100 x 100 m), assuming 40 cm row spacing, the number of rows of 100 m length will be 250. The total length of all lines will be 25000 m ha^{-1}. Therefore, the 3.75 cm long strip of fertilized soil per seed will contain 0.151 g of TSP (TSP 100 kg ha^{-1}, 45 seed m^{-2}). Similar considerations were also the basis for calculating DAP density (Experiment 1 only).

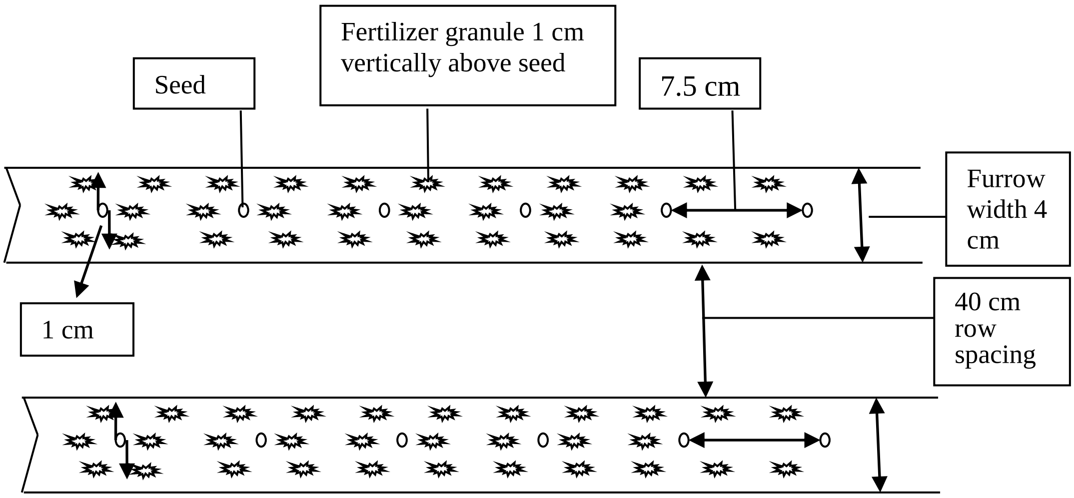

Fig. 1 Schematic diagram (plan view) of seed and fertilizer granules in a furrow made by strip-tillage in the field for a row spacing of 40 cm. Furrow width is 4 cm (not shown in the plan view) and furrow depth, 5 cm. Assumes that fertilizer granules were mixed in the bottom 2 cm depth across the furrow. The seeds were in the middle of the vertical distribution (2 cm thickness) of fertilizer granules, i.e. fertilizer granules were mixed from 1 cm below to 1 cm above the seed. Seeds were spaced horizontally 7.50 cm apart in the furrow where fertilizer granules were distributed 3.75 cm on either side of the seed in the furrow. The figure is not drawn to the scale.

Volume and amount of soil per seed: The volume of soil around each seed was calculated in relation to the previous consideration for fertilizer density calculation (row width, 4 cm; vertical thickness of fertilizer granule distribution, 2 cm; horizontal length of fertilizer granule distribution per seed, 3.75 cm). The soil volume was 30 cm^3 (4 cm x 2 cm × 3.75 cm) $seed^{-1}$. Taking in to account the bulk density (g cm^{-3}) of the soils, the required amount of each type of soil per seed was calculated.

Fertilizer mixing, column preparation, seeding and plant culture: In Experiments 1 and 3, for the calculated amount of soil, P fertilizer (TSP or DAP granule or powder according to treatment) was applied. Columns were watered with de-ionized water and maintained at 75% of field capacity during the experimental period. The columns were non-draining. In all experiments, emergence of seedlings and observations of any symptoms on the leaves were assessed daily.

Experiment 1: Experiment 1 had three TSP or DAP treatments (granule or dust: a control, 40 cm and 60 cm row spacing). Soil (~4 kg) was filled up to about 24 cm from the bottom of the column. The treatment P fertilizer for 40 or 60 cm was mixed with the 2 cm layer of soil. Forty seeds of *desi* chickpea (cv. Genesis 836) were sown in the middle of the P-fertilized soil layer (2 cm thick). A 2 cm layer of soil (not P fertilized) covered the P-treated layer, i.e., the seed was located 3 cm below the soil surface. At 12 days after sowing (DAS), 6 plants were randomly selected from each column. The selected plants were separated carefully and they were severed at the stem base. The length of each plant's shoot and root was measured and the number of root branches counted. Then the shoot and root were dried in a forced air-draft oven at 70° C for 72 h and the dry weights recorded.

Experiment 2: Experiment 2 had TSP granules only as P treatment with the same objective of Experiment 1 plus an extra treatment of TSP concentration at 90 cm row spacing (calculation for 90 cm spacing as for 40 shown in "*Fertilizer amount*" above). Filling of columns with soil, placement of TSP granules, seed sowing and data collection were similar to that of Experiment 1. The differences were: Experiment 2 was done using the HBT soil and the seed was BARI *chola* 5 (12 seeds per column). Plants were harvested at 12 DAS. Shoot and root of all plants in a column were retrieved, dried, and weighed as in Experiment 1.

Experiments 3 and 4: Experiments 3 and 4 examined the effects of placing TSP below the seed or by mixing it thoroughly with a larger volume of soil. The vertically-split PVC columns were taped together and filled up with soil. From the base of the column (30 cm high), 18 cm was filled up with air-dried soil. The top 10 cm of the column was filled up with soil and TSP according to treatments. Granular TSP required per seed (0.15 g considering 40 cm row spacing) was calculated on the basis of assumptions used in "*Fertilizer amount*". Then the granular TSP was mixed with a 2-cm layer of column soil (as in Experiment 1 and 2). This TSP-treated soil layer was placed at different depths in the column: 0 cm (seed was placed in the middle of the 2 cm thick layer of TSP-treated soil), and 2 and 5 cm directly below the seed. A control treatment was included in which TSP was thoroughly mixed in the top 10 cm of soil to simulate broadcasting and incorporation in the field. Seed was placed 3 cm below the surface in all cases. Twelve seeds of *desi* chickpea (cv. Genesis 836) were sown per column. Harvesting was done at 12 and 24 DAS. At both harvests, cutting of shoots (plants from 12 seeds), root washing, drying of roots and shoots and measurement of root length at 12 days were done following the procedures of Experiment 1. At 24 DAS, nodules were counted and separated from the root and washed roots were assessed for total root length and surface area using a scanner controlled by WinRhizo software (Regent Instruments, Quebec, Canada). In Experiment 4, 12 seeds of BARI *chola* 5 were sown. Sowing technique, watering, harvesting, root washing, drying of plant materials was done following the same procedure as in Experiment 1. The maximum root length at both harvests (in Experiment 4) was measured.

Date of all pot experiments were analyzed by one-way ANOVA based on completely randomized design.

Field studies: The experiment was done in 2013–14 chickpea growing season at two sites (sites 1 and 2) in the clay soil of the HBT of Bangladesh to test the findings of pot experiments. The sites were located in two villages of Godagari Upazila, Rajshahi, Bangladesh. The soils of both sites were clay loam, grey terrace soil (Aeric Haplaquept, Brammer, 1996).

At both experimental sites, chickpea (BARI *chola* 5) was planted with three P fertilizer treatments in randomized block design with three blocks by minimum tillage (Haque et al., 2010). Triple superphosphate at 100 kg ha^{-1} (20 kg P ha^{-1}) was applied as P fertilizer with the following treatments: full TSP at the rate of recommendation, 50% of the recommended rate, and a control without P fertilizer.

The volumetric moisture contents of surface soil (~6 cm) at sowing were between 22 to 23% at both sites. Crops were grown under rainfed conditions. Plant density after emergence (12-15 DAS) was measured in m^2 (3 spots in a plot). Seedling emergence was analyzed by performing ANOVA for a randomized complete block design (each site separately). The treatment means were compared by least significant difference test (lsd) at 5% level of significance.

Results

Pot study

Experiment 1: Plants treated with TSP dust behaved in the same way as those treated with TSP granules, so the results are described only for TSP granule treatments in Experiment 1 unless stated otherwise. The emergence of seedlings both in yellow sand and Merredin clay soil was ≥ 85% when TSP was placed with the seed (Table 2). However, Merredin clay had a higher percentage of emergence (94% to 98%) than that of yellow sand (85% to 97%). The emergence decreased significantly ($p < 0.05$) with the increase in amount of TSP in sand. In clay soil, statistically similar emergence was observed from 40 cm and control while it was reduced ($p < 0.05$) in 60 cm. Root length, root dry weight (DW), branch roots, and shoot length were higher in yellow sand than Merredin soil, but with the increase in TSP amount in yellow sand there was a significant decrease ($p < 0.01$) in all parameters (root length, shoot length and their DW, branch number).

Table 2: Response of 12-day-old chickpea to seed-placed TSP granules in sand and clay soils in Experiment 1. Forty and 60 cm refers to the P concentration in the treated column soil calculated assuming the row spacing 40 and 60 cm, and based on the recommended TSP rate (100 kg ha^{-1}) for chickpea. All values of each parameter are presented on a per plant basis (except emergence). The values are means of three replications. 'ns' refers to non-significant.

Soil	TSP	Emergence (%)	Length (mm)	Dry Weight (mg)	No. of branch	Length (mm)	Dry Weight (mg)
			Root			Shoot	
Sand	0	96.7	148.4	44.4	30.9	81.3	38.7
	40	88.3	135.9	41.1	26.7	66.7	36.2
	60	85.0	104.9	36.4	17.0	56.8	29.5
	lsd $_{(0.05)}$	8.0	10.6	5.2	3.4	9.9	3.5
Clay	0	97.9	74.8	21.8	15.2	55.7	56.3
	40	96.6	72.5	20.2	16.2	52.3	49.1
	60	94.1	70.2	17.6	13.8	48.6	44.9
	lsd $_{(0.05)}$	2.7	ns	2.9	ns	ns	2.2

In clay soil, root length and shoot length were not significantly reduced by the TSP treatments. Root and shoot DW was reduced significantly by increased P ($p < 0.05$). Root branching was reduced at 60 cm while no difference of root branching was found between control and 40 cm spacing. Overall, root DW was higher than that of shoot in sand while in clay, the DW of shoot was much higher than the DW of root.

From 9 DAS, TSP-treated plants in yellow sand showed greyish-white necrosis from the tip of leaflets of older leaves. These symptoms resemble P toxicity symptoms (Bhatti and Loneragan, 1970a in wheat). The necrosis later spread distally to the whole leaflet and even to the whole leaf. Blackening of root tips was observed in TSP-treated plants in sand. No P deficiency or toxicity symptom was observed in the plants grown in clay soil or in the control plants grown both in yellow sand and clay soil. These results showed that application of 100 kg TSP ha^{-1} with 40 or 60 cm row spacing was a risk for early growth of chickpea in sand, while a marginal early growth depression occurred in clay soil particularly for the 60 cm row spacing.

With DAP granule and dust, the seedling emergence was nil or severely depressed in sand at both 40 or 60 cm (Table 3). By contrast nearly 100% emergence was observed in clay soil with the same DAP treatments and formulations: granule or dust. Few seedlings were emerged, they were abnormal: stunted shoot and root growth with black spots at the root tips were observed.

Table 3: Emergence of chickpea with seed-placed DAP (granule and dust) in Merredin clay and yellow sand in Experiment 1. Forty and 60 cm refers to the P concentration in the soil calculated assuming a row spacing of 40 and 60 cm, and recommended DAP rate (100 $kgha^{-1}$) for chickpea. No DAP was added in the control treatment. Values are mean ± standard error of three replications. Values for each replication are the percentages for emergence of 40 seeds.

Soil	DAP form	Control	40 cm	60 cm
Clay	Granule	99.2 ± 0.8	99.2 ± 1.7	95.8 ± 1.7
	Dust	99.2 ± 0.8	95.8 ± 0.8	98.3 ± 2.2
Sand	Granule	96.3 ± 0.8	8.3 ± 2.2	0
	Dust	96.3 ± 0.8	0	0

Experiment 2: In the HBT soil, the initial emergence in the higher TSP treatments (60 and 90 cm) was slow but by 8 days nearly 100% emergence was found in all treatments (Fig. 2a). Chickpea root and shoot DW decreased significantly ($P < 0.05$ %) when TSP was placed with the seed compared to that of the control (without TSP) (Fig. 2b) but the DW was not significantly different among the row spacing treatments (40, 60 and 90 cm).

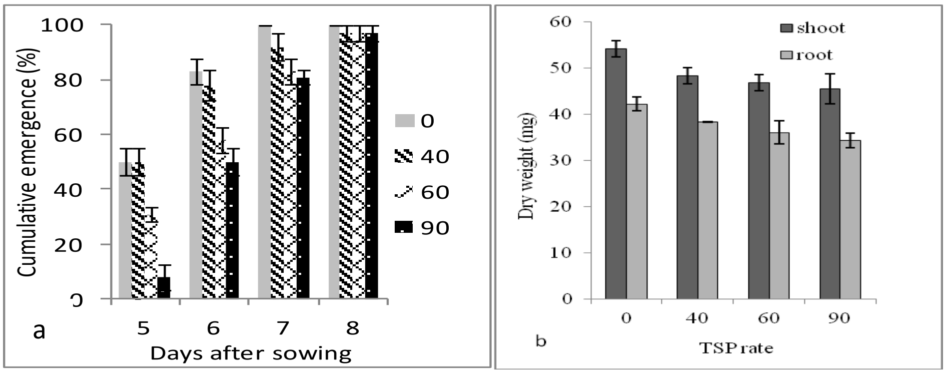

Fig. 2: Cumulative emergence (a) and root and shoot dry weight at 12 DAS (b) of chickpea in the HBT soil in seed-placed TSP (experiment 2). The treatments 40, 60, and 90 represent the P concentration that was calculated from the row spacings of 40, 60, and 90 cm at the recommended TSP rate (100 kg ha^{-1}). Zero (0) represents the control soil with no application of TSP. Vertical bars indicate standard errors of three replicates. In each replication dry weights were averaged for 6 randomly selected plants (12 plants column^{-1}). Least significance difference ($lsd_{0.05}$): for shoot, 7.3; for root, 5.3.

Experiment 3: In sand, the emergence started one day earlier than in clay and seed-placed TSP significantly decreased emergence compared to that of banding TSP below the seed (Fig.3a). In clay soil, TSP placement depth had no effect on final emergence at 10 – 11 DAS but the initial rate of emergence was slower when TSP was placed with the seed and banded at 2 cm below the seed compared with that of 5 cm banding and when TSP was thoroughly mixed with the soil (Fig. 3b).

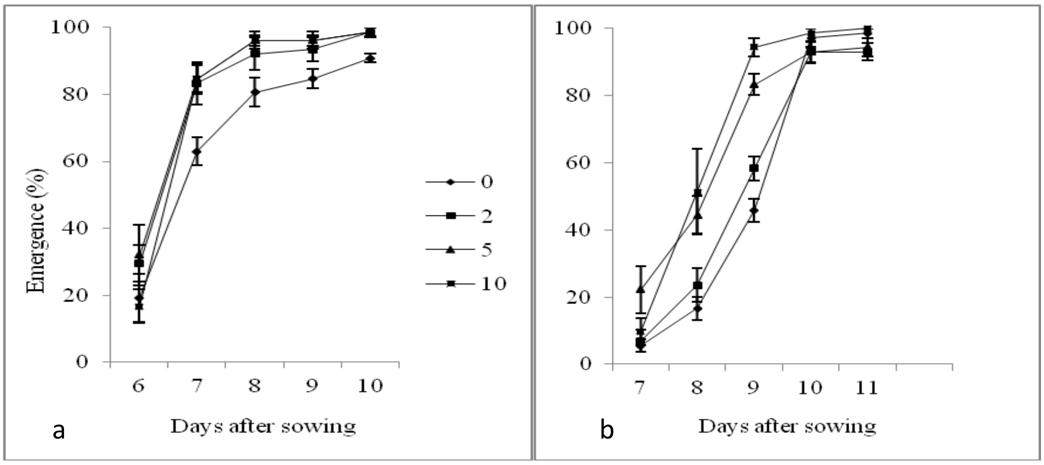

Fig. 3: Cumulative emergence of chickpea in (a) yellow sand and (b) Merredin clay soil fertilized with TSP banded with seed (0), 2 and 5 cm below the seed or mixing TSP with top 10 cm of soil. Vertical bars indicate mean ± standard error of six replications.

Seed-placed TSP decreased root length and root and shoot DW after 12 days of treatment in sand (Table 4a). With the increase in P placement distance from the seed, root and shoot length and their dry matter increased significantly. In clay soil, all the mentioned parameters were unaffected by seed-placed TSP. At 24 DAS, in sand, total root length in 0 and 2 cm treatments and root surface area in 0 cm were significantly reduced compared to 10 cm mixing treatment (Table 4b). Although there was no significant difference in root and shoot dry weight, highest values were also observed in the 10 cm mixing treatment. Nodule dry weight was significantly reduced in 0 cm due to both smaller size (visual observation) and reduced number.

Table 4a: Effect of triple superphosphate (TSP) banding on early growth of chickpea at 12 days after sowing (DAS) (Experiment 3). Means are calculated from three replications. All values of each parameter are presented on a per plant basis. 'ns' refers to non-significant.

TSP placement relative to seed (cm)	Tap root length (cm)	Shoot length (cm)	No. of root branches	Root Dry Weight (mg)	Shoot Dry Weight (mg)
Sandy soil					
0	23.9	10.7	28.6	41.7	50.9
2 cm below	23.2	9.9	27.6	68.5	46.3
5 cm below	26.6	10.6	33.1	73.1	51.4
Top 10 cm mixed	25.8	11.4	33.4	67.0	60.2
lsd $_{(0.05)}$	2.4	0.6	4.6	11.5	8.9
Clay soil					
0	15.9	11.8	21.8	24.7	67.1
2 cm below	16.4	11.6	20.3	27.3	64.7
5 cm below	16.5	11.3	22.3	29.2	66.2
Top 10 cm mixed	15.2	12.4	22.7	30.5	72.0
lsd $_{(0.05)}$	ns	ns	ns	ns	ns

Table 4b: Effect of triple superphosphate (TSP) banding on early growth of chickpea at 24 DAS (Experiment 3). Means are calculated from three replications. All values of each parameter are presented on a per plant basis. 'ns' refers to non-significant.

TSP placement relative to seed (cm)	Total root length (cm)	Root surface area (cm^2)	No. of nodule	Root	Shoot	Nodule
				Dry weight (mg)		
Sandy soil						
0	516	110	9.6	68.0	122	11.4
2	513	112	9.5	68.4	119	14.2
5	529	112	12.4	73.0	122	16.8
10	571	122	11.8	74.2	135	17.0
lsd $_{(0.05)}$	49.3	10.5	ns	ns	ns	5.5
Clay soil						
0	431	88.1	29.3	52.2	205	7.8
2	379	79.8	27.8	49.4	200	5.5
5	462	94.8	27.6	53.6	209	8.3
10	436	91.1	31.3	55.8	230	6.2
lsd $_{(0.05)}$	82.1	ns	ns	ns	ns	ns

Phosphorus toxicity symptoms (greyish-white necrosis) were first observed at 10 DAS in the lower leaves in 0 and 2 cm treatments. Symptom intensity increased with time after first appearance. This symptom was also observed in some plants of 5 cm and even in few plants of 10 cm mixing treatments.

In clay soil, banding TSP with seed produced similar root, nodule and shoot growth to 10 cm mixing treatments (Table 4b). There was no effect of P fertilizer placement on root dry weight, root surface area, nodule number and dry weight. Shoot dry weight and root length were greater in 10 cm mixing treatment than 2 cm banding.

Experiment 4: In the HBT soil, despite seed-placed TSP reduced emergence significantly at the initial stage, the final emergence was not different among the treatments and there was > 90 % emergence at all P banding placements (Fig. 4a). At 12 DAS, TSP placement with and below the seed (irrespective of placement distance) had no effect on shoot DW (Fig. 4c). The roots responded similarly to shoots, except for TSP mixing with 10 cm topsoil where root DW was increased marginally compared to that of other banding treatments. At 24 DAS, root and shoot DW increased with TSP 5 cm directly below the seed and produced equal DW to that of 10 cm mixing (Fig. 4d).

Initially, the root length was higher in the 10 cm mixing treatments than that of banding placements (Fig. 4b), but with time this suppressive effect disappeared and there was no difference among treatments in total root length at 24 DAS.

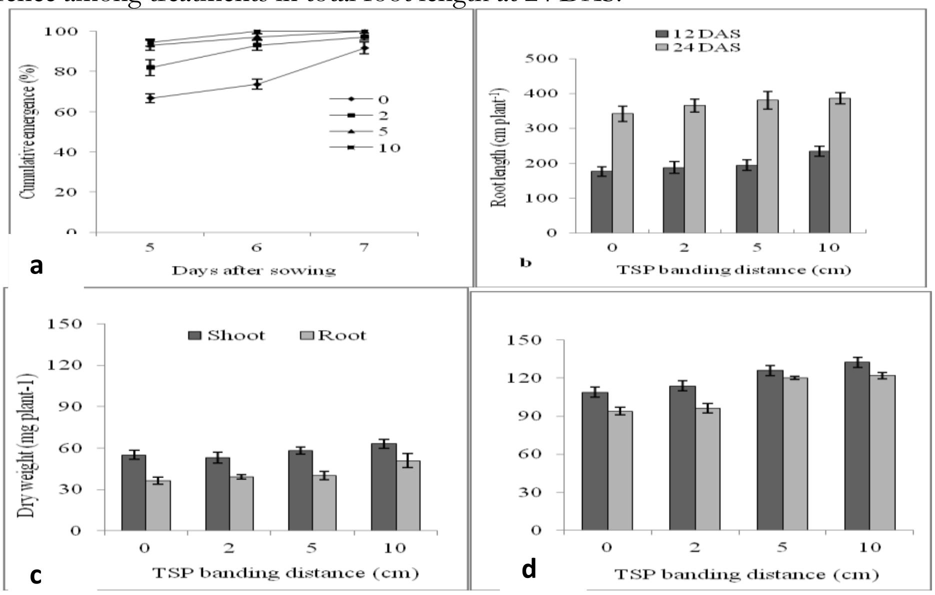

Fig. 4: Cumulative emergence (a), root length at 12 and 24 days (b), shoot and root dry weight at: 12 days(c) and 24 days(d) after sowing of chickpea in the HBT soil (experiment 4) when triple superphosphate (TSP) was banded with seed (0), 2, and 5 cm below the seed, and TSP mixed with top 10 cm of topsoil. Vertical bars indicate ± standard errors of six replications. The lsd $_{(0.05)}$ for 5 DAS, 8.1 (p<0.001); for 6 DAS, 5.8 (p<0.001); for 7 DAS, 5.2 (p<0.01).The TSP placement effect on root length at 12 and 24 DAS was not significant.The lsd $_{(0.05)}$ for shoot: at 12 DAS,3.4 (p<0.01); at 24 DAS, 12.1 (p<0.01). The lsd $_{(0.05)}$ for root: at 12 DAS, 5.4 (p<0.01); at 24 DAS, 9.3 (p <0.0001).

Emergence in the field studies: The emergence of chickpea when placed with the TSP fertilizer in rows by strip till in the clay loam soil of the HBT was unaffected by P fertilizer at either 50 or 100% of the recommended rate at both site 1 (range of plant population 38-41 plants m^{-2}) and site 2 (range 29-34 plants m^{-2}). As there was no effect of P fertilizer placement with seed on emergence, data was not shown either in tabular or graphical form.

Discussion

In the pot study, placement of 100 kg of TSP (20 kg P) ha^{-1} with chickpea seeds affected early growth by reducing seedling emergence and slowing the rate of emergence. The effect was pronounced in sand but much less so in clay soil (Experiment 1, Table 2; Experiment 3, Table 4a). In wheat, drilling 15-20 kg P ha^{-1} and in lupin (*Lupinus angustifolius* L.) drilling even 10 kg P ha^{-1} as superphosphate with the seed caused toxicity at early stages of growth in a sand with comparable clay level to the present study (Loneragan *et al*., 1966; Jarvis and Bolland, 1991; Bolland and Jarvis, 1996).

The toxicity symptoms and suppression of early growth of this study (Experiments 1 and 3) were observed where the clay content of the sand was 1% and PRI 2.4 (Table 1), which was consistent with the values (< 2% clay or PRI values < 2) causing P toxicity reported by Jarvis and Bolland (1991) and Bolland and Jarvis (1996).

Soil that contains higher clay content may avoid the early growth suppression by P fertilizer. Soils in WA that contain > 10% clay generally have capacity to sorb enough P to avoid P toxicity problems at a realistic rate of application (Bolland *et al*., 2001). In the present pot study, the clay content and PRI for the Merredin soil were 21% and 23 respectively, and that for HBT soil was 23% and 117 (Table 1). The higher clay content and PRI value of soils in the present study most likely minimized the suppressive effect of P fertilizer when it was applied with the seed (in both pot and field trials).

Suppression of emergence in Experiment 3 (Fig. 3a) in sand and Experiment 4 (Fig. 4a) in HBT clay soil might be due to the osmotic effect of P fertilizer (TSP) which could limit moisture uptake by the germinating seed. As P fertilizers have lower salt index (SI) than nitrogen and potassium fertilizers (Mortvedt, 2001), and TSP has a lower SI value than that of mono- and di-ammonium phosphate, the emergence in sand when TSP was placed with seed (Table 2) was much better than with DAP (Table 3). The severe effect of DAP on germination and emergence in sand (Table 3) may not only be from P or salt effects but also from NH_4^+ released from DAP dissolution (Bennett and Adams, 1970). Miller et al., (1970) suggested that DAP-related growth reduction was due to Ca deficiency caused by precipitation of Ca-P complexes; the black root tips found in sand in this study might be due to Ca deficiency (Carrow *et al*., 2001).

The osmotic/salt effect of P fertilizer in sand reduced root length and dry weights of root and shoot (Table 2). Although there were no symptoms in plants grown in clay soil throughout the experimental period, decreased root length in 2 cm banding treatments in Experiment 3 (significantly less than in 10 cm mixing) (Table 4b), and root and shoot DW (Fig. 4c in Experiment 4) might be due to an adverse osmotic effect of TSP in the root environment. This result is in accordance with Bhatti and Loneragan (1970b), who found that severe depression of root growth in wheat starts before appearance of any symptom in the shoots. Just after emergence of the radicle, the tender tip in the 2 cm banding treatment might be inhibited in elongation when it encounters the concentrated fertilizer bands just below the germinating seed, which would not be present when TSP was mixed in the top 10 cm of soil.

Root growth suppression due to P fertilizer banding was observed in several studies with cereals. Blanchar and Caldwell (1966) found that oat roots did not grow into a monocalcium phosphate (MCP) band. Also, Ouyang *et al*., (1998) reported that root growth stopped in the vicinity of a band containing urea and TSP. Trapeznikov et al., (2003) showed that shorter roots of wheat with more laterals grew in the nutrient-rich patch, while longer roots were observed where the same amount of nutrients (NPK compound fertilizer 11:10:11) was thoroughly mixed with the soil. Mixing TSP with 10 cm depth of sand in Experiment 3 at 24 days increased root growth more than banding treatments, which supports the findings of Trapeznikov *et al*., (2003). They predicted that abscisic acid (ABA) produced in the root due to increased nutrient concentration reduced root elongation, since ABA is known to inhibit root elongation of well-watered maize seedlings (Sharp and LeNoble, 2002). Increased root length in the 5 cm banding (Table 4b) treatment in both soils may be the result of avoiding salt toxicity due to greater distance between seed and P fertilizer than that the 2 cm distance.

Conclusion

The placement of TSP with the seed and banding at 2 cm below seed in sand was risky for seedling emergence and early growth of chickpea. In sand, a banding distance > 5 cm below the seed seems necessary but it still had some suppressive effect on early growth. In sand (~ 1% clay content) P fertilizer placement by the minimum-till planter should be more than 5 cm directly below or to the side of the seed. In clay loam soil, the recommended dose of TSP (100 kg ha^{-1}) had little or no effect on emergence and negligible effects on seedling growth. Thus banding of TSP directly with seed in the clay loam HBT soils in strip tillage is not likely to result in toxicity to chickpea so long as there is adequate soil moisture at sowing. Placement of TSP adjacent to the seed, as in strip tillage, may increase the efficiency of fertilizer use, and thus a reduced rate could meet the P needs of the crop.

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