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Phosphorus transitions in traditional eco-knowledge versus chemical based agri-amendment systems of stress-prone semi-arid tropics: Finding the real game-changer

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ABSTRACT

Fixation of Phosphorus into locked forms hampers the availability of this important soil element. Phosphate Solubilising Microorganisms (PSM) play an important role of solubilisation and mineralization of these fixed forms into bio-available forms through reactions that are complex but provide simple solutions to P deficiency in soils. Semi-arid soil may have high total phosphorus concentrations but as most of the P is in an unavailable form, it leads to deficiency of this essential macronutrient in the crop. The use of microbial inoculants (biofertilisers) that possess the Phosphate solubilizing activities in agricultural soils is considered as an eco-friendly alternative to chemical based P fertilizers. The present study is a first of its kind attempt to understand the impact of Traditional Ecological Knowledge (TEK) (A1) vis-à-vis conventional chemical intensive integrated (A2) based agriculture amendment systems in altering/modifying the Phosphorus dynamics of the soil in the semiarid tropical region of Kachchh, Western India. The study was carried out for the pre, mid and post-harvest phases of crops for six seasons spread across 4 years.

Higher Phosphorus Activation Coefficient (PAC), which is the ratio of available P (AP) to total P (TP) was observed in A1, that coincided with higher soil organic carbon (SOC) as well, across all seasons. The present study tried to answer questions as to how indigenous knowledge-based systems suited to local supply/demand complex system are precursors/indicators of a better microcosm in agriculture ecology studies that owing to its organic matter content improves SOC and PAC and in turn the overall P availability.

1. Introduction

Amongst the three major nutrients (Nitrogen, Phosphorus and Potassium) required to sustain any soil system; the story of Phosphorus is the most interesting and astonishing (Sharma et al., 2013). The content of P in average soil is around 0.05% (w/w) but only 0.1% of the total P is available owing to poor solubility and its fixation in soil (Illmer and Schinner, 1995). Due to this deficiency of available P, chemical Phosphatic fertilizers are widely used to achieve optimum yields (Del Campillo et al., 1999; Shenoy and Kalagudi, 2005). However, the detrimental effects of chemical fertilisers are now quite evident and the post green revolution era has been a witness to these deleterious effects that are caused to the ecosystem in general and soil in particular (Sharma et al., 2013).

According to the World fertilizer trends and outlook to 2018 report of FAO, the global potential phosphorus balance (i.e. the difference between P potentially available for fertilizers and P fertilizer demand) is expected to steadily rise from 2,700,000 tonnes in 2014 to 3,700,000 tonnes in 2018 or from 6.4 percent of total demand to 8.5 percent. Phosphate rock is the basic raw material for P based fertilisers, however this raw material is a finite resource and at the present rate of mining, the time is not very far when we would be running short of this important resource. The 'Peak Phosphorus' concept (Cordell and White, 2011) is a myth or reality, is though debatable, but what is quite evident is that we need to look for alternatives that are not only replenishable, but also are able to maintain the ecosystem sustainability in the long

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run. The researches on restoration of degraded landscape also identifies increase in bioavailable P, content in the soil as an indicator of a successful ecorestoration project (Maiti, 2012; Ahirwal and Maiti, 2016, 2018; Ahirwal et al., 2017).

The present study is a first of its kind attempt to understand the role of two different amendment systems viz. Traditional Ecological Knowledge (TEK) (A1) vis-à-vis conventional chemical intensive (A2) in altering/modifying the Phosphorus dynamics of the soil in the semiarid tropical settings of Kachchh, Western India, which is a typical representative of allied regions prone to natural threats as salinity, drought and incessant rainfall. The pre, mid and post-harvest phases of crops for six seasons spread across 4 years were studied. Knowledge and practices that are adapted to the local cultures and microenvironments are collectively referred to as TEK and that may include eco-friendly sustainable soil and pest management systems (CBD 2016). Unfortunately, a lot of this knowledge has been lost and existing knowledge remains either unused or under used. 'Rig veda' and 'Krishi parashara' are few of those valuable treatises from ancient Indian scriptures that date back to 400 BCE and the soil adaptive management strategies mentioned in them hold relevance till date. Similar indigenous knowledge exists in different parts of the world. The Intergovernmental Panel on Climate Change has emphasised on the role of indigenous knowledge and crop varieties in climate adaptation (Parry et al. 2007).

Phosphate Solubilising Microorganisms play a crucially important role of solubilisation and mineralization of these fixed forms of P into bio-available forms through reactions that are complex but provide simple solutions to P deficiency in soils where the ironically high proportions of total P exist. PSM based biofertilisers are an eco-friendly alternative to chemical based P fertilizers (Sharma et al., 2013) . The Phosphorus Activation Coefficient (PAC) is the ratio of available P (AP) to total P (TP) (Wu et al., 2017). It is a crucial factor that is indicative of soil P availability. For the rational management of P in soil, both the amount and the chemical form play an important role. The soils may be rich in TP content; however, the AP fractions are the decisive factor. The study tried to explain the relationship that exists between SOC (soil organic Carbon), OM (organic matter) and the PAC and addressed questions as to how indigenous knowledge-based systems suited to local supply/demand complex provide resilience in crop seasons that are prone to stressors in the form of drought in challenging settings as tropical aridisols. Management practices affect the PAC and in turn P availability to a large extent. The mid-phase is the most crucial phase in terms of crop P requirement and SOC pool alleviates the PAC and serves the role of matching the timely bioavailability of this important plant nutrient. Conclusively, the study came out with interesting results that could very well advocate the superiority of TEK based inputs to maintain a soil environment that is conducive for rich SOC and higher PAC through microbial mediated transformations.

2. Materials and method

2.1. Study site and field selection strategy

The area for the present study was a geo-ecologically unique terrain of Western India-Kachchh (Fig. 1) that is a typical representative of allied arid and semi-arid tropics that are prone to various natural threats and stresses like drought, salinity, incessant rainfall pattern etc in terms of agriculture management (Sharma and Thivakaranl, 2020). The National Bureau of Soil Survey and Land Use Planning NBSS and LUP circular, 2005 classified the soils of this zone into great group typic camborthids. The soils are typically sandy loams and calcareous tropical aridisols. Salinity is a huge problem for the farmers in Kachchh, this may be attributed to the geological origin of this area from marine deposits of Mesozoic and Cenozoic periods which impart the inherent salinity to the soil and hence the ground water [Biswas, 2016]. The highly erratic nature of rainfall coupled with a high coefficient of variation (52%) leads to immense risk in rain-fed agriculture (GEC, 2011). However, post the onset of Narmada Canal Project and setting up of smaller dams, now irrigation facilities have considerably reduced the rain failure-driven risks in this area (Jagadeesan et al., 2016).

Spread across four years, the pre, mid and post-harvest phases of crop in six cropping seasons were compared in 10 fields/system of TEK (A1) and chemical intensive-integrated (A2) systems. In India, the cropping pattern follows two distinct seasons. From July to October is Kharif season and Rabi season lasts from October to March. For the present study, three Kharif (Summer crop; 2012, 2013, 2014) and three Rabi (winter crop; 2011–12, 2012–13, 2013–14) were studied. The TEK agrisystems used organic manures of different types. Farm yard compost (FYC) was applied @4 ton (Mg) /hectare as a basal dose before sowing and modified'Jivamrit S' (Palekar, 2006), a fermented concoction consisting of cow urine, cow dung, jaggery, gram flour and soil, was applied with watering twice, at seven days interval from sowing. This concoction/Jivamrit-S was prepared on site in composting pits. The chemical intensive integrated amended fields used farm yard manure (FYM) as a basal dose (applied at rate of 1 ton/ha) and synthetic

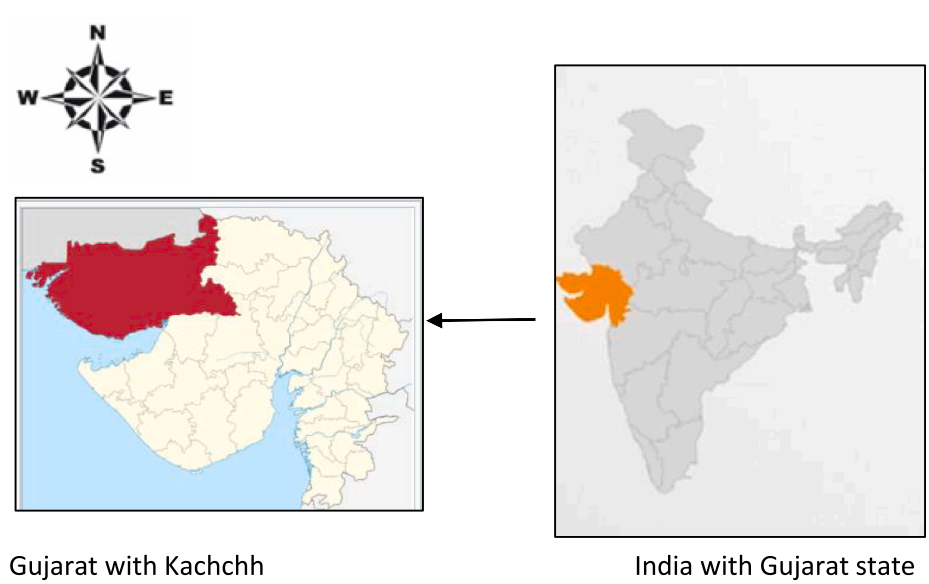

Fig. 1. Study area location.

fertilisers as sources of Nitrogen and Phosphorus. Urea (N source) @ 60 Kg/ha was applied as top dressing at around 15–20 days after sowing (DAS) and Di ammonium phosphate (P source) @ 40–60 Kg/ha was applied as top dressing at around 15–20 DAS. Consistency in management practices for both the amendment systems was maintained for all the six cropping seasons studied (Sharma and Thivakaranl, 2020)

Using standard soil sampling protocols (EPA. 1992), sample collection was carried out from the rhizosphere of the crop upto the depth of 12–15 cm. As the experiments were carried out at the farmers' fields and not experimental stations hence the crops were not restricted to one or two varieties. However, the sites for experiment grew crops viz. Sorghum (*Sorghum bicolor*), Maize (*Zea mays*),) as Kharif (summer) and castor (*Ricinus communis*), wheat (*Triticum aestivum*) crops as Rabi (winter) depending upon the monsoon which is highly erratic. Four samples were collected per ha per field and were further pooled to form one composite sample. These composite samples were then analyzed in triplicates. Soil samples were divided into two parts, out of which one part of the sample was air dried in shade and sieved through a sieve size of 2 mm. and analyzed for available and total P and SOC; and second part of this soil sample was stored at 4 °C for PSM and TMC evaluation (Sharma and Thivakaranl, 2020).

2.2. Soil analysis

The physical and chemical properties of soils were analyzed according to the standardized standard protocols, as explained by Alef and Nannipieri (1995). For available Phosphorus, Olsen's method for neutral alkaline soil (Olsen et al., 1954) was adopted. The total P in soil samples was extracted by a mixture of concentrated sulphuric acid, hydrofluoric acid and hydrogen peroxide (Bowman, 1988) and the P concentration of the extract was determined using the same method as for available P. Soil organic carbon (SOC) and organic matter (OM) was determined using the titrimetric determination (Walkley and Black, 1934) method. Microbial isolation was carried out from each of the soil samples using standard protocols for PSM (Pikovskaya, 1948).

2.3. Statistical analysis

Various statistical software were used to analyse the data obtained. The data sets for different soil parameters for six cropping seasons were subjected to a GLM (general linear model) three-way analysis of variance, and significant effects ($p < 0.05$) were noted using the SPSS version 20 (IBM). Multiple comparison was done among all the main effects and interactions to identify the homogenous effects using Tukey's HSD (honestly significant difference) comparison for least square means (LSM) (SAS version 9.3). A probability level of 0.01 was considered to be statistically significant. Pearson's test of correlation (two tail) was performed.

3. Results

3.1. Soil organic Carbon (SOC) and organic matter (OM)

The range of SOC across the six cropping seasons for amendment A1 and A2 was from 0.03% to 0.98% with SE = ± 0.01% and SD = ± 0.20% (Table 1). The mean value for SOC for both the amendments was 0.37 ± 0.01%. However, A1 had a higher value (0.45%; SE = ±0.01%) as compared to A2 (0.27%; SE = ± 0.01%) (Table 1A). The mid-phase had a higher SOC value (0.53 ± 0.01%) than both the pre- sowing (0.29 ± 0.01%) and post-harvest phase (0.27 ± 0.01%) across all the amendments and seasons. The highest SOC value amongst the six seasons was observed in season 1 (0.48 ± 0.02%) and lowest in season 5 (0.33 ± 0.03%). SOC had a significant positive correlation with all parameters except total P (Table 2).

Further analyses of the interaction effects for SOC revealed that all the interactions viz. season by phase ($F (10,324) = 2.87$, $P < 0.001$), season by amendment ($F (5,324) = 3.97$, $P < 0.001$) and phase by amendment ($F (2,324) = 32.99$, $P < 0.0001$) interactions are significant (Table 3). Tukey's HSD test was applied to assess the pair-wise significance of the means of each of the factors and their interactions (Supplementary data).

The rest of the seasons were not significantly different from each other. The mean SOC during phase 2 (0.53%) was significantly higher than phase 1 (0.29%) and phase 3 (0.27%). However, the difference in SOC and OM during phase 1 and 3 were not statistically significant. Organic amendments had substantially higher SOC (0.45%) and OM (0.78%) as compared to chemical-based farming systems (0.27% and 0.48% SOC and OM, respectively). Further, on analysing the interaction effects the phase 2 of amendment 1 (A1) had highest SOC (0.69%) and it was significantly higher than phase 2 of amendment 2 (0.38%). In order to understand whether organic inputs provide better resilience towards drought, the season and amendment interaction effect on SOC and OM was analysed. Here it was evident that cropping seasons affected by drought season 2 (Kharif 2012) and season 3 (Rabi 2012–13) had higher SOC levels in A1 (0.42% and 0.43% in season 2 and 3, respectively) than A2 (0.25% and 0.32% in season 2 and 3 respectively). (Supplementary data)

3.2. Available and total phosphorus

The range of available P across the six cropping seasons for amendment A1 and A2 was from 3 Kg/ha to 56 Kg/ha with SE = ±0.42 Kg/ha and SD = ±7.89 Kg/ha (Table 1). The mean value for available P for both the amendments was 13.69 ± 0.41 Kg/ha. However A1 had a higher value (17.15 Kg/ha; SE = ±0.66 Kg/ha) as compared to A2 (10.23 Kg/ha; SE = ±0.34 Kg/ha) (Table 1A). The mid-phase had a higher available P value (20.02 ± 0.87 Kg/ha) than both the pre- sowing (10.96 ± 0.42 Kg/ha) and post-harvest phase (10.08 ± 0.32 Kg/ha) across all the amendments and seasons. The highest available P value amongst the six seasons was observed in season 5 (16.36 ± 1.4 Kg/ha) and lowest in season 6 (11.35 ± 0.91 Kg/ha) (supplementary data Table S3). The range of total P across the six cropping seasons for

Table 1
Overall descriptive Statistics for different variables in agriculture systems A1 and A2.

	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Soil organic carbon (SOC)	0.95	0.03	0.98	0.3673	0.01075	0.20402
Organic matter (OM)	1.64	0.05	1.69	0.6334	0.01853	0.35161
Available P	55.00	3.00	56.00	13.6657	0.41591	7.89127
Total P	141.00	56.00	197.00	121.5583	1.27454	24.18261
Total Microbial Count	192.00	7.89	222.00	39.3222	1.54729	22.20377
Phosphate Solubilising Microorganisms	9.2	0.00	9.20	2.2258	0.1235	2.14165

A1 = Traditional Ecological Knowledge based amendment system; A2 = Chemical Intensive integrated system.

Table 1A
Amendment wise descriptive Statistics for different variables in agriculture systems A1 and A2.

A1	Range	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic
Soil organic carbon (SOC)	0.87	0.11	0.98	0.4548	0.01592	0.21353
Organic matter (OM)	1.50	0.19	1.69	0.7843	0.02742	0.36791
Available P	55.00	1.00	56.00	17.0979	0.66636	8.94020
Total P	109.00	56.00	165.00	110.4500	1.50237	20.15645
Total Microbial Count	197.00	11.00	215.00	49.6000	2.5612	34.63559
Phosphate Solubilising Microorganisms	8.79	0.00	8.79	2.9061	0.12436	2.57098
A2						
Soil organic carbon (SOC)	0.95	0.03	0.98	0.2798	0.01118	0.14997
Organic matter (OM)	1.64	0.05	1.69	0.4824	0.01926	0.25837
Available P	24.00	3.00	27.00	10.2334	0.34377	4.61218
Total P	119.00	78.00	197.00	132.6667	1.69708	22.76869
Total Microbial Count	90.00	7.99	99.90	33.0444	1.27811	22.51426
Phosphate Solubilising Microorganisms	7.98	0.00	8.10	1.1456	0.01731	1.57393

A1 = Traditional Ecological Knowledge based amendment system; A2 = Chemical Intensive integrated system

Table 2
Pearson's Correlation matrix (2-tail) for different variables in agri-amendments.

	SOC	OM	AP	TP	TMC	PSM
SOC	1	1.000**	0.575**	−0.488**	0.404**	0.563**
OM	1.000**	1	0.576**	−0.488**	0.405**	0.564**
AP	0.575**	0.576**	1	−0.510**	0.559**	0.575**
TP	−0.488**	−0.488**	−0.510**	1	−0.446**	−0.487**
TMC	0.404**	0.405**	0.559**	−0.446**	1	0.550**
PSM	0.563**	0.564**	0.575**	−0.487**	0.550**	1

**. Correlation is significant at the 0.01 level (2-tailed).
(SOC = Soil organic Carbon; OM = organic matter; AP = Available Phosphorus.
TP = total Phosphorus; TMC = total microbial count; PSM = Phosphate Solubilising microorganisms).

amendment A1 and A2 was from 56 Kg/ha to 197 Kg/ha with SE = ±1.27 Kg/ha and SD = 24.18 Kg/ha (Table 1). The mean value for total P for both the amendments was 121.55 ± 1.27 Kg/ha. However, A1 had a lower value (110.45 Kg/ha; SE = ± 1.50 Kg/ha) as compared to A2 (132.66 Kg/ha; SE = ±1.69 Kg/ha). The post-harvest phase had a higher total P value (132.27 ± 1.81 Kg/ha) than both the mid-phase (107.28 ± 2.08 Kg/ha) and post-harvest phase (125.11 ± 2.06 Kg/ha) across all the amendments and seasons. The highest total P value amongst the six seasons was observed in season 3 (130.56 ± 2.23 Kg/ha) and lowest in season 1 (117.23 ± 2.23 Kg/ha). The results have shown that there was a significant effect of season, phase and amendment on the total P and available P levels. Further, the two-way interaction studies of season by phase yielded significant F values for both available P ($F (10,324 = 3.07, P < 0.001)$) and total P ($F (10,324 = 4.84, P < 0.0001)$ (Table 3). The total P values for all the seasons are at par. However, season 3 (130.56 Kg/ha) had highest total P and the second lowest value of available P was observed in the same season (11.35 Kg/ha). On analysing the phase statistics for Phosphorus levels, it was evident that the mid-phase of crop cycle was the one with highest available P (20.02 Kg/ha) and lowest total P (107.28 Kg/ha). This trend continued irrespective of the season. Amendment A1 had significantly higher available P (17.09 Kg/ha) and lower total P (110.45) than A2 (10.23 and 132.66 available and total P respectively). This trend was followed in all six seasons.

3.3. PSM count and TMC (total microbial count) in the soil

The range of PSM count across the six cropping seasons for amendment A1 and A2 was from 0.00 cfu/gm soil to 9.2 cfu/gm soil with SE =± 0.12 cfu/gm soil and SD = ±2.14 cfu/gm soil (Table 1). The mean value for PSM count for both the amendments was 2.22 ± 0.11 cfu/gm soil. However, A1 had a higher value (2.90 cfu/gm soil; SE = ±0.12 cfu/gm soil) as compared to A2 (1.14 cfu/gm soil; SE = ±0.01 cfu/gm soil). The range of TMC count across the six cropping seasons for amendment A1 and A2 was from 7.89 cfu/gm soil to 192 cfu/gm soil with SE =± 1.5 cfu/gm soil and SD = ±22.2 cfu/gm soil. The mean value for TMC count for both the amendments was 39.32 ± 1.54 cfu/gm soil. However A1 had a higher value (49.6 cfu/gm soil; SE = ± 2.56 cfu/gm soil) as compared to A2 (33.04 cfu/gm soil; SE = ±0.01 cfu/gm soil).

Across all seasons (Figs. 2a–f) it was observed that A1 had a higher PAC which coincided with higher levels of SOC and PSM, it may be inferred that TEK based soil systems had a rich organic matter content and hence a higher microbial flora including P solubilsers, that ensued the conversion of unavailable P forms into available forms through various processes (Sharma et al., 2013). Similarly, the correlation matrix Table 2 has also revealed that available P is correlated positively to SOC and PSM.

4. Discussion

Soil organic Carbon is a soil property considered as one of the most important indicators of soil nutrient status; it has positive effects on soil physical properties and promotes water infiltration, storage and drainage. It is directly related to the maintenance of soil structure, the presence of different groups of micro-organisms, mineralization of organic matter, and nutrient availability (Goidts et al., 2009). It could be discerned from the present study that the effect of the cropping season, the crop phase and the kind of amendments on the SOC and OM of the soil was very highly significant ($P < 0.0001$). As far as the cropping seasons are concerned, the SOC in season 1 was significantly higher than rest of the seasons, probably because the years preceding season 1 in 2010 had above average annual precipitation (922 mm in 2010 and 703 mm in 2011). The resulting good moisture level contributes to the better decomposition of organic materials in the soil and hence for the OM and the SOC. The rest of the seasons were not significantly different from each other. The mean SOC during phase 2 was significantly higher than phase 1 and phase 3. However, the difference in SOC and OM during phase 1 and 3 were not statistically significant. The mid-phase of crop cycle is irrigated frequently than the pre and post phases; moreover,

Table 3
The F Statistics for dependent variables using the GLM Procedure.

Source	DF	SOC (%)		OM (%)		AP (Kg/Ha)		TP (Kg/Ha)		PSMcfu/gm soil		TMCcfu/gm soil	
		F Value	Sig.	F Value	Sig.	F Value	Sig.	F Value	Sig.	F Value	Sig.	F Value	Sig.
SEASON	5	15.52	<0.0001	15.49	<0.0001	8.67	<0.0001	4.66	0.0004	3.16	0.02	192.07	<0.0001
PHASE	2	202.36	<0.0001	203.53	<0.0001	160.78	<0.0001	66.49	<0.0001	103.95	<0.0001	198.56	<0.0001
SEASON*PHASE	10	2.87	0.0019	2.89	0.0018	2.80	0.0024	4.84	<0.0001	2.32	0.024	26.17	<0.0001
AMENDMENT	1	212.15	<0.0001	213.29	<0.0001	185.74	<0.0001	148.61	<0.0001	199.55	<0.0001	198.70	<0.0001
SEASON*AMENDMENT	5	3.97	0.0017	4.00	0.0015	2.16	0.0585	2.00	0.0777	0.43	0.656	9.08	<0.0001
PHASE*AMENDMENT	2	32.99	<0.0001	32.96	<0.0001	24.10	<0.0001	6.53	0.0017	2.89	0.023	6.78	0.0005
SEASON*PHASE*AMENDMENT	10	1.72	0.0756	1.70	0.0787	1.75	0.0693	0.19	0.9968	1.76	0.134	2.98	<0.0001

SOC = Soil organic Carbon (%); OM = organic matter (%); AP = Available Phosphorus (Kg/ha); TP = total Phosphorus (Kg/ha); TMC = total microbial count (cfu/gm soil) ; PSM = Phosphate Solubilising microorganisms (cfu/gm soil).

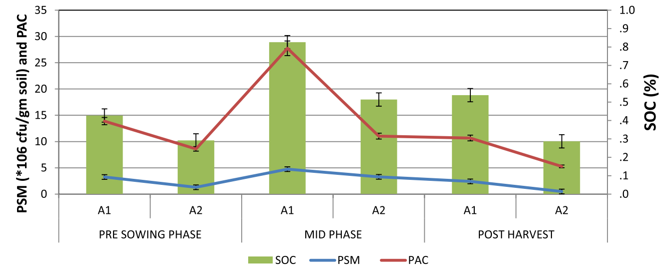

Fig. 2a. Soil organic Carbon (SOC), Phosphate solubilising microoorganisms (PSM) and Phosphorus activation coefficient (PAC) for season 1 in amendment A1 and A2.

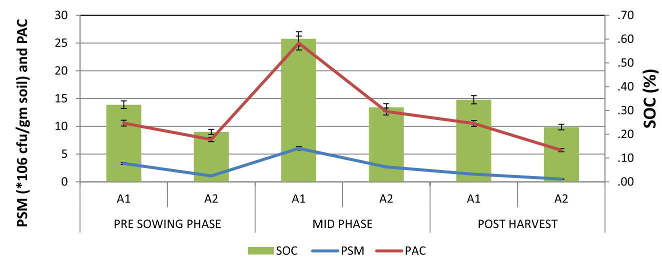

Fig. 2b. Soil organic Carbon (SOC), Phosphate solubilising microoorganisms (PSM) and Phosphorus activation coefficient (PAC) for season 2 in amendment A1 and A2.

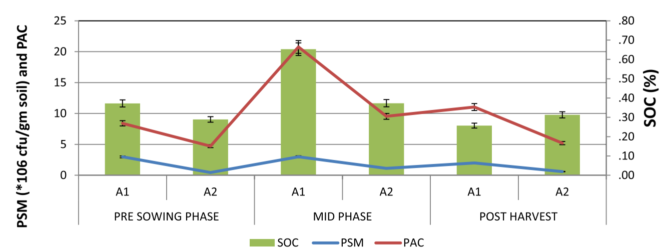

Fig. 2c. Soil organic Carbon (SOC), Phosphate solubilising microoorganisms (PSM) and Phosphorus activation coefficient (PAC) for season 3 in amendment A1 and A2.

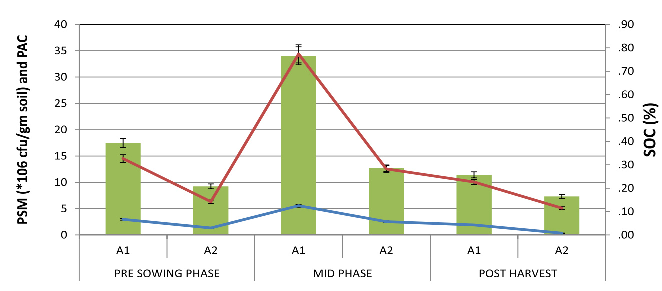

Fig. 2d. Soil organic Carbon (SOC), Phosphate solubilising microoorganisms (PSM) and Phosphorus activation coefficient (PAC) for season 4 in amendment A1 and A2.

organic manures are added as a second batch just before the beginning of the mid-phase of the crop, hence this coupling effects could account for higher SOC and OM during the mid-phase. Organic amendments had substantially higher SOC and OM as compared to chemical based farming systems. This was quite an obvious observation because higher inputs of the organic manures in A1 contributed to more of carbonaceous material which tends to increase SOC of the soil. Further, on analysing the interaction effects the phase 2 of amendment 1 (A1) had

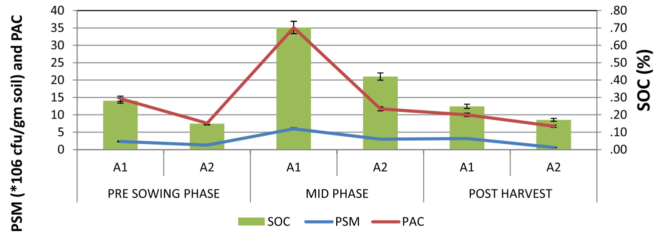

Fig. 2e. Soil organic Carbon (SOC), Phosphate solubilising microoorganisms (PSM) and Phosphorus activation coefficient (PAC) for season 5 in amendment A1 and A2.

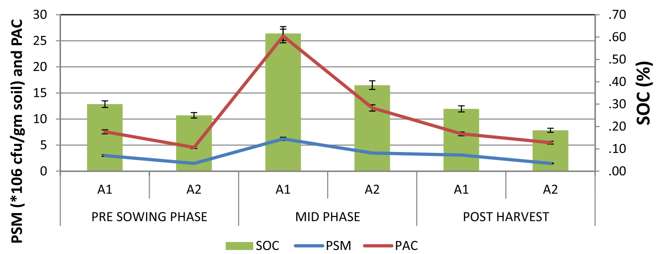

Fig. 2f. Soil organic Carbon (SOC), Phosphate solubilising microoorganisms (PSM) and Phosphorus activation coefficient (PAC) for season 6 in amendment A1 and A2.

highest SOC and it was significantly higher than phase 2 of amendment 2. The irrigation water during mid-phase of crop cycle is able to maintain soil moisture content to good levels which in turn helps in decaying process in both the agri-amendment practices but during the postharvest phase i.e. phase 3 the organic amendments are able to retain their moisture content in-spite of no crop cover to prevent soil moisture evaporation. This could be attributed to humic substances in organic soils.

It was evident that cropping seasons affected by drought Season 2 (Kharif, 2012) and season 3 (Rabi 2012–13) had higher SOC levels in A1 than A2. This indicates that the organic inputs are an important precursor in preparing drought resistant soils. The carbonaceous material in organic manures contributes to SOC after decomposition. Schjønning et al. (2007) have shown that different land management will influence SOM level after 5–6 years. This is in accordance with the finding that soil organic matter levels and soil microbial activities vital for nutrient turnover and long-term productivity of soil are enhanced by use of organic inputs (Goyal et al., 1999). The results of a similar study conducted to know the long term effect on continuous use of fertilizers and manures on fertility status of soil have revealed that organic matter of the soil was increased at a steady rate over years due to application of organic manures (Patiram and Singh, 1993). A study by Yu et al. (2017) has shown the impact of land use type on Soil Organic Carbon. Dash et al. (2019) have demonstrated various environmental constraints that are sensitive to management practices and in turn affect the SOC in soil.

Similarly, the additive effect of organic manures and concoctions like *Jivamrit S* in maintaining higher soil organic carbon levels in A1 as compared to A2 was quite perceptible. This higher SOC level serves as a catalyst for imparting any soil the microbial fertility as well as enhanced stability.

Phosphorus is the second major nutrient required for plant growth (Sharma et al., 2016). Major percentage of total soil Phosphorus is in a locked form and it is rendered available only when it is solubilised and mineralised to bio-available forms. The Kachchh eco-region has high total P deposits as depicted by our study. The results have shown that there was a significant effect of season, phase and amendment on the total P and available P levels. Seasonal variations in soil P fractions have been observed by other workers (Fabre et al. (1996) and McGrath et al. (2000). The results of phase statistics have confirmed that during mid-phase, available P was higher than post-harvest and pre-sowing phases and to reaffirm the fact, the total P values were lowest during mid-phase. This concludes that the solubilisation and mineralization of organic and inorganic fractions of total P occurs and it is rendered useful to crops in a bio-available form. Amendment A1 had significantly higher available P and lower total P than A2. This trend was followed in all six seasons. Mineralization and immobilization of phosphorus in soil with the addition of organic source have been reported by number of workers (Das and Dkhar, 2011). Incorporation of FYM alone or along with inorganic fertilizers was found to have a beneficial effect on available phosphorus status of soil (Singh et al., 1982). The reason for this was attributed to the enhanced solubilization of native phosphorus and added phosphorus by the decomposition products of organic manures. Farm Yard Manure (FYM) treated plots showed an increase in available phosphorus than inorganic fertilizers, which was due to coating of sesquioxides by organic materials that reduced phosphorus fixing capacity of soil (Bharadwaj and Omanwar, 1994). High total P in A2 and higher available P in organic amendments is in affirmation with works by De Oliveira Freitas et al. (2011). Similar studies in dry tropics were carried out by Singh et al., 2020 that demonstrate LUC (land use change) impact on soil biological properties, SOC and the nutrient pool including Phosphorus. He et al., (2001) reported that compost applications can increase plant available P in the soil. Furthermore, through long term experiments, Zhang et al., (2006) have shown an increase in available P concentration with compost and organic manure application.

5. Conclusions and future prospects

Phosphorus is a vital element in crop nutrition. Adverse environmental effects of chemical based P fertilizers, depleting resources of high grade Phosphatic rocks and their skyrocketing prices have compelled us to find a sustainable approach for efficient P availability in agriculture to meet the ever-increasing global demand of food. Soil microorganisms are involved in a range of processes that affect P transformation and thus influence subsequent availability of P (as phosphate) to plant roots. In particular, microorganisms can solubilize and mineralize P from inorganic and organic pools of total soil P. In our study a highly significant positive correlation was observed between the PSM count and the PAC values. However, PSM count and total P values were inversely proportional. This was as expected, as a higher PSM value is indicative of higher conversion of the non-available total P to an available form. Organic amendments, that were able to manage a higher PSM count, consequently had a higher availability of P in the soil. This again points to the central idea of maintaining a good organic matter in the soil to increase the available P pool of the soil.

The present study affirms that a soil system that is able to maintain a good organic matter contents, the chemical reactions are geared towards making the locked nutrients available for use by crops. This trend was observed in all the cropping seasons and phases. Organic amendments rich in SOC provide a congenial environment for nutrient availability in the soil. Similar positive correlation was seen between SOC and PSM /TMC and eventually PAC. So it is a chain of reactions which is explained by this analysis that a good SOC and OM in soil help in microbial build-up which convert non available forms to a bio-available forms. Our results are in affirmation with studies by Lal, 2007 and Murphy et al., 2007. Van-Camp et al. (2004) found that organic amendments influence soil characteristics by the interdependent modification of biological, chemical and physical properties. Also, fertility improvement through an effective management of these properties has the capability of optimizing crop production.

The present study proves to be a milestone in research related to agro-amendment based sustainable solutions for the agricultural activities of the semi-arid tropics. Kachchh eco-region faces various implications of environment in the form of drought, inconsistent rainfall, high salinity levels and these affect the soil and the agricultural activities in the area. The traditional ecological knowledge of farmers of the zone that incorporates organic inputs, if given a scientific beckoning can prove to be a real solution to deteriorating environmental conditions of agri-sector of similar areas or elsewhere, where scarcity of natural resources remains a big question. Organic based farming systems address the issue of nutrient availability at appropriate time along with rendering to the soil its true essence in the form of the rich microbial diversity which has been well advocated by the present study. The study came out with interesting results that could very well advocate the superiority of organic inputs to maintain a bio-culturally rich soil environment. The bioavailability of P coincided with higher TMC and PSM count. These added benefits of stress resilience along with providing environmental-friendly sustainable solutions to degraded soil systems that are drastically declining in their fertility parameters due to chemical inputs are an important criterion to understand phosphorus dynamics of any soil system in conjugation with the microbial communities.

CRediT authorship contribution statement

Seema B. Sharma: Conceptualization, Methodology, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing - review & editing. **Abhiroop Chowdhury:** Resources, Validation, Visualization, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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