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Extracting Insoluble Inorganic Phosphorus from Organic Farm Soils in Mountains: Identifying Effective Organic Acid Extractants

Pritisha Patgiri*[1], Sanjay-Swami[2], Ventina Yumnam[3]
[1]School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam (Barapani) -793 103, Meghalaya, India.
E-mail: pritishapatgiri@gmail.com | ORCID: https://orcid.org/0009-0005-7350-0756
[2]School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam (Barapani) -793 103, Meghalaya, India.
E-mail: sanjayswamionline@gmail.com | ORCID: https://orcid.org/0000-0001-8961-4671
[3]School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam (Barapani) -793 103, Meghalaya, India.
E-mail: ventinayumnam19961@gmail.com | ORCID: https://orcid.org/0009-0005-4475-6517
Corresponding Author

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Abstract

Phosphorus, among others, is quite a vital nutrient for the life of a plant. Because of the dominance of iron and aluminium oxides in acidic soils, they facilitate the fixation of phosphorus which results into phosphorus deficiency in large amounts. Hence, proper replenishment of the soil phosphorus (P) is very much important to cater the need of plant P requirement for better yield and development. The agricultural soils of Meghalaya (India) are by default rich in organic contents and organic P pool contributes 15-80% of the total plant P nutrition. Moreover, a different nature of nutrient pools is present in organic farming system compared to the conventional farming system. Lack of knowledge of these pools results in an imbalanced manuring plan, which hinders successful production system. The dynamic fraction of P cannot represent the correct status of phosphorus in soils under organic production systems, as the conventional soil testing protocols do not take into account the potentially available inorganic pools of phosphorus. Hence, a different extractant that can extract such potentially available P in an acidic soil under organic production system is highly required. The mineralization, solubilization and extraction (of the potentially available P pool) by using various organic acids produced through the beneficial soil microorganisms can serve this purpose. Therefore, the present research work was carried out to identify the best suitable P extractant to extract such potentially available inorganic P pool. The result of the present investigation revealed that out of 6 different extractants selected, 2% citric acid and double lactate extractants were found to be strongly correlated to the total P of the selected sites. Conventional Bray 1 extractant was taken as a check extractant. The outcome of the research is to develop a proper recommendation of fertilizer dose and an appropriate soil testing protocol for phosphorus being used in organic cultivation.

Keywords

Phosphorus; Pools; Extractants; Organic farming system; Soil testing protocol

Introduction

Mountains cover almost 24 percent of the Earth's surface supporting around 3 billion people worldwide through food, fresh water, shelter, hydropower, indigenous/local industries, etc. Hill and mountainous areas in India are vastly distributed all over the country with a larger area located in Himalayas, extending up to 2,500 km in length and 250-400 km in breadth. About 30 percent of the total land area in India is occupied by mountains covering mainly the parts of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Assam, and other North-Eastern states along with West Bengal. The dominant features of hill or mountain farming in North-East Himalayas are small landholdings, sloping marginal land, rainfall-dependent farming and shallow soils prone to erosion. The North-Eastern states of India are particularly hilly and are mostly covered by forests and hills, such as Garo hills, Lushai hills, Patkai hills, Khasi hills, Jaintia hills, Naga hills, etc.

India holds a unique position among 172 countries practicing organic agriculture. It has 6,50,000 organic producers, 699 processors, 699 exporters and 7,20,000 hectares under cultivation (Goyal, 2019). But, with merely 0.4% of total agricultural land under organic cultivation, the industry has a long journey ahead. India produces around 1.35 million tonnes (2015-16) of certified organic products which includes all varieties of food products (Jha, 2017). The country ranked first in terms of the number of organic producers among over 170 countries and ninth in terms of the area under organic agriculture. India ranked eleventh in organic product exports in 2015. Officials from APEDA (Agricultural and Processed Food Products Export Development Authority) had reported that the demand for Indian organic food products is on constant increase worldwide, as India exported organic products worth $515 million in financial year 2017-18 (Business Standard, 2018). Besides transfer and store of energy, phosphorus (P) enables a plant to promote root, flower and fruit development, and allows early maturity. Organic P in soils serves as an important source of P for plant growth, as most of the P (50-80%) is found in the organic form such as inositol phosphate, phytate, nucleic acids, etc. under organic production system. Being a major plant nutrient, P is vital for plant life. However, the problem in acidic soil is that plants face major deficiency of P, as it remains unavailable due to high fixation by the dominant Fe/Al oxides and hydroxides.

The conventional soil test protocols for phosphorus (P) do not take into account the potentially available inorganic P pools under organic production system. Inorganic P is a very important contributor as far as plant P nutrition is concerned (Saha and Mandal, 2011). Due to the lack of an appropriate soil-testing based management strategy of nutrients in organic farms, the farmers apply the organic manures based on their Indigenous knowledge, which results in nutrient imbalance due to progressively declining residual nutrients in the soil leading to low yield and poor-quality produce (Saha and Mandal, 2011). The knowledge of the status of these nutrients in the soil and their requirement by crops is very important in a bid to recommend appropriate amount of the organic inputs to be added in order to maintain higher productivity and high quality of produce. The conventional inorganic P extractant used for extracting the phosphorus in acidic farms is the 'Bray 1' extractant. It is not likely to be equally efficient in extracting the potentially available P or the insoluble inorganic phosphorus pools in organic farming system. It means that the dynamic fraction of P, which is applied in conventional soil testing, cannot help measure the correct status of phosphorus in soils under organic production systems (Saha and Mandal, 2011).

Thus, through applying the conventional methods of P extraction, one cannot know exactly the amount of P, which is available in an organic farm. Hence, a different and suitable extractant that can extract such potentially available P in acidic soils under organic production system is highly required to develop proper and efficient recommendation of phosphorus doses necessary to attain the expected yields. Therefore, the objective of this research is to find out the most suitable organic acid extractants which can give us the appropriate results of potentially available P in acidic soils of organic farms.

Study Area

The North-Eastern Region (NER) of India and other hilly or mountainous areas, where a lot of biomass is available from forest, weeds, crops, etc., organic farming would be economical. Moreover, organic produces are expected to fetch premium price (at least 25%) and, therefore, should be economical to poor farmers.

The NER of India is mostly mountainous and covers around 26.2 million hectares of land and around 8 percent of the country's land mass. North-East mountain region in India is blessed with the highest amount of rainfall as compared to the other parts of the country. However, due to high rainfall and the hilly or mountainous regions in most of the parts of North-East India, soil erosion is quite common, which, in turn, leads to severe decline in soil fertility, biomass carbon, organic matter, etc. The phenomenon of soil erosion in such mountainous regions also leads to Al^{3+} toxicity (high soil acidity) and exposure of compact sub-soil of poor physiological properties. Among others, the state Meghalaya is mainly covered with hills, valleys and mountains in almost the entire state except in some pockets. Terrace and contour farming in the mountains can be seen most popular amongst the farmers. The undulating topography of the mountains makes it difficult for the farmers to go for conventional farming system with the application of chemical fertilizers through standard recommended process, leaving them with no choice except following the Indigenous and organic farming system. Apart from difficulties in supplying the required chemical fertilizers and pesticides for the conventional farming due to hilly and mountainous terrains, the farmers here are unaware of Green Revolution and, hence, the farming is by default organic in nature.

Meghalaya is one of the promising states of NER of India as far as the organic farming potential is concerned. Hills or mountains restrict the farm modernization of the region and, hence, farmers are mostly found to practice the traditional or Indigenous farming system having organic base as against the conventional practice requiring supply of chemical inputs. Like other states of the NER, Meghalaya is mountainous and by default organic, and the farmers of this state are mainly organic producers (Mandal *et al.*, 2006). The farmers here use very low levels of chemical fertilizers and pesticides and the nutrient conversion is highly influenced by various residues from livestock and the available forest biomass. As reported in The Telegraph (2020), 1,410 hectares of agricultural land have been certified for organic farming in the state. Focus has been put on developing the identified organic farms or areas of the state into certified ones.

Various important crops like ginger, turmeric, pineapple, cashew, orange, vegetables, tea plantation, etc. are organically grown in different areas of Meghalaya.

Organic Farming

Organic agriculture is a production system which avoids or largely excludes the use of synthetic compounded fertilizers, pesticides, growth regulators and livestock feed additives (Lampkin, 1990). To the maximum extent feasible, organic farming system relies on crop rotations, crop residues, animal manures, legumes, green manures, off-farming organic wastes and biological pest control to maintain soil productivity, to supply plant nutrients, and to control insects, weeds and other pests. It was considered that organic farming might solve all the problems of weeds, insects and pests, and is still considered as one of the best options for protecting/sustaining soil health. It gained a lot of importance in present day agriculture. It is conceptualized as the approach of farming geared to increase the production and productivity with the use of organic manures and natural methods of plant protection instead of using synthetic fertilizers and pesticides. Along with that, it aims for sustainability by not disturbing the ecological balance, thereby, sustaining soil life and beneficial interactions.

Organic manure contains numerous macro- and micro-nutrients. It is capable of supplying every nutrient to the extent that can be assimilated by plants. Organic manure, being a complex mixture, is a storehouse of nutrients. It releases nutrients gradually so that all nutrients are supplied over a longtime in right proportions (Swami, Singh and Patgiri, 2022). Its compounds are subjected to minimal loss by leaching. The colloidal product of decomposition of organic manure has a high ‘base exchange’ capacity, which means the exchanged ions are not flushed out and the contact between plant root hairs and the organic manure particles is ensured. Thus, there is a built-in economy of supply and demand. Due to actions of various microbes, earthworms and other factors, the organic matter is continually reverting to inorganic state to make mineral salts such as compounds of phosphorus, potassium, calcium, magnesium, sodium, iron, manganese, zinc, copper, boron, etc. available for plants (Swami *et al*., 2021). Due to various difficulties of carrying large and massive machineries and inputs used in conventional agriculture, farmers in mountainous regions of Meghalaya rely mostly on organic farming.

Organic Farming in the NER of India

NER of India is essentially an organic region with almost every NE state practicing organic farming.

- The inorganic chemicals and agro-chemicals are not preferred by the farmers both in planes and in hills.
- In almost every household, farmers are maintaining livestock (pig, poultry, cattle, goats, etc.) producing sufficient quantity of on-farm manures.
- NER of India receives higher amount of rainfall leading to profuse production of biomass including weeds, shrubs and herbs which can be used for self-sufficiency.
- This region has a potential of about 47 million tons of producing organic manure including 37 million tons from animal excreta and 9 million tons from crop residues (Munda *et al*., 2014).

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- Crops like rice, wheat, maize, pulses, oilseeds, fruits and vegetables are grown organically in the fully organic NE state of India, Sikkim.
- Turmeric, ginger, black pepper, cardamom, pineapple, etc. are grown organically in Meghalaya.
- Various other products like arecanut, ginger, passion fruit, vegetables, various cereals, pulses, oilseeds, etc. are grown organically in Assam, Manipur, Mizoram, Arunachal Pradesh, Nagaland, Tripura of NE India.

Importance of Phosphorus and its Availability in Organic Farms

Among others, phosphorus (P) plays a very important role in growth and development of plants. Its contribution towards energy storage and transfer, root development, photosynthesis, respiration, signal transduction, nutrient movement, and transfer of the genetic characters within the plant system prove it to be vital for the life of a plant (Malhotra, Sharma and Pandey, 2018). It is also a major structural component of phosphoproteins, phospholipids, coenzymes, sugar phosphates and enzymes. Cell division and development, root development, bringing early maturity, contribution towards nitrogen fixation process, flower and seed formation, improving drought and salinity resistance, enhancing disease resistance, and alike are some other significant roles played by phosphorus. Hence, it is claimed to be one of the most essential macro-nutrients in a plant system. However, this essential nutrient remains significantly deficient in high rainfall zones of tropical and subtropical mountainous regions mainly due to fixation and precipitation of the phosphate ions underlying iron and aluminium oxides and hydroxides that are dominant in such acidic mountains (Nanganoa and Njukeng, 2018). The P concentration in soil solution is significantly low having the range of 0.003 ppm to 3 ppm P (average ~0.05 ppm) whereas the average quantity of P needed by plants is 0.3 to 0.5 kg P/ha/day (Tisdale *et al.*, 2013). Hence, proper replenishment of the solution P is required to meet the plant P requirement and the chemical phosphatic fertilizers serve this purpose. However, the overuse of these chemical fertilizers leads to imbalance of micronutrients as well as the microbial functions of the soil. Hence, a drift towards organic farming can be justified.

Besides the solution P pool, the organic as well as insoluble inorganic P pools are quite significant as far as the phosphorus nutrition of the plants is concerned because both these pools contribute quite a high amount of available phosphorus for plant uptake through mineralization processes. More than 50% of the total P is contributed by organic P with the range varying from 15 to 80 percent (Tisdale *et al.*, 2013). Inositol phosphate, phospholipids, nucleic acids, nucleotides and sugar phosphates are the important organic pools of P out of which the inositol phosphate (>35%), phospholipids (1-5%) and nucleic acids (0.2-2.4%) are the major contributors of the organic P (Das, 1996). The most common phosphate ester, inositol hexaphosphate, contributes around 50% of total soil organic P.

Around 95% soils of the North Eastern Mountain region of India are acidic, out of which around 65 percent soils come under strong acidic range with less than 5.5 pH. Meghalaya is no exception. Out of the 21 million hectares (m ha) acidic soils of North Eastern Mountain region of India, 2.24 m ha soil covers Meghalaya (Singh and Sanjay-Swami, 2020). These soils can be seen deficient in phosphorus mainly due to leaching of bases from up above the mountains through high rainfall water that result into dominance of iron and aluminium oxides facilitating fixation of phosphate. Therefore, systematic study and access to the organic P pool in acidic soils, particularly for phosphorus nutrition, have its paramount importance.

The mineralization of the organic P and the insoluble inorganic P present in the soil is mainly catalyzed by the enzymes and organic acids released by various soil microorganisms, plant roots and decomposing organic matters. Several of the released organic acids have the ability to bond with Al, Fe, Ca, Mg, Mn, and Zn by way of ion-exchange, surface adsorption, coagulation and peptization reactions; therefore, they play an important role in the mobilization of such metals in soil-water systems. These complex reactions may lead to the release of P from P-bearing minerals (Kpomblekou-Ademawou, 1993). Hence, for extracting or estimating these potentially available pools of P under organic farming, generally, the organic acids are recommended. Therefore, the research work is based on identifying the best suitable organic acid extractant for acidic mountainous soils of Meghalaya under organic production system. By knowing the amount of potentially available P in an organic farm using the suitable extractant, which can extract the accurate amount of that P in such type of soils, a proper recommendation for P can be prescribed.

Keeping the above facts in view, an investigation was carried out with the following objective: Identification of the suitable organic acid extractants to extract the potentially available insoluble inorganic P pools in acidic soils under organic farming system.

Methodology

Different organic acid extractants are used to extract the potentially available phosphorus under organic production system, which is a very important fraction of phosphorus for plant availability in organic farming. This fraction is not appreciated through conventional method of extraction by Bray-1 extractant. P extraction is affected by the choice of organic acid (Gerke, Beißner, and Römer, 2000), extraction pH, extraction time (Turner, 2008) and solution to soil ratio (Chapman, Edwards, and Shand, 1997).

Meghalaya is predominantly mountainous and geographically known as “Meghalaya Plateau”. The present investigation was conducted at five different sites of Ri-Bhoi district of Meghalaya representing two farming systems i.e., conventional and organic farming systems. The five selected sites are: 1) College of Post Graduate Studies in Agricultural Sciences (CPGS-AS) research farm, Central Agricultural University (CAU-I), Umiam, 2) Palwi village of Bhoirymbong block, 3) ICAR research farm, Umiam, 4) CPGS-AS, Krydemkulai and the 5) Krydem village of Bhoirymbong block. The first two sites were conventionally managed, while the later three were organically managed. The soil samples were collected from the selected sites and were then analyzed and extracted in the laboratory with five different organic acid extractants along with a check extractant (Bray-1) to estimate the potentially available phosphorus. The organic acid extractants used for analysis of potentially available phosphorus are citric acid, double lactate, 2-keto-glutaric acid, acetic acid and lactic acid extractant. The analysis was done following the standard protocols. The composition of the extractants and the standard protocols of the analysis are referenced in table 1. One

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conventional P testing extractant Bray-1 extractant was used as the check extractant. The strength of extraction is highly dependent on the structural and functional properties of the organic acid extractants which vary in chelation properties.

Thereafter, multiple linear regressions were performed taking total P as dependent variable to adjudge the best suitable extractants in organic acidic soils. The soils of the research farm of CPGS-AS, Umiam, research farm of ICAR, Umiam and the virgin forest soil farm of CPGS-AS, Krydemkulai were of dominantly Inceptisols (USDA Taxonomy) and the soils of the farm of Palwi village and Krydem village of Bhoirymbong block were of Alfisols. Soils were mostly light to medium textured (sandy loam and clay loam) with depth ranging from deep to very deep. Soils of the study area were found to be acidic (pH below 5.5). Chemical composition of the different types of soils existing in Meghalaya is illustrated in table 1.

Table 1: Organic acid extractants employed to extract the potentially available inorganic phosphorus

S. N.	*Extractant*	*Composition*	*Reference*
1.	Acetic acid extractant	0.54 N Acetic acid + 0.7 N Sodium acetate at pH 4.8	Morgan, 1941
2.	Lactic acid extractant	0.02 M Ca-lactate + 0.02 M HCl at pH 3.7	Egner and Riehm, 1955; Egner *et al.*, 1960
3.	Citric acid extractant	2% Citric acid	Blazer and Blazer-Graf, 1984
4.	Double lactate extractant	0.02 M Ca-lactate + 0.05 M Lactic acid at pH 4.1	Dey *et al.*, 2019; Riehm, 1943
5.	2, keto-glutaric acid extractant	0.05 M 2, keto-glutaric acid+0.02 M HCl at pH 4.0	Dey *et al.*, 2019
6.	Bray 1 extractant (Check extractant)	0.03 N NH_4F + 0.025 N HCl	Bray and Kurtz, 1945

Result & Discussions

Details of the Existing Soil's Chemical Characteristics in the Study Area

As analyzed in the laboratory, the pH, soil organic carbon (SOC) (%), available P (kg/ha) and total P (kg/ha) of the sampling sites are presented in table 2.

As reported in table 2, the pH of all the studied organic soils was higher than that of the conventional soils. The lowest pH was found to be in the soil of conventional Palwi village, Bhoirymbong (4.58) followed by the soil of conventional CPGS-AS farm, Umiam (4.70). The pH of the organic soil of ICAR farm, Umiam, Krydem village, Bhoirymbong and CPGS-AS farm, Krydemkulai were found to be 4.91, 4.94 and 5.15, respectively. The higher pH of the organic soils might be due to the buffered status of soil under organic farming system than that of the conventional system.

Table 2: Chemical properties of the soil sampling sites

Sites → / Particulars ↓	*CPGS-AS farm, Umiam*	*Palwi village, Bhoirymbong*	*ICAR farm, Umiam*	*Krydem village, Bhoirymbong*	*CPGS-AS farm, Krydemkulai*
Status	Conventional	Conventional	Organic	Organic	Organic
pH	4.70±0.20ab	4.58±0.12b	4.91±0.11ab	4.94±0.09ab	5.15±0.09a
SOC (%)	1.13±0.06c	1.20±0.07c	1.81±0.14b	1.65±0.10b	2.53±0.13a
Avl. P (kg/ha)	16.25±0.67a	11.1±1.02b	16.07±0.82a	18.37±0.54a	17.25±0.35a
Total P (kg/ha)	1321.58±13.57e	1542.12±6.59d	1933.35±4.30a	1748.18±3.60b	1645.67±4.44c

*Means not sharing the same letters in the same column differs significantly (at $p<0.01$) by DMRT

Soil organic carbon (SOC, %) was resulted higher in the soils of organic farming system than that of the soils under conventional farming system. The highest value of 2.53% of SOC was evident in CPGS-AS farm, Krydemkulai. The other two organic sites *viz.* ICAR farm, Umiam and Krydem village, Bhoirymbong resulted SOC to be 1.81% and 1.65%, respectively. Conventional farming sites resulted lower SOC of 1.13% and 1.20% in CPGS-AS farm, Umiam and Palwi village of Bhoirymbong, respectively. The higher values of SOC in the organic soils might be due to continuous addition of organic manures in such soils and lesser decomposition of the organic matter. On the other hand, lower values under conventional soils might be due to non-addition of organic manures and only usage of chemical fertilizers (table 2).

Available P was found to be very low under conventional farming systems, especially in Palwi village of Bhoirymbong (1.11 kg/ha) whereas the value of the other site was found to be at par with all the 3 sites under organic farming system. ICAR farm, Umiam, Krydem village, Bhoirymbong and CPGS-AS farm, Krydemkulai sites had the values of 16.07, 18.37 and 17.25 kg/ha of available P, respectively. The low value of available P might be due to extreme fixation of P by iron/aluminium oxides and hydroxides dominant in acidic soils (table 2).

Total P was higher in organic soils than that of the conventional soils. Highest total P was reported in the ICAR farm, Umiam (1933.35 kg/ha) followed by Krydem village, Bhoirymbong (1748.18 kg/ha) and CPGS-AS farm, Krydemkulai (1645.67 kg/ha). The values in the conventional soils were quite low with 1321.58 kg/ha and 1542.12 kg/ha in the CPGS-AS farm, Umiam and Palwi village, Bhoirymbong, respectively. The higher values of total P might be because of the organic and other fractions of P which were not considered in available P estimation (table 2).

The results obtained are summarized in the following table 3. As depicted in table 3, the extractable P pools extracted by the organic acids were relatively higher in size under organic farming system as compared to the conventional system. Acetic acid, being a monobasic acid with one carboxyl functional group, triggered lesser extent of chelation of the predominant iron and aluminium ions as compared to the other extractants. So, this pool could contribute lesser towards P nutrition. The lowest value of 3.52 kg/ha was evident in the conventional Palwi village and the highest value of 6.827 kg/ha was evident in the organic site of Krydemkulai under the acetic acid extractable pool.

Table 3: Acetic acid, citric acid, lactic acid, double lactate and 2, ketoglutaric acid soluble P_2O_5 of different sites

Site	*Status*	*Acetic acid soluble P_2O_5 (kg/ha)*	*Citric acid soluble P_2O_5 (kg/ha)*	*Lactic acid soluble P_2O_5 (kg/ha)*	*Double lactate soluble P_2O_5 (kg/ha)*	*2-ketoglutaric acid soluble P_2O_5 (kg/ha)*
CPGS-AS	Conventional	4.227±0.41b	12.220±0.90d	18.790±0.75a	33.180±1.00c	29.631±1.06c
Palwi	Conventional	3.520±0.41b	5.630±0.46e	17.983±0.68ab	27.137±1.06d	25.257±1.00c
ICAR	Organic	6.427±0.37a	45.365±0.75a	16.340±1.00abc	47.590±1.03a	60.413±1.06b
Krydem	Organic	6.599±0.29a	32.231±0.90b	14.990±0.60c	43.736±1.29ab	63.344±1.49ab
Krydemkulai	Organic	6.827±0.63a	24.027±1.28c	15.693±0.62bc	42.517±1.28b	68.120±1.71a

A significant contributable size solubilized by citric acid was reported by scientists, as it is an alpha-hydroxy derivative of tribasic acid with three carboxyl and one hydroxyl functional groups (Gour, 1990; Drouillon and Merckx, 2003). The sizes of this pool were much higher under organic sites than that of the conventional sites. Under this study, highest value of 45.365 kg/ha P_2O_5 is obtained in the organic soils of ICAR and the lowest value of 5.63 kg/ha is obtained in the soils of Palwi village, which is conventionally managed (Table 3).

The contribution of lactic acid extractable P pool was routinely found to be relatively lower. However, it is higher than acetic acid extractable P pool observed in this study, because of the presence of a carboxyl and a hydroxyl functional group facilitating greater chelation property. The unique observation of this pool is that this particular extractant could extract the potentially available phosphorus almost equally under both conventional and organic farming system.

Bigger sizes of double lactate soluble P_2O_5 is reported in organically managed soils compared to the conventional soils because of the formation of highly buffered extractant. Much higher values within organic sites are observed than that of the conventional sites. Values of 47.59 kg/ha, 43.736 kg/ha and 42.517 kg/ha P_2O_5 are recorded in the organic sites of ICAR, Krydem village and Krydemkulai, respectively. Values of 33.18 kg/ha and 27.137 kg/ha P_2O_5 were recorded in the conventional sites of CPGS-AS and Palwi village, respectively (Table 3). 2-keto-glutaric acid extractable P pool is reported to be the highest contributing pool. The presence of a keto group and two carboxyl groups in 2-keto-glutaric acid contributed excellent sizes of P_2O_5 extracted. This pool also contributed more in organic soils compared to the conventional soils. Enormous values of 60.413 kg/ha, 63.344 kg/ha and 68.12 kg/ha are reported at the organic sites of ICAR, Krydem village and Krydemkulai, respectively. On the other hand, values of 29.631 kg/ha and 25.257 kg/ha are reported at the conventional sites of CPGS-AS and Palwi village, respectively (Table 3).

Using the data in table 3, regression equations are generated by performing multiple linear regression taking 'Total P' as the dependent variable and organic carbon (OC%) and organic acid extractable P_2O_5 as the independent variables. All the organic acid extractants, singly and in combination, are considered; and many regression equations with respective R^2 values are derived for both single and combination extractants (Table 3). The results of the regression equations (single) suggest that the highest R^2 values is evident for citric acid extractant (R^2=0.78) followed by double lactate extractant (R^2=0.62). Similarly, the results of the combination extractants regression equation suggest that the best combination of extractants is the citric acid and double lactate extractants with R^2 value of 0.93. On the other hand, extremely low value of R^2 is obtained with conventional Bray-1 extractant (R^2=0.26). This suggests that the variability of total P in the soils can be best explained by the citric acid extractant and double lactate extractant while very low degree of variability of total P can be explained by Bray-1 extractant. Total P is taken as the dependent variable because the suggestions of organic manure doses in an organic production system are made based of the values of total P of the particular organic site. The results along with the generated R^2 values are presented in the table 4.

Table 4: Regression equations taking Total P as the dependent variable along with the generated R^2 values

S. N.	*Equation*	*R^2*
1.	Total P= 1289.18 + 36.77 OC% + 12.05 (Citric acid-P)	0.78
2.	Total P= 804.18 – 19.70 OC% + 22.32 (Double lactate-P)	0.62
3.	Total P= 1283.70 + 203.10 OC% + 1 (Bray-1 P)	0.26
4.	Total P= 2566.36 + 268.41 OC% + 37.75 (Citric acid-P) – 58.63 (Double lactate-P)	0.93

Conclusion

Five different organic acid extractants are chosen to determine the best extractant that can extract the potentially available P under organic farming system. Multiple linear regression is performed taking total P as dependent variable with all the extractants and organic carbon. All the possible combination of extractants are considered and the results have proved that a very poor relationship is evident between organic carbon and Bray-1 soluble P (considered as check) having R^2 value of 0.26. Among the organic acid extractants, citric acid followed by double lactate are found to be best in defining the highest amount of variation of total P in organic soils bearing R^2 value 0.78 and 0.62, respectively. The combination regression reveals that both citric acid and double lactate extractants are strong enough to define the variation of total P in organic farming system with highest R^2 value of 0.93.

Based on the results of the present investigation, it may be concluded that the highest R^2 value i.e., 0.93 for citric acid and double lactate extractant, defines the highest variation of total P in an organic production system. The R^2 values of all other regression equations are lesser. The value for conventional Bray-1 extractant is very small i.e., 0.26. Hence, the famers of Meghalaya, particularly of Ri-Bhoi district, may be advised to get tested their soils for potentially available phosphorus through citric acid and double lactate extractants in an organic production system; and, accordingly, they can apply P doses from organic nutrient sources that not only restore soil health but also ensure a successful organic cultivation.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*
Conceived and designed the research or analysis	Yes	Yes	No
Collected the data	Yes	No	Yes
Contributed to data analysis & interpretation	Yes	No	No
Wrote the article/paper	Yes	Yes	No
Critical revision of the article/paper	Yes	Yes	Yes
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