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Mineralization of phosphorus as influenced by different organic and inorganic sources of phosphorus in calcareous soil

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Abstract
A laboratory incubation experiment was carried out at Division of Soil Science and Agricultural Chemistry, RCSM College of agriculture, Kolhapur under MPKV, Rahuri, during 2021-22 The study for 90 days was initiated to evaluate the effect of different organic manure alone and in combination with inorganic fertilizer of phosphorus on release pattern of phosphorus in calcareous soils at field capacity of soil moisture. The experiment was laid out in a Factorial Completely Randomized Design (FCRD) with three replication and fifteen treatments. The treatment comprised of Control, FYM, VC, POL, PMC, SSP, DAP, SSP+ FYM, SSP +VC, SSP + POL, SSP + PMC, DAP+ FYM, DAP+VC, DAP+ POL, DAP+ PMC. The results revealed that the phosphorus release rate was slow in the beginning, followed by a sharp increase, reaching a peak rate at 45 days of incubation, followed by a gradual decline thereafter in all the organic sources however press mud compost and poultry manure were found to be continuous source of phosphorus during the incubation period. Application of diammonium phosphate as inorganic source of phosphorus was more prominent as compared to SSP in calcareous soils. Diammonium phosphate could be better option in calcareous soil to elevate phosphorus requirement as compared to SSP. The combination of inorganic and organic sources was found to be more pronounced as compared to only organic or inorganic treatment in supplementing phosphorus in calcareous soil. Use of DAP along with organic sources should be advocated over SSP in combination with organic sources. Application of DAP along with press mud compost or poultry manure could be more reliable combination to ensure maximum availability of phosphorus in calcareous soil.

Keywords: Mineralization, phosphorus, organic manures, inorganic fertilizers, calcareous soil

Introduction
The availability of P in calcareous soils as P from manure changes in soil phosphorus availability with poultry compost. The application of poultry manure @ 5 t ha^{-1} had distinct effect on N, P, and K content in soil, followed by application of press mud compost @ 5 t ha^{-1} which had a significant effect on soil properties under 60 days incubation study (Thite *et al.* 2021) [19]. The application of poultry manure compost or organic fertilizer increased the available phosphorus (P) and organic matter content in all soils; however, the quantity of P and organic matter decreased with an increase in incubation time. The organic materials added via the treatments reduced the strength of P adsorption by the soil derived from basalt. For soils derived from granite and river alluvial deposits, the strength of P adsorption declined after poultry manure compost was added, but increased after the application of organic fertilizer. The maximum phosphate buffering capacity (MPBC) and standard P retention (SPR) of soil derived from basalt decreased following the application of poultry manure or organic fertilizer, whereas changes in MPBC and SPR for soils derived from granite and alluvial deposits were dependent on the organic content and incubation time (Yu *et al*. 2013) [21]. The vermicompost, neem cake, and composted coir pith, poultry manure, goat dung, and press mud released N, P, K, Ca, Mg, and S continuously and steadily all through the incubation period up to 90 DAI (Kiruthika *et al.* 2022) [6].

Materials and Methods
Soil: The bulk soil samples were collected having depth 0-30 cm belongs to calcareous soil

from Block No. 47 of Horticulture Farm, Division of Horticulture, Rajarshee Chhatrapati Shahu Maharaj, College of Agriculture, Kolhapur (M.S.). The soil samples were collected, air dried, grounded with wooden mortar and pestle to passed through 2.0 mm sieve. The initial soil chemical properties were analysed by adopting standard methods of soil analysis.

Organic manures

The organic sources FYM, poultry manure and vermicompost were collected from Dairy Farm, Division of Dairy Science and Agronomy Farm, Division of Agronomy of Rajarshee Chhatrapati Shahu Maharaj, College of Agriculture, Kolhapur. While press mud compost was collected from Shree Datta Shetkari Sahakari Sugar factory, Shirol, Tal. Hatkanagale, Kolhapur District (M.S.). The characteristics of organic manure is given in table 1.

Soil analysis

The collected soil samples were analysed for initial physio-chemical properties by adopting standard analytical methods. Standard methods were used for chemical analysis pH (1:2.5) Potentiometry by Jackson (1973) [5], EC (1:2.5) Conductometry by Jackson (1973) [5], Organic carbon by Wet oxidation method Nelson and Sommer (1982) [10], $CaCO_3$ Acid neutralization by Piper (1966) [24], Available Nitrogen Alkaline Permanganate by Subbiah and Asija (1956) [17], Available Phosphorous 0.5M $NaHCO_3$ (pH 8.5) by Olsen *et al*. (1954) [11], Available Potassium N- NH_4OAc extractant (Flame photometry) by Hanway and Heidal (1952) [23], DTPA extractable Micronutrient (Fe, Mn, Zn, Cu) Atomic absorption Spectrophotometry by Lindsay and Norvell 1978.

Incubation Study

The air dried 2 mm sieve soil (1 kg) was taken in 45 plastic containers. The requisite quantity of organic manures and chemical fertilizer were applied as per the above treatments in incubation study. The soil samples were collected at 15 days interval up to 90 days *i.e.* O, 15, 30, 45, 60, 75, 90 days after incubation by adopting discard method and analysed for phosphorus estimation. Experiment was started on 13th July 2022 and prior to incubation the initial chemical soil properties were analysed. The phosphorus was estimated after each interval of incubation period *i.e.*, O DAI, 15 DAI, 30 DAI, 45 DAI, 60 DAI, 75 DAI and 90 DAI. After completion of incubation the soil samples were analysed for other chemical properties *viz;* pH, EC, organic carbon, $CaCO_3$, available (N, P and K) and DTPA extractable micronutrients (Fe, Zn, Mn and Cu). There are 45 pots for three replications and each replication required 15 pots for incubation study.

Table 1: Characteristics of organic manure

Sr. No.	Parameter	FYM	Vermicompost	Poultry manure	Press mud compost
1.	pH (1:10)	6.2	7.1	6.7	6.8
2.	EC (dS m^{-1})	2.14	2.18	1.78	1.76
3.	OC (%)	20.88	24.36	17.21	16.24
4.	N (%)	0.84	1.75	2.20	1.30
5.	P (%)	0.21	1.10	0.95	0.55
6.	K (%)	0.44	1.05	1.20	0.50
7.	Fe (mg kg^{-1})	1000	2564	2800	3090
8.	Zn (mg kg^{-1})	100	180	140	130
9.	Mn (mg kg^{-1})	8620	7250	7200	6910
10.	Cu (mg kg^{-1})	1840	2050	2341	1650
11.	C:N ratio	24.85	13.92	7.82	12.49

Statistical Analysis

The results were statistically analysed and appropriately interpreted as per the method given by Panse and Sukhatme (1985) [25].

Results and Discussion

Phosphorus Release at 0 Days After Incubation

The data pertaining to release phosphorus at 0 day after incubation (DAI) is depicted through fig. 1. The results indicated that among two chemical sources of phosphorus fertilizers, DAP recorded significantly superior release (24.27 mg kg^{-1}) over SSP (23.01 mg kg^{-1}) at 0 DAI. The release of phosphorus was affected significantly due to application of different organic manures. Amongst the treatments of different organic manures, VC exhibited significantly superior phosphorus release (21.51 mg kg^{-1}) over control 0 DAI. However, it was at par with FYM (21.15 mg kg^{-1}) POL (21.0 mg kg^{-1}) and PMC (21.05 mg kg^{-1}) at 0 DAI. The P release at Day was not significantly influenced by combination treatments however, treatment of DAP+VC recorded highest P release (24.76 mg kg^{-1}) as compared to other treatments. The treatment of DAP+FYM recorded second highest P release (24.70 mg kg^{-1}) at 0 DAI. However, the lowest amount of phosphorus release was observed in treatment *i.e.*, SSP+POL (22.51 mg kg^{-1}). The results indicated that the combine effect of inorganic and organic sources of phosphorus was more prominent in context of phosphorus release. These findings align closely with previous studies by Abbasi *et al*. (2015) [1], Naima *et al*. (2015) [9] and Bihari *et al.* (2018) [4].

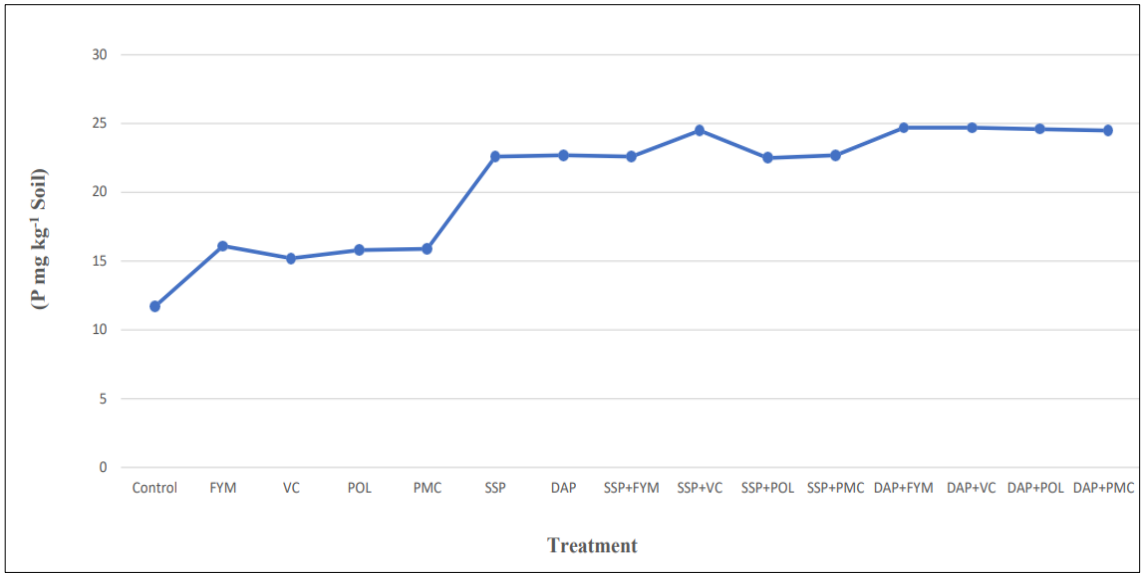

Fig 1: Cumulative release of phosphorus at 0 DAI

Phosphorus Release at 15 Days After Incubation

The phosphorus release at 15 days after incubation (DAI) is presented in depicted through fig. 2. The results indicated that among two chemical sources of phosphorus fertilizers, soil treated with DAP recorded significantly superior release (28.85 mg kg^{-1}) over SSP (26.74 mg kg^{-1}) at 15 DAI. The release of phosphorus was affected significantly due to application of different organic manures. Amongst the treatments of different organic manures, VC exhibited significantly superior phosphorus release (24.97 mg kg^{-1}) over control (21.10 mg kg^{-1}) at 15 DAI. Nevertheless, it was at par other organic manure treatments at 15 DAI. The treatments consisting conjunct use of inorganic and organic sources of phosphorus were found to be non-significant at 15 DAI. However, the combination treatment of DAP+VC was recorded highest P release (29.75 mg kg^{-1}) compared to other combination treatments. The treatment of DAP+FYM recorded second highest release (29.54 mg kg^{-1}) at 15 DAI. However, the lowest amount of phosphorus release was observed in treatment i.e SSP+PMC (26.25 mg kg^{-1}). It was noticed that the organic sources coupled with DAP as inorganic source of phosphorus recorded higher P release as compared to combine treatment of organic manure and SSP at 15 DAI. The findings are in corroboration with the findings of Asif *et al*. (2013) [3], Abbasi *et al*. (2015) [1] and Mali *et al*. (2017) [8].

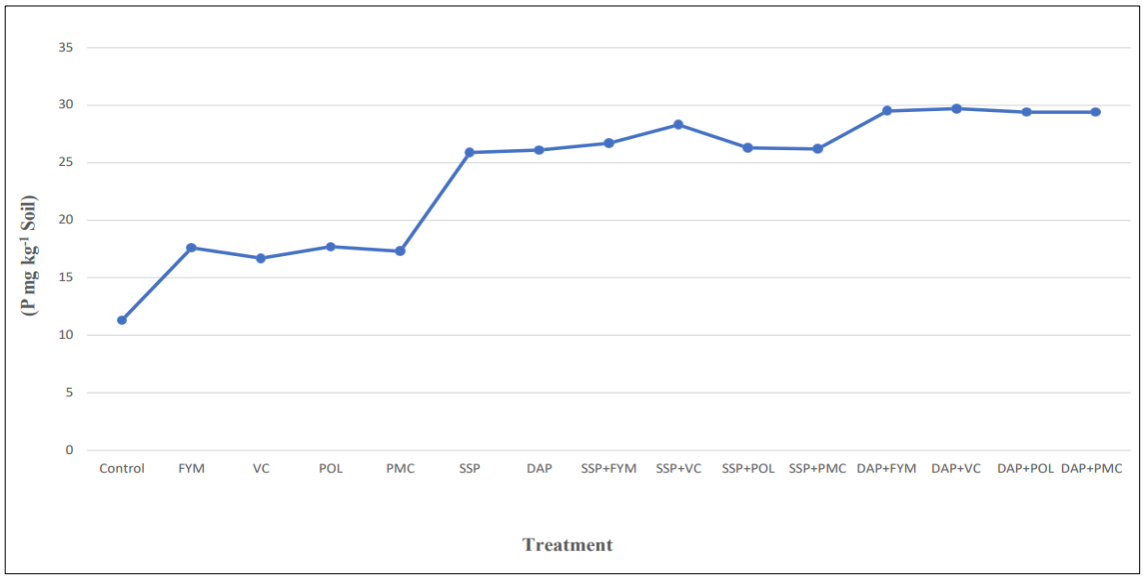

Fig 2: Cumulative release of phosphorus at 15 DAI

Phosphorus Release at 30 Days After Incubation

The data related to release phosphorus at 30 days after incubation (DAI) is depicted through fig. 3. The results indicated that among two chemical sources of phosphorus fertilizers, DAP continued to record significantly superior release (40.55 mg kg^{-1}) over SSP (35.17 mg kg^{-1}) at 30 DAI. The release of phosphorus was affected significantly due to application of different organic manures. Amongst the treatments of different organic manures, POL recorded significantly superior phosphorus release (33.97 mg kg^{-1}) over control (25.47 mg kg^{-1}) and FYM (31.20 mg kg^{-1}) and was at par with VC (33.77 mg kg^{-1}), and PMC (33.67 mg kg^{-1}) at 30 DAI. The release of phosphorus was also found to be significantly influenced by conjunct use of inorganic and organic source of phosphorus. The combination treatment of DAP+VC was found to be significantly superior in releasing

phosphorus (42.16 mg kg^{-1}) over most of the combination treatments however it was at par with soil treated with DAP+FYM (41.84 mg kg^{-1}), DAP+POL (40.99 mg kg^{-1}), DAP+PMC (40.68 mg kg^{-1}), SSP + PMC (39.38 mg kg^{-1}), SSP+POL (38.45 mg kg^{-1}) at 30 DAI. The results indicated that organic manure in combination of inorganic P fertilizer exhibited significant effect on P release as compared to only inorganic or organic treatments. The effect of organic acid along with inorganic P source is documented by Roy *et al.* (2014) [15]. The pronounced effect of DAP as an inorganic fertilizer as compared to SSP in calcareous soil is also reported by Asif *et al.* (2013) [3]. The results are also in close agreement with that of Asif *et al.* (2013) [3], Abbasi *et al.* (2015) [1], Mali *et al.* (2017) [8] and Vanitha *et al.* (2020) [20].

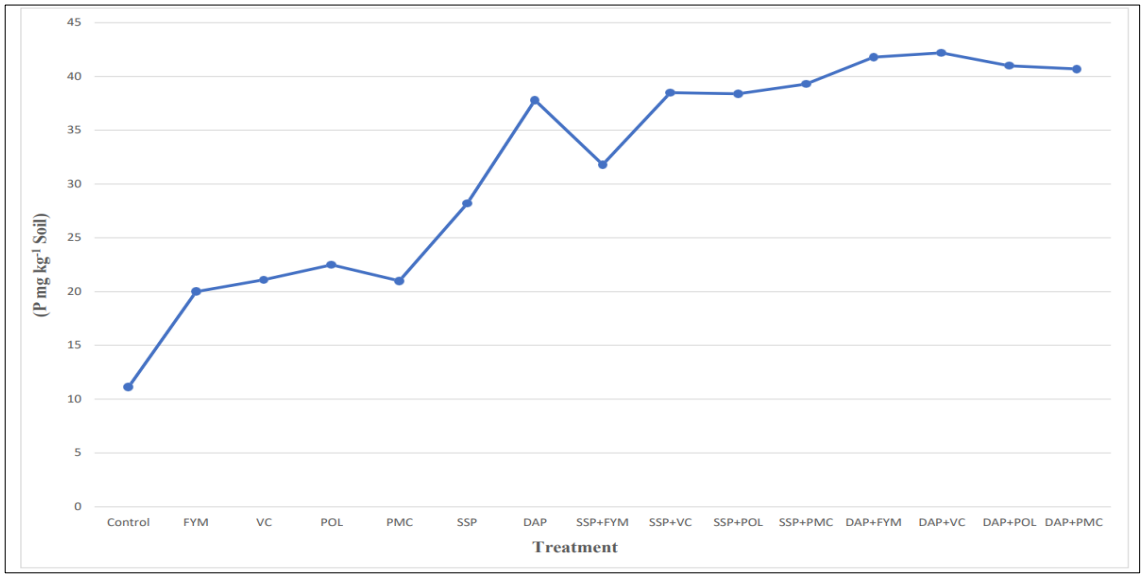

Fig 3: Cumulative release of phosphorus at 30 DAI

Phosphorus Release at 45 Days After Incubation

The data pertaining to release phosphorus at 45 DAI is illustrated in fig. 4. The perusal of the data indicated that sole DAP as inorganic P source recorded significantly superior P release (50.83 mg kg^{-1}) over sole SSP (39.35 mg kg^{-1}) at 45 DAI. The P release was affected significantly due to application of different organic manures. Amongst the treatments of different organic manures, poultry manure exhibited significantly superior phosphorus release (42.37 mg kg^{-1}) over the rest organic amendments however, it was at par with PMC (41.38 mg kg^{-1}) at 45 DAI. The lowest phosphorus release was observed by FYM (34.60 mg kg^{-1}) at 45 DAI. The release of phosphorus was also found significantly influenced by conjunct use of inorganic and organic sources of phosphorus. The combination treatment of DAP+POL was found to be significantly superior in releasing phosphorus (59.38 mg kg^{-1}) among all other combination treatments. The treatment of DAP+VC recorded second best P release (51.54 mg kg^{-1}) at 45 DAI. However, the lowest amount of phosphorus release was observed in treatment *i.e.* SSP+FYM (34.11 mg kg^{-1}). Higher value of P due to effect of organic acid on RP at 45 DAI was also reported by Naima *et al.* (2015) [9], Roy *et al.* (2014) [15] also reported high P release after 45 DAI due to incorporation of MAP as compared to SSP in calcareous soil.

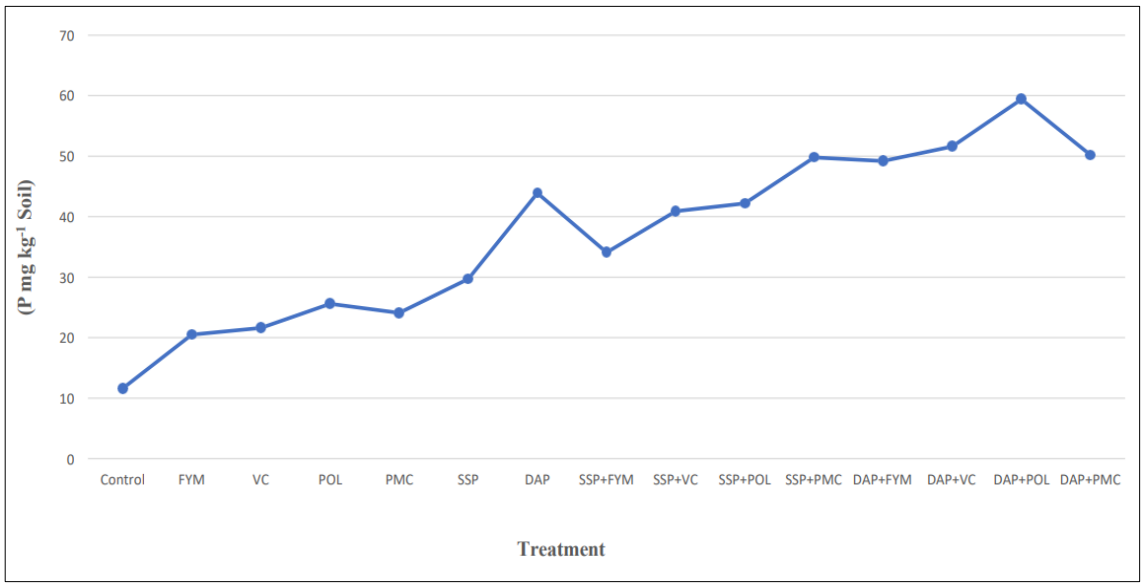

Fig 4: Cumulative release of phosphorus at 45 DAI

Phosphorus Release at 60 Days After Incubation

The data pertaining to release phosphorus at 60 days after incubation (DAI) is represented in fig. 5. The results showed that P release in treatment having sole DAP continued recording significantly superior release (54.40 mg kg^{-1}) over SSP (34.94 mg kg^{-1}) at 60 DAI. The positive effect of only organic manure treatment in terms of P release was observed even at 60 DAI. Within the different only organic manures treatments, poultry manure exhibited significantly superior phosphorus release (43.61 mg kg^{-1}) over FYM (31.78 mg kg^{-1}), VC (38.97 mg kg^{-1}) and control (25.04 mg kg^{-1}) however it was at par with PMC (43.19 mg kg^{-1}). The lowest P release among the organic manures was recorded by FYM (31.78 mg kg^{-1}) at 60 DAI. The release of phosphorus was also found significant influenced by conjunct use of inorganic and organic sources of phosphorus. The combination treatment of DAP+POL was found to be significantly superior in releasing phosphorus (62.74 mg kg^{-1}) among all other combination treatments. However, the treatment of DAP+PMC recorded at par and second highest P release (58.28 mg kg^{-1}) at 60 DAI. The lowest amount of phosphorus release was observed in treatment i.e. SSP+FYM (24.12 mg kg^{-1}). The results are in close agreement with that of Pal *et al.* (2018) [12], Thite *et al.* (2021) [19] reported that the P release increased due to combine application of organic and inorganic as compared to only inorganic during latter hours of incubation.

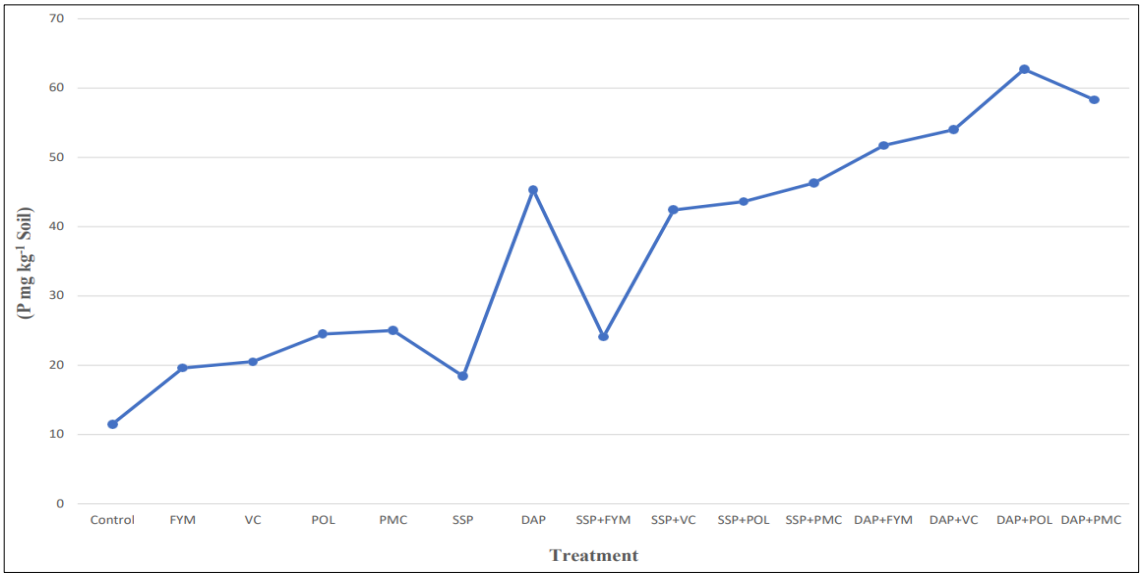

Fig 5: Cumulative release of phosphorus at 60 DAI

Phosphorus Release at 75 Days After Incubation

The data regarding phosphorus release at 75 days after incubation (DAI) is represented in fig. 6. Taking into account P release at previous days of incubation, release of P at 75 DAI was observed to be subsiding. Yet, the phosphorus release at 75 DAI was found to be showing significant difference between the treatments of sole organic, inorganic and combination treatments. Within inorganic sources of phosphorus, DAP exhibited a significantly higher release (59.34 mg kg^{-1}) compared to SSP (32.64 mg kg^{-1}) at 75 DAI. At 75 DAI, among the only organic treatments, PMC emerged as the most effective, demonstrating a superior phosphorus release (45.34 mg kg^{-1}) compared to other organic amendments however, it was at par to POL (42.55 mg kg^{-1}). FYM exhibited the lowest release (29.21 mg kg^{-1}) at 75 DAI. Additionally, the combined use of inorganic and organic phosphorus sources had a significant impact on phosphorus release. The treatment having combination of DAP and PMC showed the highest phosphorus release (68.54 mg kg^{-1}) over all the combination treatments. The DAP+POL treatment recorded at par and the second-highest P release (65.97 mg kg^{-1}) at 75 DAI. The lowest among the combination treatment of inorganic and organic was observed in SSP+FYM (15.68 mg kg^{-1}). The results are also in conformity with the results of Abbasi *et al.* (2015) [1], Naima *et al.* (2015) [9] and Thite *et al.* (2021) [19].

Phosphorus Release at 90 Days After Incubation

At 90 DAI, the findings implied that phosphorus release further revealed a decline over the earlier days of incubation (fig. 7). The data though exhibited significant variation among the treatments. The inorganic source of phosphorus especially, DAP recorded significantly superior release (60.28 mg kg^{-1}) over SSP (32.42 mg kg^{-1}) at 90 DAI. Amongst the treatments of different organic manure, PMC exhibited significantly superior phosphorus release (44.10 mg kg^{-1}) over the rest of other organic amendments at 90 DAI. The second-best P release was observed in POL (41.79 mg kg^{-1}) however, the lowest phosphorus release was observed by FYM (28.02 mg kg) at 90 DAI. Among the combination treatments of organic and inorganic P sources, DAP+PMC compost was found to be significantly superior in releasing phosphorus (68.70 mg kg^{-1}) over all other combinations treatments and at par with DAP+POL (67.60 mg kg^{-1}) at 90 DAI. However, the lowest amount of phosphorus release was observed in treatment i.e. SSP+FYM (14.44 mg kg^{-1}). Similar results are also reported by Naima *et al.* (2015) [9] and Thite *et al.* (2021) [19].

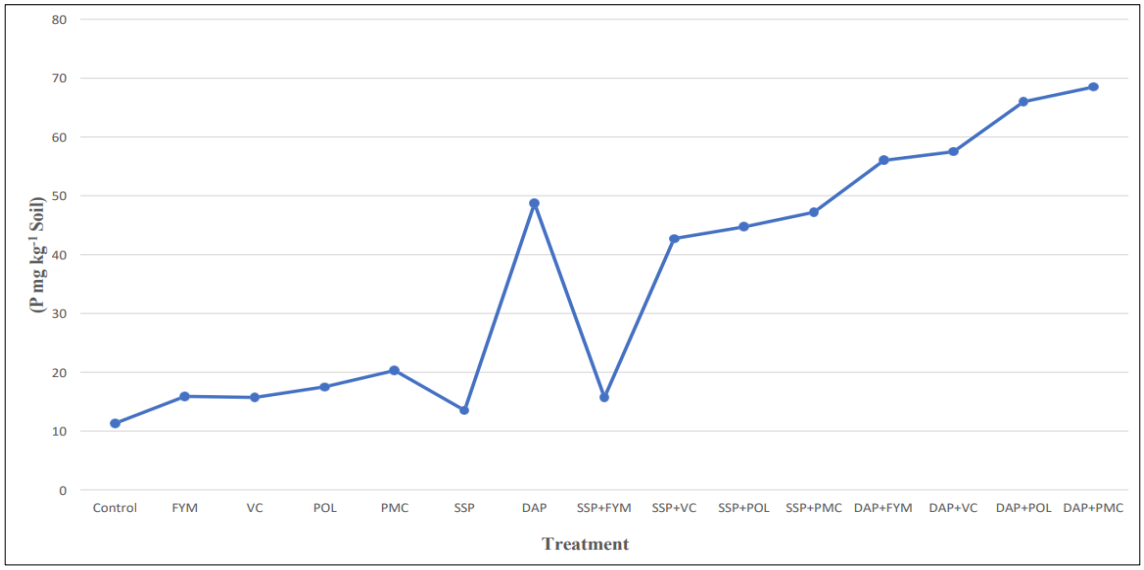

Fig 6: Cumulative release of phosphorus at 75 DAI

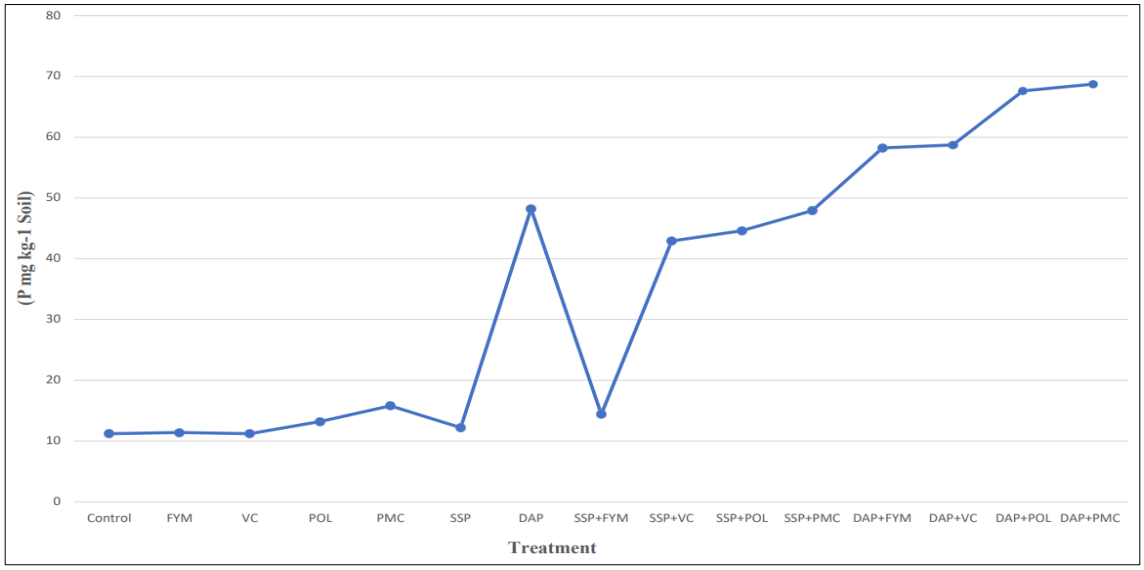

Fig 7: Cumulative release of phosphorus at 90 DAI

Periodical Release of Available Phosphorus during Incubation Period

The periodical release of available phosphorus during complete incubation period presented in table 2. The data indicated that the treatment consisting only organic, only inorganic and combining of organic and inorganic all exhibited change in phosphorus release with the time of incubation. The findings implied that there was gradual increase in rate of P release with time in all the treatments except the control. Notably, phosphorus release increased from 0 DAI onwards due to application of either organic/inorganic or combination of both. Considering, only organic treatment, P release in calcareous soil was observed to be impacted by nature of organic manure perhaps, the total P content and rate of mineralization of organic manure. The available P release was highest during 45 DAI however, after 60 DAI there was a declining trend observed up to 90 DAI in all the treatment having only organic amendments except PMC. Nevertheless, the P availability was highest in treatment consisting poultry manure (25.60 mg kg^{-1}) as compared to other organic sources at 45 DAI. The treatment consisting PMC alone emerged as second-best organic source in terms of P availability (24.10 mg kg^{-1}) at 45 DAI. Unlike other organic sources, maximum P release in treatment having PMC was noticed at 60 DAI (25.0 mg kg^{-1}). The mean phosphorus availability during 0 to 90 DAI was found to highest in PMC (19.9 mg kg^{-1}) which was closely followed by poultry manure (19.5 mg kg^{-1}) while lowest mean P release was recorded by only FYM treatment (17.3 mg kg^{-1}). The available phosphorus among only organic treatments followed the sequence as PMC> POL> VC>FYM.

The two inorganic sources of phosphatic fertilizer, *viz*., SSP and DAP exhibited noticeable difference in their potential to enhance P availability in calcareous soil. The significantly highest available P was recorded in treatment with only DAP to the tune of (48.7 mg kg^{-1}) at 75 DAI while, the only SSP treatment recorded highest available P (29.7 mg kg^{-1}) at 45 DAI. The availability of P was found to be decreasing with increasing time of incubation in both inorganic P fertilizer treatments nonetheless, the values of available phosphorus during the latter days of incubation was higher in sole DAP compared to sole SSP treatments. The mean available phosphorus was highest in sole DAP (39.0 mg kg^{-1}) compared to SSP (21.5 mg kg^{-1}).

The combination treatments of SSP+ organic manures and DAP+ organic manures differed similarly to that of other treatments. In context of SSP along with organic amendment treatments, SSP + PMC recorded highest P release (49.8 mg kg^{-1}) at 45 DAI as compared to other organic amendment in calcareous soil. However, SSP+POL proved to be second-best combination treatment by registering (42.2 mg kg^{-1}) available P at 45 DAI. The treatment SSP + VC recorded (40.94 mg kg^{-1}) available P and lowest was observed in treatment SSP+FYM (34.1 mg kg^{-1}) at 45 DAI. At 60 DAI, among the combination treatment of SSP and organic manures, SSP+PMC registered a slight decline as compared to earlier day of incubation however, other combination treatments revealed slight increase. The reason behind such abnormal trend is unknown. Despite, this decline SSP+PMC was found to highest in terms of P content (46.3 mg kg^{-1}) compared to other combinations at 60 DAI. After 75 and 90 DAI, the phosphorus availability was found to be marginally increasing in combination treatment of SSP and organic manures except SSP+FYM wherein a decline in available P was observed. In terms of mean P release, SSP+PMC recorded highest mean available P (39.9 mg kg^{-1}) followed by SSP+POL (37.5 mg kg^{-1}) while, the lowest value of mean available P was recorded by treatment SSP+ FYM (24.2 mg kg^{-1}). The combination treatment of DAP surpassed combined treatment of SSP in terms of P release during the period of incubation. The highest P release at 45 DAI was observed in treatment DAP+POL (59.4 mg kg^{-1}), which was followed by DAP+VC (51.6 mg kg^{-1}). The pattern of P release in case of DAP+PMC treatment was contrast to other treatments. The highest P release in DAP+PMC treatment was recorded to the tune of (68.5 mg kg^{-1}) and (68.7 mg kg^{-1}) at 75 DAI and 90 DAI respectively as compared to other combination treatment of organic manure with DAP. The mean available P release was highest in DAP+POL (50.1 mg kg^{-1}) followed by DAP+PMC (48.6 mg kg^{-1}) while, the lowest mean available P was recorded in DAP+FYM treatment (44.4 mg kg^{-1}).

The higher available P in sole PMC and POL treatments for the complete incubation period could be attributed to higher mineralization rate in composed press mud and POL as compared to other organic amendments. Moreover, comparatively higher total P content in PMC and POL could have resulted in higher availability of phosphorus. The decline in P release after 45 days in organic treatment could be due to meagre P supply power of organic sources and fixation of P as tricalcium phosphate during later days of incubation. The results are aligned with the results of Thite *et al.* (2021) [19] who reported highest P release in POL treatment as compared to VC and FYM at 45 DAI and a decline in P availability thereafter in all organic treatments. Tamboli *et al.* (2016) [18] reported that 50% recommended dose of phosphorus through inorganic fertilizer and rest through PMC significantly increased soil available phosphorus. Bihari *et al.* (2018) [4] demonstrated declining P availability due to organic inputs after 30 DAI. Lower nutrient content in organic manures as compared to inorganic fertilizer is also advocated by Roba (2018). The increase P mineralization at initial stage due to addition of poultry manure as a result of higher mineralization rate and lower C:N ratio and high P content was also reported by Pal *et al.* (2018) [12]. The findings suggested that inorganic P fertilizer revealed higher concentration of P during incubation period as compared to organic sources. This might be due to higher mineralization rate and higher P content of inorganic fertilizer than organic. The results are in corroboration with that of Bihari *et al.* (2018) [4], Thite *et al.* (2021) [19] and Ahmad *et al.* (2022) [2]. Moreover, among the inorganic sources DAP as a P source was found to be efficient than SSP in calcareous soil. This warrant further investigation because there are some contradictory studies that show SSP to be more beneficial in calcareous soil while other exhibited DAP to be superior. Higher P concentration in DAP treatments could be attributed to generation of more acidity and lesser pH thereby reducing the adsorption of P as compared to SSP in calcareous soil. Similar results are also reported by Naima *et al.* (2015) [9]. Mali *et al.* (2017) [8] reported higher yield and uptake due to application of 75% P_2O_5 through DAP as compared to SSP and vermiculture.

The conjunct use of organic and inorganic P sources revealed higher P concentration than sole organic or inorganic sources. In case of combination treatment with single super phosphate, SSP+PMC recorded highest P release as compared to other treatments which was almost similar to SSP+POL. Similarly, in treatment consisting of DAP in conjunction with organic manures, DAP+PMC surpassed other treatments in terms of P release which was closely followed by DAP + POL. Among these two integrated approaches of inorganic P fertilizers and organic manure, DAP in combination of organic manure was found to be more pronounced compared to SSP and organic sources in calcareous soil. Overall, it was found that the both inorganic sources *viz*., SSP and DAP in combination with organic manures exhibited higher P release as compared to only organic and only inorganic treatments.

The peak of P release in only organic treatment was observed at 45 DAI and thereafter a decline was observed in all the treatments receiving only organic manures. While, among the inorganic sources of phosphorus SSP showed highest available at 45 DAI and subsequently decrease in latter stages however unlike SSP, DAP revealed an increasing tread with time. The combination treatments of SSP and organic manures such as SSP+VC, SSP+POL and SSP+ PMC exhibited increase in available P content with time however, SSP+FYM revealed a decline after 45 DAI. In case of combination treatment of DAP and organic manure the peak in P availability was observed at 45 DAI which was found to gradually increasing up to 90 DAI in all the combination treatments. Considering, the mean P release the treatment of DAP+PMC was found to slightly behind DAP+POL in terms of P release.

Though the difference is not much, it could be attributed to the varied mineralization rate of organic manure. The conjoint use of DAP+POL emerging as the best combination treatment in calcareous soil can be attributed to improvement in soil properties and enhanced microbial activity in this treatment. The other reason could be development of high acidity due to decomposition of organic manures. Abbasi *et al.* (2015) [1] demonstrated that application of both SSP and DAP in combination with POL and P solubilizer increased phosphorus mineralization in calcareous soil. They further stated that the P mineralization rate was higher at 45 DAI and subsequently decrease afterwards. The findings are in close agreement with that of Asif *et al.* (2013) [3], Mali *et al.* (2017) [8] and Song *et al.* (2017) [16].

Table 2: Periodical release of available phosphorus during incubation period (mg kg^{1})

	0 DAI	15 DAI	30 DAI	45 DAI	60 DAI	75 DAI	90 DAI	Mean
Control	11.7	11.3	11.1	11.6	11.5	11.3	11.2	11.4
FYM	16.1	17.6	20.0	20.5	19.6	15.9	11.4	17.3
VC	15.2	16.7	21.1	21.6	20.5	15.7	11.2	17.4
POL	15.8	17.7	22.5	25.6	24.5	17.5	13.2	19.5
PMC	15.9	17.3	21.0	24.1	25.0	20.3	15.8	19.9
SSP	22.6	25.9	28.2	29.7	18.4	13.5	12.2	21.5
DAP	22.7	26.1	37.8	43.9	45.3	48.7	48.2	39.0
SSP+ FYM	22.6	26.7	31.8	34.1	24.1	15.7	14.4	24.2
SSP +VC	24.5	28.3	38.5	40.9	42.4	42.7	42.9	37.2
SSP + POL	22.5	26.3	38.4	42.2	43.6	44.7	44.6	37.5
SSP + PMC	22.7	26.2	39.3	49.8	46.3	47.2	47.9	39.9
DAP+ FYM	24.7	29.5	41.8	49.2	51.7	56.0	58.2	44.4
DAP+VC	24.7	29.7	42.2	51.6	54.0	57.5	58.7	45.5
DAP+ POL	24.6	29.4	41.0	59.4	62.7	66.0	67.6	50.1
DAP+ PMC	24.5	29.4	40.7	50.2	58.3	68.5	68.7	48.6

Conclusion

The application of phosphorus through diammonium phosphate (DAP) proved to be the most effective source for achieving higher phosphorus release compared to single super phosphate (SSP). Among the organic sources, POL and PMC both outperformed vermicompost (VC), and farmyard manure (FYM) in phosphorus release. Utilizing, DAP or SSP in combination with POL or PMC not only enhanced phosphorus availability but also contributed to the overall improvement in the fertility status of calcareous soil.

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