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Research Paper

Evaluation of the potentiality of diverse weed species in mobilising soil bioavailable phosphorus

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ABSTRACT

The present study was carried out to assess the inorganic phosphorus (P)-dynamics under the rhizosphere of 10 weed species belonging to 8 different families. A fractionation study revealed that sol-P and Ca_2-P were highest in *M. denticulata* L. and *C. rotundus* L. with 67.25 mg kg^{-1} and 48.37 mg kg^{-1}, respectively ($p<0.05$) which could be attributed to high alkaline phosphatase activity in the rhizosphere. Out of the selected weed species, labile-P: non-labile-P content was highest in *M. denticulata* L. (0.42) which is 38% higher than *C. arvensis* L. In terms of biomass and leaf P (%) *C. didymus* (L.) Sm. recoreded highest but, interestingly *M. denticulata* L. though had a higher sol-P but failed to translocate P-to the above and below-ground parts. Hence, *M. denticulata* L. being legume was an excellent mobilizer of non-labile P and can improve the available P for the subsequent crop.

Key words: Alkaline phosphatase, Biomass, Phosphorus fractions, Shoot Phosphorus concentration, Weed species

INTRODUCTION

Phosphorus (P) is the second most essential element for crop nutrition and with increasing food production the requirement for P-fertiliser also escalated remarkably over time (Dutta and Trivedi 2022). Soils contain around 200-2000 kg ha^{-1} of the total–P of which 54-84% is in inorganic form but, technologies or management practices which can utilize this enormous source are modest. Despite significant scientific endeavors it is hard to achieve P-use efficiency (PUE) beyond 20% (Dutta and Trivedi 2022). Nonetheless, sustained efforts must be directed to achieve the same using native vegetation. Weeds can be defined as undesired plants in agricultural fields or in common human habitat areas and are the arch-rival of grain legumes particularly in the initial days (Hedayetullah and Kumar 2023, Reddy *et al.* 2018). Weeds are pioneers in diversifying agriculture ecosystems using assorted environmental capabilities which entitle them to utilize native or applied natural resources and compete with the standing crops (Little *et al.* 2021). Contrary to modern-day cultivars, weeds are excellent utilisers of native soil-P through modifying root growth towards P-rich patches, formation of lateral roots, mycorrhizal association, better allocation of nutrients specifically under deficiency and rhizospheric acidification especially in calcareous soils (Fransson *et al.* 2003). Apart from the innate physiological capabilities of the weeds, crop management practices like irrigation, fertilizer management, sowing methods, and previous crop history also play crucial roles in P-allocation to weeds (Reddy *et al.* 2018). Also, reports are there highlighting the solubilization and further mobilization of P by weeds which may be available for the subsequent crops in the system (Santos *et al.* 2013). As previously mentioned weeds can mobilize the non-available nutrients mostly P, but information about the distribution or the temporal dynamics of different inorganic P-fractions (labile and non-labile) in the rhizosphere of diverse weed species is few and far between. Therefore, an endeavor has been made to assess the mobilization potential via investigating the dynamics of P-fractions with associated P-cycling enzyme namely alkaline phosphatase in the rhizosphere of ten different weed species belonging to eight different families in an alkaline Inceptisol of Indo-Gangetic plain of India (IGP). This information will likely help us to understand the P-mobilisation potential of different weed species to subsequent crops.

MATERIALS AND METHODS

Site characteristics, basic soil properties and details of weed species

The weed samples were collected from weedy check plots of a well-established field experiment (started in: 2018) on weed management in the D-2 block of the new research campus of ICAR-Indian Institute of Pulses Research, Kanpur in the *Rabi* season of 2021-22. The study site is located in a sub-tropical climate with a mean annual rainfall of 799 mm. The experimental field was well–drained having sandy–loam soil texture with pH 8.16–8.28, electrical conductivity 0.28–0.32 dS m^{-1} (non–saline), low in available N (228–242 kg ha^{-1}), medium in available P (15–18 kg ha^{-1}), available potassium (K) (178–191 kg ha^{-1}) and available sulfur (S) (11.4–13.8 kg ha^{-1}). A detailed list of all ten (10) weed species is presented in Table 1. For, every weed species five plant samples were collected and the rhizosphere soil from each plant was collected using a scalpel.

Analysis of soil-P fractions and alkaline phosphatase

The collected soil samples from the individual weed species were mixed and prepared composite samples to avoid any bias. Samples were air-dried and passed through a 2 mm sieve for analysis of different P-fractions using the procedure by Kuo (1996). The P fractions are divided into seven parts *viz*. soluble-P (Sol-P), di-calcium P (Ca_2-P), octa-calcium P (Ca_8-P), aluminum P (Al-P), iron P (Fe-P), occluded-P (Occ-P) and deca-calcium P (Ca_{10}-P). Briefly, 0.5-gram soil sample was sequentially treated with 1 M ammonium chloride (NH_4Cl), 0.25 M sodium bicarbonate ($NaHCO_3$) (pH 7.5), ammonium acetate ($C_2H_7NO_2$) (pH 4.2), 0.5 M ammonium fluoride (NH_4F) (pH 8.2) and 0.1 M sodium hydroxide (NaOH) for extracting Sol-P, Ca_2-P, Ca_8-P, Al-P and Fe-P respectively. Occluded-soluble P (Occ-P) within the matrices of retaining aggregates and minerals was extracted with CDB (sodium citrate ($Na_3C_6H_5O_7.2H_2O$)-sodium dithionate ($Na_2S_2O_4$)-sodium bicarbonate). Lastly, Ca_{10}-P was extracted using 25 ml 0.25 M sulphuric acid (H_2SO_4) for 1 hour followed by washing with saturated NaCl for 15 minutes. In every step after extraction and washing, the decantation of the supernatant was done in a 50 mL volumetric flask and final volume makeup was done using deionized water. In the final step, 10 mL of supernatant was taken in a separate 25 ml volumetric flask, and P concentration was determined using the phospho-molybdate method (Murphy and Riley 1962). Alkaline phosphatase was estimated by following the procedure of Tabatabai and Bremner (1969).

Processing of plant samples and statistical analysis

Plant samples were cleaned with distilled water followed by 0.1 N HCl and dried in an oven at 55° C till constant weight was achieved. Finely ground plant parts (root, shoot, and leaf) were digested with di-acid mixture (HNO_3: $HClO_4$:: 3:1, v/v) and analyzed for total-P using a spectrophotometer (Jackson 1973). Significant differences among the mean of treatments were calculated using the Duncan multiple range test (DMRT) at $p \leq 0.05$.

RESULTS AND DISCUSSION

Distribution of soil P- fractions and enzyme activity

Among the weed species, sol-P content was recorded highest under *M. denticulata* L. (67.25 mg kg^{-1}) and lowest under *P. minor* Retz. (30.5 mg kg^{-1}). In the contrary, Ca_2-P content was recorded highest in *C. rotundus* L. (48.37 mg kg^{-1}) accounting for over 16% in comparison to *M. denticulata* L. The lowest Ca_2-P was found in the rhizosphere of *C. arvensis* L. (22.5 mg kg^{-1}) (Table 2). Higher alkaline phosphatase activity under *M. denticulata* L. (194.21 µg p-nitrophenol phosphate g^{-1} hr^{-1}) together with below-ground C-allocation with proliferated root system facilitated higher P-solubilisation in the later promoting transformation of non-labile P fractions into labile-P fractions (Table 3) (Richardson *et al.* 2009). Alternately, leguminous weeds like *Trifolium repens* L. showed non-significant change in phosphatase activity under limited P conditions pointing towards the need for more concrete evidence (Hayes *et al.* 1999). Although experimental plots were medium in available-P, earlier studies outlined that perennial leguminous weeds such as *Kennedia prorepens* L. and *Medicago sativa* L. showed prolific rooting patterns under sub-optimal soil P-contents assisting P-uptake (Denton *et al.* 2006). Octa-calcium P (Ca_8-P) varied from 51.37-71.5 mg kg^{-1} where, *C. arvensis* L. recorded highest and weeds like *C. rotundus* L., *M. denticulate* L., and *A. mexicana* L. were statistically at par. Interestingly, lower Ca_8-P with an associated increase in sol-P in M. *denticulata*. and Ca_2-P in *P. minor* Retz. indicates the mobilization of non-labile P into labile P or available P. Aluminium-P (Al-P) and iron-P (Fe-P) recorded highest under *C. rotundus* L. and *A. mexicana* L., respectively with 51.25 mg kg^{-1} and 53.27

mg kg^{-1}. The highest occluded-P (Occ-P) was found under the rhizosphere of *F. parviflora* Lam. (36.62 mg kg^{-1}) and the lowest was in P. *minor* Retz. (16.6 mg kg^{-1}). Lastly, the range of Ca_{10}-P was 58.0-79.25 mg kg^{-1} with maximum and minimum values in *P. minor* Retz. and *C. arvensis* L., respectively. Modified root architecture with surface proliferation in association with high foraging ability particularly in the low P-patches enables *C. rotundus* L. and *P. minor* Retz. to make use of both Ca_2-P and redirecting non-labile Ca_{10}-P into labile form (Richardson *et al.* 2009). Singh *et al.* (2013) found an efficacious role of *Cynodon dactylon* L. in mobilizing non-labile P specifically in high pH and the primary reason was an accumulation of organic-C exudates with root-mediated secretions. The content of Ca_{10}-P was statistically at par in weed species like *F. parviflora* Lam., *C. album* L., *M. denticulata* L., and *C. murale* L. (Table 2).

Correlation between soil P-fractions and the ratio of labile and non-labile soil P pools

Heat map revealed the differential relationship between weeds and P-fractions. Soluble-P was strongly correlated with *M. denticulata* L. followed by *F. parviflora* Lam. *i.e.* these are the most efficient utilisers of native soil P and can mobilise the non-labile P into labile-P most proficiently. A previous study by Řezáčová *et al.* (2022) strongly highlighted the role of mycorrhiza in species like *Centaurea diffusa* L. with a prolific hyphal network favoring P-acquisition. Weed species, *C. didymus* (L.) Sm. and *A. mexicana* L. had a positive relation with Fe-P. While, Al-P and Ca_2-P were positively correlated with *C. arvensis* L. and *P. minor* Retz., respectively. Out of all the P-fractions, any of the weeds failed to utilize the occ-P which remained in close association with sesquioxides via the chemisorption mechanism (Figure 1). The ratio of labile-P to non-labile P indicated that *M. denticulata* L. had the highest bio-available P (0.42) followed by *F. parviflora* Lam. (0.38), *C. rotundus* L. (0.35) and *P. minor* Retz. (0.34). Amidst weed species, *C. arvensis* L. recorded lowest labile-P: non labile-P, which may be due to the inability to secrete alkaline phosphatase or no mycorrhizal colonization in the root surface (Table 3 and Figure 2) (Richardson *et al.* 2009).

Biomass and P-content in different plant parts

In terms of biomass, *C. didymus* (L.) Sm. had the highest and *A. arvensis* L. had the lowest with 810.5 mg $plant^{-1}$ and 35.5 mg $plant^{-1}$, respectively (Table 3). Shoot-P content ranged from 0.714% to 0.321% with the highest in *A. arvensis* L. (0.714%). The highest shoot-P with the lowest biomass in the former is the typical case of luxury uptake as the shoot-P had hardly any significant role in shooting up the biomass (Andreasen *et al.* 2006). Dilution effect in *C. didymus* (L.) Sm. resulted in lowering of shoot-P concentration as observed in a previous study by Blackshaw *et al.* (2004). Leaf P- P-content was highest in P. *minor* Retz. and statistically at par with *C. didymus* (L.) Sm., *F. parviflora* Lam. and *C. arvensis* L. Among all the weed species, the lowest leaf-P content was found 42.5% lower in *C. rotundus* L. than the highest in *P. minor* Retz. (0.601%). Root P content was found maximum in

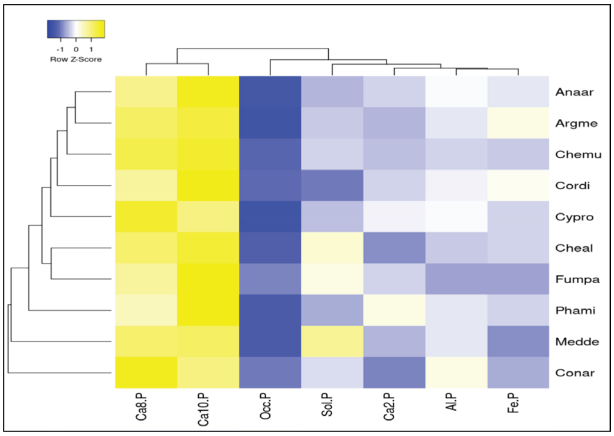

Fig. 1. Heat map cluster showing association between P-fractions and weed species

On the left side the names of the weeds are given in short form. The scientific names along with their short forms are given below:

Annar- Anagalis arvensis L.; Argme- Argemone mexicana L.; Chemu- Chenopodium murale L.; Cordi- Coronopus didymus (L.) Sm.; Cypro- Cyperus rotundus L.; Cheal- Chenopodium album L.; Fumpa- Fumaria parviflora Lam.; Phami- Phalaris minor Retz.; Medde- Medicago denticulate L.; Conar- Convolvulus arvensis L.

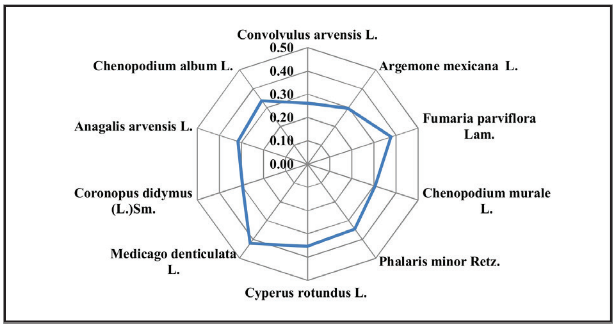

Fig. 2. Proportion of labile-P and non-labile-P in different weed species

Table 1. Details of the weed species collected

S. No.	Common name	Scientific name	Family
1	Field bind weed	*Convolvulus arvensis* L.	Convolvulaceae
2	Mexican poppy	*Argemone mexicana* L.	Papaveraceae
3	Indian fumitory	*Fumaria parviflora* Lam.	Papaveraceae
4	Nettle-leaved goosefoot	*Chenopodium murale* L.	Amaranthaceae
5	Little seed canary grass	*Phalaris minor* Retz.	Poaceae
6	Purple nut sedge	*Cyperus rotundus* L.	Cyperaceae
7	California bur clover	*Medicago denticulata* L.	Fabaceae
8	Wart cress	*Coronopus didymus* (L.) Sm.	Brassicaceae
9	Scarlet pimpernel	*Anagalis arvensis* L.	Primulaceae
10	Bacon weed	*Chenopodium album* L.	Amaranthaceae

Table 2. Soil Phosphorus (P) fractions in the rhizospheric soil of different weed species

Weed species	Different P-fractions (mg Kg^{-1})						
	Sol-P	Ca_2-P	Ca_8-P	Al-P	Fe-P	Occ-P	Ca_{10}-P
C. arvensis L.	35.67^{cd*}	22.5^{f}	72.5^{a}	43.12^{bcd}	27.25^{e}	21.75^{e}	58^{c}
A. mexicana L.	39.79^{cd}	39.05^{cd}	70^{ab}	46.62^{abc}	53.27^{a}	23.8^{de}	73^{ab}
F. parviflora Lam.	50.57^{b}	42.12^{bc}	61.62^{d}	36.37_{d}	37^{cd}	36.62^{a}	76.6^{ab}
C. murale L.	39.65^{cd}	35.37^{de}	66^{bcd}	40.62^{cd}	38.75^{cd}	25.5^{cd}	74.25^{ab}
P. minor Retz.	30.5^{d}	45.87^{ab}	51.37^{e}	39.5^{cd}	35^{d}	16.6^{f}	79.25^{a}
C. rotundus L.	42.81^{c}	48.37^{a}	69.75^{ab}	51.25^{a}	45.18^{b}	30.25^{b}	60.97^{c}
M. denticulata L.	67.25^{a}	40.54^{bcd}	70^{ab}	48.75^{ab}	36^{d}	25.5^{cd}	75.17^{ab}
C. didymus (L.) Sm.	31.25^{d}	40.62^{bcd}	55.47^{e}	43.01^{bcd}	45.94^{b}	27.75^{bc}	70.72^{b}
A. arvensis L.	39.85^{cd}	41^{bcd}	63.82^{cd}	47.5^{abc}	44.75^{b}	24^{de}	76^{ab}
C. album L.	53.44^{b}	30.62^{e}	69.12^{abc}	40.25^{cd}	41.5^{bc}	23^{de}	75.77^{ab}

*Values followed by different lower case letters (a-f) are significantly different between treatments at $p \leq 0.05$.

Table 3. Biomass (mg plant^{-1}) and P-content (%) in different plant parts of weed species

Weed species	Biomass (mg plant^{-1})	Shoot-P (%)	Leaf-P (%)	Root-P (%)	Alk P$^{\#}$ activity (µg pnp g^{-1} hr^{-1})
C. arvensis L.	215.05^{d*}	0.441^{d}	0.595^{a}	0.333^{f}	67.62^{f}
A. mexicana L.	182.25^{e}	0.394^{e}	0.482^{b}	0.603^{c}	84.34^{e}
F. parviflora Lam.	222.5^{d}	0.601^{b}	0.591^{a}	0.396^{d}	177.56^{b}
C. murale L.	295.5^{c}	0.479^{c}	0.496^{b}	0.397^{d}	91.24^{e}
P. minor Retz.	494.4^{b}	0.477^{c}	0.601^{a}	0.357^{e}	123.29^{c}
C. rotundus L.	43.5^{h}	0.321^{f}	0.345^{f}	0.24^{g}	184.26^{b}
M. denticulate L.	167.6^{f}	0.33^{f}	0.464^{d}	0.364^{e}	$194..21^{a}$
C. didymus (L.) Sm.	810.5^{a}	0.328^{f}	0.6^{a}	0.771^{b}	85.64ef
A. arvensis L.	35.5^{h}	0.714^{a}	0.378^{e}	0.903^{a}	108.69^{d}
C. album L.	132.25^{g}	0.411^{e}	0.46^{d}	0.389^{d}	160.29^{bc}

*Values followed by different lower case letters (a-h) are significantly different between treatments at $p \leq 0.05$.

$^{\#}$AlkP activity: Alkaline phosphatase activity (µg p-nitrophenol phosphate g^{-1} hr^{-1})

A. arvensis L. with 0.903% which was significantly higher than the rest (Table 3). In association with the root-mediated physiological and morphological traits better leaf dry mass per unit of leaf area and internal P-recycling are major traits that may keep *M. denticulata* L. ahead of other weed species in mobilizing soil available P (Wright *et al.* 2002).

CONCLUSIONS

In the end, it can be concluded that *M. denticulata* L. is the most efficient user of native soil P and its beneficial effects can be utilized for the subsequent crops. However, field studies involving both crops and weeds must be carried out with special emphasis on diverse above- and below-ground morphological traits and dynamics of organic P-fractions to answer different open-letter questions regarding weed-mediated P-recycling.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

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