



RESEARCH ARTICLE

Radiotracer Study on Phosphorus Use Efficiency in Sorghum and Blackgram Using Phosphorus (^{32}P) in Calcareous Soils

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Abstract

Phosphorus (P) is one of the least available of all essential nutrients in the soil and its concentration is generally below that of many other macronutrients. An experiment was conducted to study the phosphorus use efficiency (PUE) of the sorghum and blackgram in soils of varying calcium carbonate content using radiotracer phosphorus (^{32}P). The pot culture experiment was conducted during 2017-2018 at Radioisotope (Tracer) Laboratory, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. The treatment structure of the pot culture experiment comprised of four types of soils and two levels of phosphorous (control and recommended level of phosphorus as phosphoric acid) with sorghum and blackgram as test crop. The results of the pot culture experiment showed that the grain yield of sorghum and blackgram decreased with increasing calcareousness of the soil. Lowest grain yield recorded was 14.14 g pl^{-1} for sorghum and 2.20 g pl^{-1} for blackgram in strongly calcareous soil (S_4). In both sorghum and blackgram non calcareous soil (S_1) was recorded the highest total P uptake (101.24 mg pl^{-1}), (37.07 mg pl^{-1}) respectively. Among crops, blackgram recorded the highest per cent Pdfs (69.71%) than the sorghum (24.31 %). The highest sorghum per cent Pdfs (100 %) was observed with control (T_1) which differed significantly from P application (75.70%), in blackgram the highest per cent Pdfs in blackgram (67.35 %) was recorded in slightly calcareous soil (S_2) and the lowest % Pdfs (60.04 %) was registered in strongly calcareous soil (S_4). Mean Phosphorus Use Efficiency (PUE) showed significant difference in non-calcareous soil (27.13 %) followed by slightly calcareous soil (23.81%). The mean lowest efficiency was observed in strongly calcareous soil (19.41%). Blackgram recorded higher PUE than sorghum in all the soils.

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Phosphorus (P) is an essential nutrient for all living organisms and is indispensable because no other element can replace its vital role in many physiological and biochemical processes (Syers *et al.*, 2008). Phosphorus is called the “key to life” nutrient and historically, phosphorus played a key role in enhancing and sustaining crop productivity world wide (Subba Rao, 2010). Calcareous soils cover more than 30 per cent of the earth’s surface and their calcium carbonate (CaCO_3) content varies from a few percent to 95 per cent (Nurlaeny *et al.*, 1996). In India, calcareous soils are predominantly found in the states of Gujarat, Rajasthan, Madhya Pradesh, Andhra Pradesh and Tamil Nadu (Pasricha *et al.*, 2001). In Tamil Nadu, nearly four per cent is dominated by slightly calcareous soils, about 17 per cent by moderately calcareous soils and 12 per cent by strongly calcareous soils (Mathan and Selvakumari, 2000). In calcareous soil, precipitation of both soil and added P as a result of reaction between P and CaCO_3 where its precipitation as relatively insoluble di-calcium phosphate such as hydroxyl – apatite and carbonate apatite. The presence of CaCO_3 reduces the availability of P through sorption process. High Ca content in these soils precipitates P to unavailable forms resulting in low available P content in soil solution (Bertrand *et al.*, 2006)

Sorghum is one of the major cereal crops consumed in India after rice and wheat and is grown in the area of 5.65 million hectares with a production of 4.41 million tons. The crop is primarily produced in Maharashtra and Southern states of Karnataka and Tamil Nadu (Agricultural statistics at a glance, 2016). Blackgram (*Vigna*

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mungo L. Hepper) is an important pulse crop in India and is grown in 7.23 million hectare area with a production of 2.89 million metric ton (Agricultural Statistics at a Glance, 2016). Among all the pulses, blackgram is a highly priced pulse for its biological protein value and high phosphoric acid content. Being a legume, phosphorus nutrition is more important than nitrogen.

Material and Methods

Physico - chemical properties of soils

Four surface soils were collected from different locations. Soil samples collected were air dried and ground to pass through a 2-mm sieve for pot culture experiments. Particle size distribution was determined by pipette method (Piper, 1966), soil pH and EC were determined using 1:2.5 soil water extract (Jackson, 1973). Cation exchange capacity was estimated by neutral normal ammonium acetate method (Jackson, 1973). Calcium carbonate content was determined by rapid titration with acid and available -P was determined by using a soil to solution ratio 1:10 and 30 min of shaking, phosphorus in the extractant was determined by using the ammonium molybdate - ascorbic acid method (Olsen, 1954). Available nitrogen by alkaline permanganate method (Subbiah, 1956). Available potassium by Neutral Normal ammonium acetate extraction followed by emission spectrometry (Stanford and English, 1949).

The pot culture experiment was conducted during 2017-2018 at Radioisotope (Tracer) Laboratory, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore. The treatment structure of the pot culture experiment comprised of four types of soils and two levels of phosphorous (control and recommended level of phosphorus as phosphoric acid) which were replicated four times in a completely randomized block design with sorghum and blackgram as test crop. Treatments involving phosphorus was applied with recommended dose of phosphorus (45 kg P₂O₅ ha⁻¹ for sorghum, 50 kg P₂O₅ ha⁻¹ for blackgram) as phosphoric acid tagged with ³²P @ 0.5 m Ci g⁻¹ of P.

The plant samples were collected from each pot at post harvest (PH) stage and analyzed for P content (Piper, 1966), Measured quantity of digested extractant was transferred to the scintillation vials and counting was done directly (L'Annunziata and Legg, 1984) without using any flour as ³²P is a hard beta emitter. Using the data obtained, derived parameters like per cent phosphorus derived from fertiliser (%Pdff), per cent phosphorus derived from soil (%Pdfs), P uptake from fertiliser and PUE were calculated.

Derived parameters

$$\begin{aligned} \text{Percent Phosphorous Derived from Fertilizer (\% pdff)} &= \frac{\text{Specific activity in plant sample}}{\text{Specific activity of the standard}} \times 100 \\ \text{Percent Phosphorous Derived from Soil (\% pdfs)} &= 100 - \% \text{ pdff} \\ \text{Phosphorous Uptake from Fertilizer} &= \frac{\text{Total phosphorous uptake}}{100} \times \% \text{ pdff} \\ \text{Phosphorous Use Efficiency or} &= \frac{\text{Phosphorus uptake from fertiliser}}{\text{Total Phosphorus uptake}} \times 100 \\ \text{Phosphorous Utilisation Efficiency} & \end{aligned}$$

Result and Discussion

The initial characteristics of the experimental soils (Table 1) revealed that, among the four soils the texture of non calcareous soil (S₁) was clay, slightly calcareous soil (S₂) was of sandy clay loam with pH of 8.42, moderately calcareous soil (S₃) with texture of clay loam and strongly calcareous soil (S₄) with texture of clay. The pH of the soils varied from 7.51 in non calcareous soil (S₁) to 8.47 strongly calcareous soil (S₄). The highest available phosphorus (43.06 kg ha⁻¹) was registered in non calcareous soil (S₁) and lowest (10.70 kg ha⁻¹) was recorded in strongly calcareous soil (S₄). The maximum available potassium (960 kg ha⁻¹) was noticed in non calcareous soil (S₁) and minimum (510 kg ha⁻¹) was recorded in moderately calcareous soil (S₃). Organic carbon status of the experimental soil was in medium range. The calcium carbonate content of the soil was lowest in non calcareous soil (S₁) (0.5%) and in highest strongly calcareous soil (S₄) (27 %).

Grain and stover yield

The soils used in the study varied in the grain and stover yield of both blackgram and sorghum crops.

Table 1. Physical and chemical properties of soil sample used in pot culture experiment

Parameters	Unit	NC(S ₁)	SLC(S ₂)	MC(S ₃)	SC(S ₄)
A. Physical Properties					
Texture		Clay	Sandy clay loam	Clay loam	Clay
B. Physico chemical properties					
pH (1:2.5)		7.51	8.41	7.88	8.47
EC (1:2.5)	dSm ⁻¹	0.123	0.15	0.129	0.32
CEC	c mol (p+) kg ⁻¹	21	13	25	26
C. Chemical properties					
Available nitrogen	kg ha ⁻¹	260	274	241	185
Available phosphorous	kg ha ⁻¹	43.06	27.38	18.62	10.70
Available potassium	kg ha ⁻¹	960	754	510	774
Organic carbon	g kg ⁻¹	6.4	6.0	5.6	5.2
Calcium carbonate content	Per cent	0.5	7.0	10.0	27.0
Total Phosphorus	Per cent	0.09	0.13	0.11	0.14

Among the four soils non calcareous soil (S₁) recorded the highest grain yield of 17.53 g pl⁻¹ and stover yield (40.87 g pl⁻¹) in sorghum and grain yield of 2.96 g pl⁻¹ and stover yield (4.15 g pl⁻¹) in blackgram was significantly superior to rest of the soils (Table 2).

Table 2. Grain and Stover yield (g pl⁻¹) of Sorghum and Blackgram as influenced by phosphorus application in soils of varying calcium carbonate content

Crops /Soils	Grain yield (g pl ⁻¹)					Stover yield (g pl ⁻¹)				
	NC (S ₁)	SLC (S ₂)	MC (S ₃)	SC (S ₄)	Mean	NC (S ₁)	SLC (S ₂)	MC (S ₃)	SC (S ₄)	Mean
Sorghum										
Control (T ₁)	15.56	14.91	13.53	12.98	14.25	35.48	34.60	32.74	33.22	34.01
PA (T ₂)	19.51	18.32	16.17	15.30	17.33	46.25	44.51	40.92	41.00	43.17
Mean	17.53	16.62	14.85	14.14	15.48	40.87	39.56	36.83	37.11	38.59
Black gram										
Control (T ₁)	2.50	2.38	2.19	2.03	2.28	3.65	2.9	2.91	2.99	3.11
PA (T ₂)	3.42	2.90	2.63	2.36	2.83	4.65	4.62	4.39	3.93	4.40
Mean	2.96	2.64	2.41	2.20	2.55	4.15	3.76	3.65	3.46	3.76

Source	Sorghum				Black gram			
	Grain yield		Stover yield		Grain yield		Stalk yield	
	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)
Soils (S)	0.35	0.75	0.85	1.80	0.15	0.32	0.21	NS
Treatment (T)	0.25	0.53	0.60	1.27	0.10	0.22	0.15	0.32
S × T	0.50	NS	1.20	NS	0.21	NS	0.30	NS

(Note: NC – Non calcareous; SLC – Slightly calcareous; MC – Moderately calcareous; SC – Slightly calcareous; PA – Phosphoric acid)

As the CaCO₃ content increases in soil the yield is decreased irrespective of the treatments. In control, strongly calcareous soil (S₄) registered a decrease of 19.88 % of grain yield in sorghum and 23.15 % of grain yield in blackgram. Irrespective of the soils, P applied treatment (T₂) recorded higher grain yield (17.33 g pl⁻¹) and stover yield (43.17 g pl⁻¹) in sorghum and grain yield (2.83 g pl⁻¹) and stover yield (4.40 g pl⁻¹) in blackgram than the control (T₁). (Hussain *et al.*, 2011) reported that dry matter yield of wheat and broad bean exhibited negative correlation with CaCO₃ content of soil. It is due to negative effect to precipitation of both soil and added P as a result of reaction between P and CaCO₃ where its precipitation as relatively insoluble di-calcium phosphate such as hydroxyl – apatite and carbonate apatite. Many studies have shown that generally application of phosphatic fertilizers has a great impact on crop yields because P deficiency limits the response of plants to other nutrients (Ahmad *et al.*, 1992 and Alam *et al.*, 2003). The positive response of added P by sorghum

yield has been reported by (Sujathamma et al., 2015). Similar results were also obtained for blackgram by several workers; (Singh et al., 2016).

Total P uptake from soil in sorghum and blackgram

In both sorghum and blackgram the highest total P uptake was in non calcareous soil (S_1) (101.24 mg pl^{-1}) and (37.07 mg pl^{-1}) compare to other soils (Table 3). The reduction in P uptake in strongly calcareous soil (S_4) over non calcareous soil (S_1) was 18.7 mg pl^{-1} for sorghum and 7.79 mg pl^{-1} for blackgram. The lower available P status of the soil combined with other factors as well as comparatively low productivity observed in these soils might be the cause for the lower amount of P uptake by the crops in these soils. Among the treatments P applied treatment registered the highest total P uptake (93.46 mg pl^{-1}) in sorghum and (37.60 mg pl^{-1}) in blackgram. Sorghum response to P uptake in calcareous soils by P application was reported by (Sahrawat et al., 1995) in black calcareous vertisol. Similar results were obtained by (Rudreshappa and Hallikatti, 2002) in blackgram.

Table 3. Total Phosphorus uptake (mg pl^{-1}) and Per cent Phosphorus Derived from Soil (%) of Sorghum and Blackgram as influenced by phosphorus application in soils of varying calcium carbonate content

Soils / Treatments	Total P uptake (mg pl^{-1})					%Pdfs (%)				
	NC (S_1)	SLC (S_2)	MC (S_3)	SC (S_4)	Mean	NC (S_1)	SLC (S_2)	MC (S_3)	SC (S_4)	Mean
Sorghum										
Control (T_1)	82.59	55.06	49.41	44.59	57.91	100.00	100.00	100.00	100.00	100.00
PA (T_2)	119.89	101.29	73.96	78.69	93.46	77.12	77.11	73.07	75.48	75.70
Mean	101.24	78.18	61.69	61.64	75.69	88.56	88.56	86.54	87.74	87.85
Black gram										
Control (T_1)	29.83	25.17	20.49	18.07	23.39	100.00	100.00	100.00	100.00	100.00
PA (T_2)	44.31	40.26	36.64	29.18	37.60	34.66	34.70	31.73	20.08	30.29
Mean	37.07	32.72	28.57	23.63	30.50	67.33	67.35	65.87	60.04	65.15

Source	Sorghum				Black gram			
	Total P uptake (mg pl^{-1})		%Pdfs (%)		Total P uptake (mg pl^{-1})		%Pdfs (%)	
	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)
Soil (S)	1.10	4.24	0.74	NS	1.15	2.44	1.32	2.79
Treatment (T)	1.41	2.10	0.52	1.04	0.81	1.73	0.93	1.98
S × T	2.82	5.10	1.04	NS	1.63	3.45	1.86	3.95

Per cent phosphorus derived from soil

In sorghum, the highest per cent Pdfs was recorded in the non calcareous soils (S_1) where it was on par with slightly calcareous soils (S_2). Among treatments control (T_1) recorded the highest per cent Pdfs (100 %) compare to P applied treatment (T_2). In blackgram, slightly calcareous soil (S_2) observed mean maximum per cent Pdfs (67.35 %) and mean minimum was recorded in highly calcareous soil (S_2) (60.04 %) (Table 3). Treatments followed the same trend as sorghum. The per cent pdfs in sorghum was the highest. This trend of result was quite reverse to the trend observed with per cent Pdf. This was only a logical trend since per cent Pdf and per cent Pdfs are mutually exclusive parameters and any increase in one would naturally mean a corresponding decrease in another.

Per cent phosphorus derived from fertilizer

Per cent Pdf is a parameter indicating the contribution of the fertilizer source. In sorghum and blackgram based on the % Pdf values, the soil rankings were $S_3 > S_4 > S_2 > S_1$ in sorghum and $S_4 > S_3 > S_2 > S_1$ in blackgram. The mean maximum % Pdf (69.79 %) in blackgram (C_2) compare to sorghum (C_1) (24.31 %) (Table 4). This would imply that the ability of the crop to absorb P from the native and applied source varying from soil to soil and the proportion of P absorbed from these sources is not the same for all types of soils. Higher per cent Pdf observed with blackgram (C_2) indicates the ability of blackgram to maintain higher level of applied P in soluble form thereby increasing the availability to the crop. This draws support from the findings of (Dravid,

1990) who observed in peas and lentil crops a tremendous increase in Pdf values with P application. Also, Hashmi *et al.* (2017) in a greenhouse study with ³²P tracer technique showed that P derived from fertilizer was highest 47.5% with phosphoric acid application.

Table 4. Per cent Phosphorus Derived from Fertilizer (%) and Phosphorus uptake from fertilizer (mg pl⁻¹) of Sorghum and Blackgram as influenced by phosphorus application in soils of varying calcium carbonate content

Soils / Treatment	Per cent Phosphorus Derived from Fertilizer (%)					Phosphorus uptake from fertilizer (mg pl ⁻¹)				
	NC (S ₁)	SLC (S ₂)	MC (S ₃)	SC (S ₄)	Mean	NC (S ₁)	SLC (S ₂)	MC (S ₃)	SC (S ₄)	Mean
Sorghum										
Control (T ₁)	-	-	-	-	-	-	-	-	-	-
PA (T ₂)	22.88	22.89	26.94	24.53	24.31	26.36	23.10	20.35	17.41	21.81
Black gram										
Control (T ₁)	-	-	-	-	-	-	-	-	-	-
PA (T ₂)	65.24	65.3	68.27	79.93	69.69	29.87	26.26	24.88	22.99	26.00
Mean	44.06	44.10	47.61	52.23	47.00	28.12	24.68	22.61	20.20	23.90

	%Pdf (%)		Phosphorus uptake from fertilizer (mg pl ⁻¹)	
	SE _d	CD (P=0.05)	SE _d	CD (P=0.05)
Soil (S)	1.99	4.21	1.02	2.17
Crop (C)	1.41	2.98	0.72	1.53
S × C	2.81	NS	1.45	NS

P uptake from fertilizer in sorghum and blackgram

Phosphorus uptake from fertilizer was highest in non calcareous soil (S₁), it decreased as the calcareousness increases in the soil (Table 4). The presence of CaCO₃ reduces the availability of P through sorption process. High Ca content in these soils precipitates P to unavailable forms resulting in low available P content in soil solution (Bertrand *et al.*, 2006). Among crops blackgram (C₂) was recorded the highest P uptake (26.00 mg kg⁻¹) compare to the sorghum (C₁) (21.81 mg kg⁻¹).

Table 5. Phosphorus Use Efficiency (%) in Sorghum and Blackgram as influenced by P application in soils of varying calcium carbonate content

Soil / Treatment	PUE(%)				Mean
	NC (S ₁)	SLC (S ₂)	MC (S ₃)	SC (S ₄)	
Sorghum					
Control (T ₁)	-	-	-	-	-
PA (T ₂)	26.84	23.52	20.72	17.73	22.20
Black gram					
Control (T ₁)	-	-	-	-	-
PA (T ₂)	27.41	24.09	22.83	21.10	23.86
Mean	27.13	23.81	21.78	19.41	23.03

Source	SE _d	CD (P = 0.05)
Soil (S)	0.94	1.99
Crop (C)	0.46	0.97
S x T	1.33	NS

(Note: NC – Non calcareous; SLC – Slightly calcareous; MC – Moderately calcareous; SC – Slightly calcareous; PA – Phosphoric acid)

Phosphorus use efficiency

Per cent utilisation of added P in sorghum crop is in the order of non - calcareous (S_1) (26.84%) > slightly calcareous (S_2) (23.52%) > moderately calcareous (S_3) (20.72%) and strongly calcareous (S_4) (17.73%). In blackgram the PUE recorded was 27.41, 24.09, 22.82 and 21.10 per cent for non - calcareous, slightly calcareous, moderately calcareous and strongly calcareous soils (Table 5). The efficiency of P fertiliser in calcareous soils is generally low because P applied to the soil reacts with calcium forming minerals such as di-calcium mineral, Octa-calcium minerals ultimately to the hydroxyl mineral (Tunési *et al.*, 1999). Higher PUE of legumes in comparison to cereals was also reported by several earlier workers (Lakshminarayana, 2011).

Conclusion

It was concluded that the grain yield of sorghum and blackgram decreased with increasing calcareousness of the soil. The highest grain yield recorded was 17.53 g pl^{-1} for sorghum and 2.96 g pl^{-1} for blackgram in non calcareous soil (S_1). Soils and P application exerted a significant influence on P uptake. Among crops, blackgram recorded the highest per cent Pdfs (69.71%) than the sorghum (24.31 %). The highest sorghum % Pdfs (100 %) was observed with control (T_1) which differed significantly from P application (75.70%), in blackgram the highest per cent Pdfs (67.35 %) was recorded in slightly calcareous soil (S_2) and the lowest per cent Pdfs (60.04 %) was registered in strongly calcareous soil (S_4). Mean Phosphorus Use Efficiency showed significant difference in non-calcareous soil (27.13 %) followed by slightly calcareous soil (23.81%). The mean lowest efficiency was observed in strongly calcareous soil (19.41%). Blackgram recorded higher PUE than sorghum in all the soils.

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