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Distribution of Phosphorus Fractions in Orchard Soils in Relation to Soil Properties and Foliar P Contents

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Abstract: Phosphorus (P) fractionation is the validation of the nature, solubility and relative bioavailability of P. A sequential P extraction was used to determine the distribution of plant-available P fractions in soils. The relationships of these P fractions to soil properties and foliar P contents were also determined. Results of this study showed substantial differences in soil properties among orchards. Higher amounts of soil organic matter (SOM), cation exchange capacity (CEC) and major plant nutrients were found under orchard soils when compared with control soil. Most of the soil variables varied among orchard species as loquat > citrus > guava. The orchard soil exhibited a slightly higher soil pH. Overall, the P fractions were higher in all types of orchard soils and lowered in the control soils. Among tree species, P fractions in soils were achieved as loquat > citrus > guava. The extracting agents differed for P in the order residual P > HCl-P > NaOH-P > $NaHCO_3$-P > H_2O-P. Mostly higher amounts of the P fractions were achieved in the topsoil. The average amount of extractable P was found significantly higher in those soils of fruit orchards where the total amount of P was actually higher. The higher r^2 values between P fractions versus SOM, clay and CEC of soils predicted a strong interrelationship among these soil variables. Leaf N contents of loquat and guava trees were consistently higher, and leaf P contents varied as loquat > citrus > guava. Potassium and Ca contents were higher in citrus than in the other two species. Micronutrients were found as Fe > Zn > Mn > Cu in the leaves. Regression models indicated a sufficient relationship between Hedley P fractions and the foliar P contents in tree species. This study indicates that the above soil properties can be used to ascertain soil P fractions, and that can influence the bioavailability of P from orchard soils.

Keywords: P fractionation; foliar P content; tree species; soil variables; arid region

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1. Introduction

The quality of soil is commonly controlled by the properties of soil and their mutual interactions [1]. These interactions are essential for a correct balance of the agroecosystem [2,3]. The availability of plant nutrients depends upon soil properties in the rhizosphere [4]. Nutrient deficiencies adversely affect the yield and quality of fruits [5]. Chaudhari et al. [6] reported the deficiency of plant nutrients as a major constraint for the productivity and sustainability of soils. Nutritional deficiencies influenced the plant productivity of orchards [7]. Marginal soil fertility causes low productivity of fruit trees [8]. Phosphorus (P) is regarded as the major nutrient for plant growth and development [9]. Phosphorus management has agronomic and environmental significance [10]. Phosphorus dynamics in soils and P cycling in agro-ecosystems have been largely emphasized [11]. The soil P cycle is also related to soil genesis and land management [12].

Soil P transformation has been a major focus of research in soil chemistry [13]. The transformation of P forms in the soil is usually determined by the complex interactions of biotic and abiotic factors. Adsorption and dissolution are some of the abiotic factors controlling nutrient transfer between non-living pools and soluble forms, whereas biotic factors, including microbial activity, change organic P into inorganic P and vice versa [14]. Biogeochemical transformation of different forms of organic and inorganic P controls soil P availability [15,16]. Soil P transformation processes are strongly influenced by variations in temperature, moisture, plant growth and root activity and by organic matter accumulation from litterfall and rhizodeposition [17]. Changes in the land cover also affect soil properties and biogeochemical processes [18]. Land cover may alter soil P transformation by modifying the amount of plant P demand, litter quality and quantity, and soil properties [16]. Tree plantation affects the P status and its availability depending on the environmental conditions, tree species, and time scale of afforestation [19].

The total P content in soils is not a good predictor of the nutritional status of tree species [20]. Most of the soil P reserves are unavailable or not directly plant available. The relationship between total soil P and foliar P contents has not been reported well [21]. The quantification of soil P fractions has been used to evaluate the potential sources of P bioavailability. Partitioning of total P into plant-available fractions in soils has been done by the Hedley fractionation method [22,23]. These P fractions are often grouped into pools of distinct plant availability as follows: (1) a labile, fast cycling pool (labile P) supplying the short-term P demand of plants; (2) a slow-cycling pool (moderately labile P) that can be converted into labile P forms; and (3) a pool of occluded P (stable P) hardly contributing to plant nutrition in the short-term [24,25]. Variations in P fractions in soil under vegetation types are attributed to the changes in biomass production and nutrient cycling processes associated with vegetation conversion [26]. Changes in land use affect the bioavailability of P either by increasing P losses or by transforming it to more recalcitrant pools. This leads to potentially significant effects on the availability, distribution and stability of P within chemically defined pools [27].

Phosphorus characterization in soils is important because P forms influence P desorption/release patterns and their bioavailability. This also depends on the precise measurement of phyto-availability of P from soil. There is a need to predict relationships between extractable P and plant-available P in view of soil properties and P forms. There is little information available on the relationship of different soil variables with P availability [12,28]. Studies on the distribution of different P fractions across orchard soil in relation to soil properties for sustainable yield potential and quality of fruit in the Hazara Division of Pakistan are lacking. Research work on the P fertility in soils under the influence of fruit orchards is important for productive management. Therefore, this study focused on the changes in P fractions in soils under orchard species and their relationship with soil properties and foliar P content.

2. Materials and Methods

2.1. Soil Sampling

The soil was sampled from three types of fruit orchards, namely citrus (*Citrus sinensis* L.), loquat (*Eriobotrya japonica* L.), and guava (*Psidium guajava* L.), located in District Haripur of Hazara Division, Pakistan (Figure 1). In each orchard, ten random subplots (5 m $\times$ 5 m) were selected for soil samples from the two layers of soil (0~25 and 25~50 cm depth) as composite soil samples. These samples were mixed appropriately in plastic bags. Composite soil samples were taken from the adjoining fields of each orchard as control soil.

Soil samples were collected randomly from each core with an auger and kept in polythene bags under moist conditions. The materials (stones, granules, plant parts, and leaves) were removed carefully from the samples. The soil samples were air-dried, ground and passed via a 2 mm sieve.

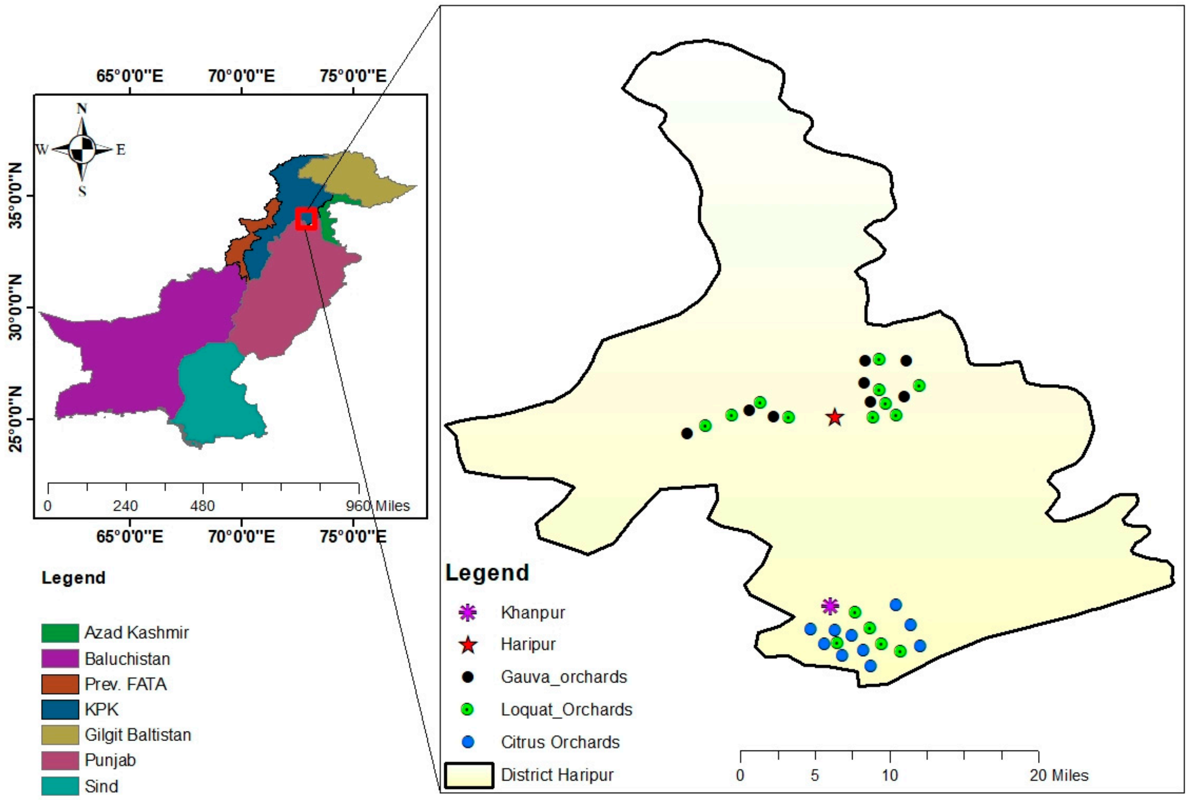

Figure 1. Study area of Haripur district, Pakistan.

2.2. Soil Analyses

The soil was analyzed for different physical and chemical properties, i.e., pH, electrical conductivity (EC), organic matter, texture (sand, silt and clay), potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na). The organic matter of soil (SOM) was calculated by the dry combustion method [29]. The total N content was determined using the Kjeldahl method [30]. The pH was determined using a pH meter (Model: HANNA HI 8520) and electrical conductivity (EC) by electrical conductivity meter (Model: 4320 JENWAY) at a ratio of 1:5 of soil with water [31]. The soil texture was determined using a hydrometric method [28]. The soil bulk density was estimated by a core method [23]. Concentrations of total macro- and micro-elements in soil were determined after digesting the soil samples in a mixture of perchloric acid ($HClO_4$) and nitric (HNO_3) acid (1:3). The contents were determined using an atomic absorption spectrophotometer (AAS) (Model: Analyst 700, Perkin Elmer) [32]. Calcium (Ca), magnesium (Mg), and potassium (K) were extracted by ammonium acetate, and these exchangeable cations were determined using AAS. For the measurement of accuracy for each element, the instrument was calibrated using a standard solution. The mean value for each sample was calculated using three measurement readings on the AAS, and the error estimate was calculated via standard deviation of the results. The machine calibration has r^2 value > 0.9.

2.3. Sequential P Fractionation

The soil samples were collected randomly, as stated above, from each orchard of loquat, guava and citrus. Samples were sieved via a 2 mm sieve. The distribution of P fractions in soils was determined by the extraction procedure of Hedley et al., [22], also used by Dou et al., [33], Eneji et al., [34]. Samples of soil were fractionated into readily plant-available P by sequential extraction with de-ionized water, labile inorganic P (another plant-available fraction) using 0.5 M $NaHCO_3$ (at pH 8.5), sesquioxide associated inorganic P (Fe-oxide and Al-oxide) using 0.1 M sodium hydroxide (NaOH), and Ca-associated P with 1 M HCl. 0.5 g soil samples were added in a 50 mL centrifuge tube. The solution was extracted sequentially with 30 mL de-ionized water, 0.5 M $NaHCO_3$, 0.1 M NaOH and 1 M HCl. With each reagent, the extraction was carried out after 16 h of end-to-end shaking and then centrifuged for 15 min at 10,000 rpm. Residual P in each soil sample after the final extraction was digested in a mixture (3:1) of HNO_3 and $HClO_4$. Phosphorus contents were determined colorimetrically on a spectrophotometer (Model: LI-UV-7000) following Murphy and Riley [35]. All the reagents/chemicals of Sigma Aldrich, Germany, were utilized during the experiment. The experiment was (2 × 3 × 5) factorial (2 soil depths × 3 fruit orchards × 5 P fractions), resulting in 30 experimental units, arranged into a completely randomized design (CRD) and replicated 4 times. Leaf samples of fruit trees were collected from ten different sites of each orchard of loquat, citrus and guava, keeping in view both young and older leaves. The citrus, guava and loquat orchards were 12–15 years of age. Each orchard occupies an area of 8–10 ha. Leaf sampling was done in the summer season (June 2020). The total contents of nutrients (macro and micro) in the recently matured leaves of fruit trees were determined after the process of wet digestion.

2.4. Statistical Analyses

Data were statistically analyzed using ORIGIN 2021 software. The treatment effects on soil and plant parameters were separated via the Tukey test at $p < 0.05$. The P contents in soil samples were correlated with the foliar P contents of each orchard. The relationship of P fractions in soils with the physico-chemical properties of soils, i.e., pH, cation exchange capacity (CEC), soil organic matter (SOM) and clay contents, were determined using regression analyses. Regression analysis for the leaf P contents with soil P fractions was also done.

3. Results

3.1. Soil Properties

Soils showed significant differences in soil properties under different orchards ($p < 0.05$) (Tables 1 and 2). A higher amount of soil organic matter (SOM) was achieved under orchard conditions than control soil. Litterfall of orchards accumulated more soil organic matter (SOM) in the surface soil (0~25 cm) when compared with subsurface soil (25~50 cm).

Table 1. Properties of soil under three fruit orchards *.

Sites	Soil Depth	pH	ECdS/m	SOM (%)	$CaCO_3$(%)	Clay(%)	Texture	CEC meq/100 g
Citrus control	00–25	7.8	0.24	1.8	6.4	23	Sandy clay loam	16.2
	25–50	7.6	0.25	1.5	6.5	28	Sandy clay loam	14.3
Citrus orchard	00–25	8.2	1.28	4.6	6.6	34	Sandy clay	18.9
	25–50	7.9	1.29	4.8	5.9	36	Sandy clay	18.5
Guava control	00–25	8.3	0.28	1.6	5.7	16	Sandy loam	17.0
	25–50	7.8	0.38	1.4	6.2	18	Sandy loam	16.5
Guava orchard	00–25	8.5	1.29	3.0	5.8	20	Sandy loam	22.5
	25–50	8.4	1.23	3.3	5.1	32	Sandy clay loam	14.3
Loquat control	00–25	7.8	0.27	1.6	6.5	28	Sandy clay loam	14.8
	25–50	8.2	0.26	1.1	6.6	26	Sandy clay loam	13.3
Loquat orchard	00–25	8.7	1.33	4.9	5.7	36	Sandy clay loam	27.6
	25–50	8.4	1.37	4.3	5.9	35	Sandy clay loam	24.6
Tukey (0.05)		0.2	0.02	0.1	0.3	1.6		1.3

* EC = electrical conductivity, SOM = soil organic matter, CEC = cation exchange capacity.

Table 2. The details of nutrients (mg kg^{-1}) in soils influenced by fruit orchards. The data are presented as means (*n* = 10), ±values are standard errors.

Sites	Soil Depth (cm)	N	P	Ca	Mg	K
Citrus control	00–25	224 ± 12	1299 ± 23	1284 ± 10	1093 ± 16	5282 ± 35
	25–50	202 ± 15	1133 ± 30	1127 ± 12	1100 ± 18	5520 ± 30
Citrus orchard	00–25	279 ± 18	1347 ± 33	1444 ± 10	1065 ± 24	6649 ± 40
	25–50	294 ± 10	1259 ± 22	1430 ± 17	1062 ± 22	6532 ± 32
Guava control	00–25	226 ± 17	1358 ± 21	1317 ± 18	878 ± 12	4311 ± 32
	25–50	226 ± 21	1112 ± 14	1390 ± 20	899 ± 10	4395 ± 26
Guava orchard	00–25	318 ± 16	1433 ± 21	1847 ± 11	1108 ± 18	5147 ± 26
	25–50	294 ± 16	1183 ± 26	1744 ± 13	1089 ± 12	5440 ± 25
Loquat control	00–25	221 ± 24	1016 ± 27	1319 ± 13	1087 ± 22	4316 ± 34
	25–50	252 ± 13	1026 ± 22	1147 ± 19	977 ± 25	4147 ± 29
Loquat orchard	00–25	459 ± 12	1557 ± 24	2440 ± 21	1475 ± 20	6440 ± 31
	25–50	434 ± 10	1333 ± 20	2391 ± 22	1398 ± 20	6280 ± 30
Tukey (0.05)		3.8	19.2	15.6	13.8	32.7

These results signified that loquat and citrus trees accumulated more C stock than guava tree species. The orchard soil exhibited a slightly higher pH value in both surface and sub-surface soils. Cation exchange capacity (CEC) of soil varied among orchards as loquat > citrus > guava trees. Higher plant nutrients (N, P, Ca, Mg and K) were found in soils of orchards (Table 2). Total P contents in soils were enhanced by citrus, guava and loquat orchards by 9.3, 18.6 and 53.2%, respectively, in the surface soil as compared to control soils. Total N contents in soils were enhanced by citrus, guava and loquat orchards by 24.5, 40.1 and 107.6%, respectively, in the surface soil. The cationic elements were differentiated in soils as K > P > Ca > Mg irrespective of the tree species. Micronutrients in soils were found in the order of Cu < Zn < Mn < Fe. Manganese concentration was higher in the citrus soil. Copper was higher in the soil planted with loquat species. Iron concentration was achieved higher in soil planted with loquat and citrus trees as compared with guava. Zinc was substantially higher in soil afforested with citrus and guava species than loquat orchard.

3.2. Distribution of P Fractions in Soil

There were significant ($p < 0.05$) variations in P fractions of soils in all three species (Figures 2 and 3). The average amounts of P fractions were different in the soil due to the tree species in the order loquat > citrus > guava. The extracting agents consistently differed for P in the order residual P > HCl-P > NaOH-P > $NaHCO_3$-P > H_2O-P. H_2O-P was enhanced in the surface soil by 11.7, 29.1 and 108.6% in the fields of citrus, guava and loquat orchards, respectively, when compared with control fields. Water P was found higher in the soil samples of loquat and guava orchards than in citrus. $NaHCO_3$-P increased in the topsoil samples from 108 to 236 mg kg^{-1} under loquat trees and from 132 to 173 mg kg^{-1} under guava trees. The $NaHCO_3$-P did not change under citrus trees as compared to control fields. Relatively lower H_2O-P contents in the control soil of guava field. Tree plantation also influenced the NaOH-P in the soil. NaOH-P contents in the soils varied with the species of a tree, and the contents were found in the order loquat > guava > citrus (Figures 2 and 3). The cumulative amount of HCl-P and residual P in the soils identically varied as loquat > citrus > guava. Lower P fractions were noticed in most of the subsurface soil samples.

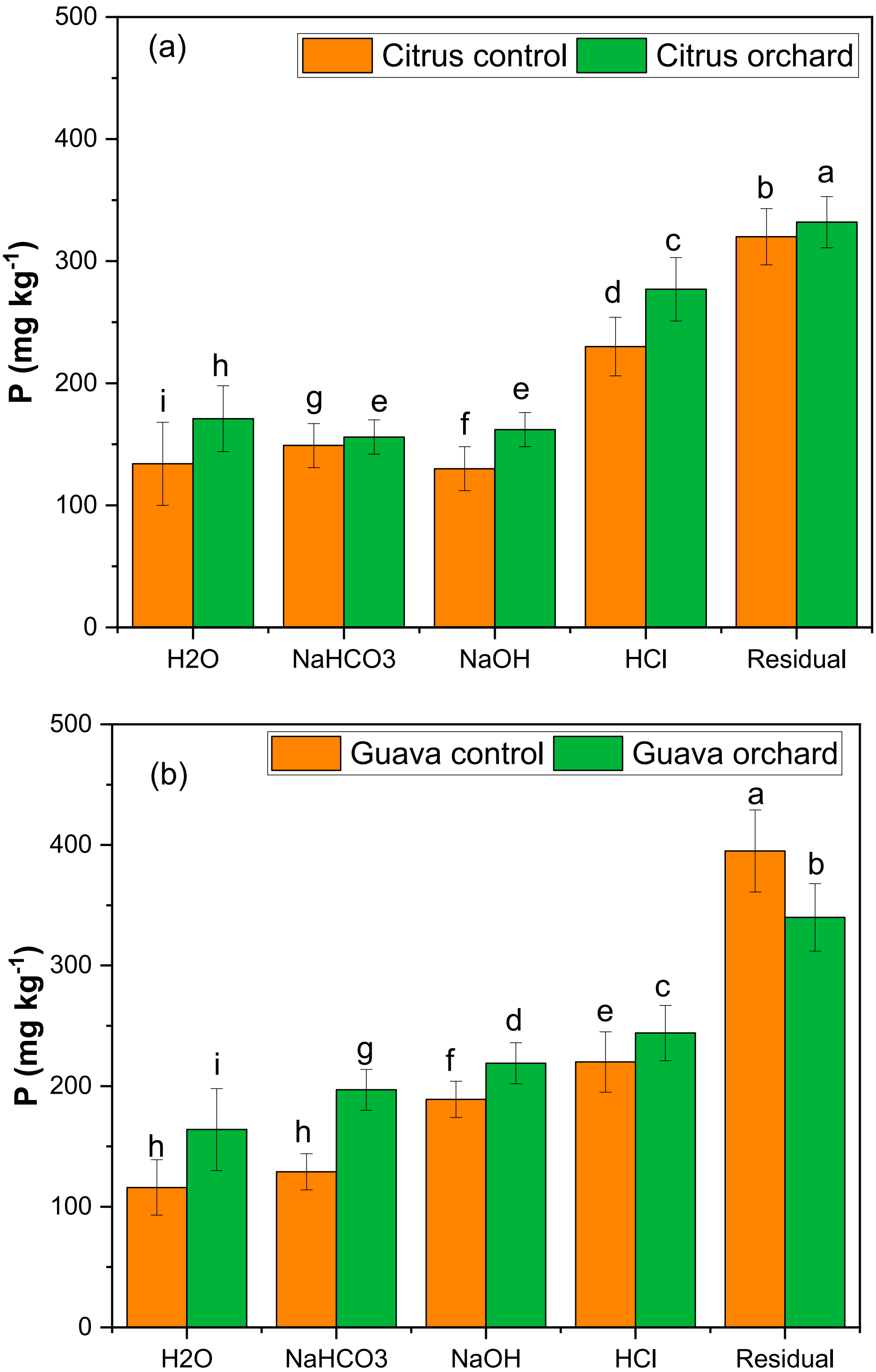

Figure 2. *Cont.*

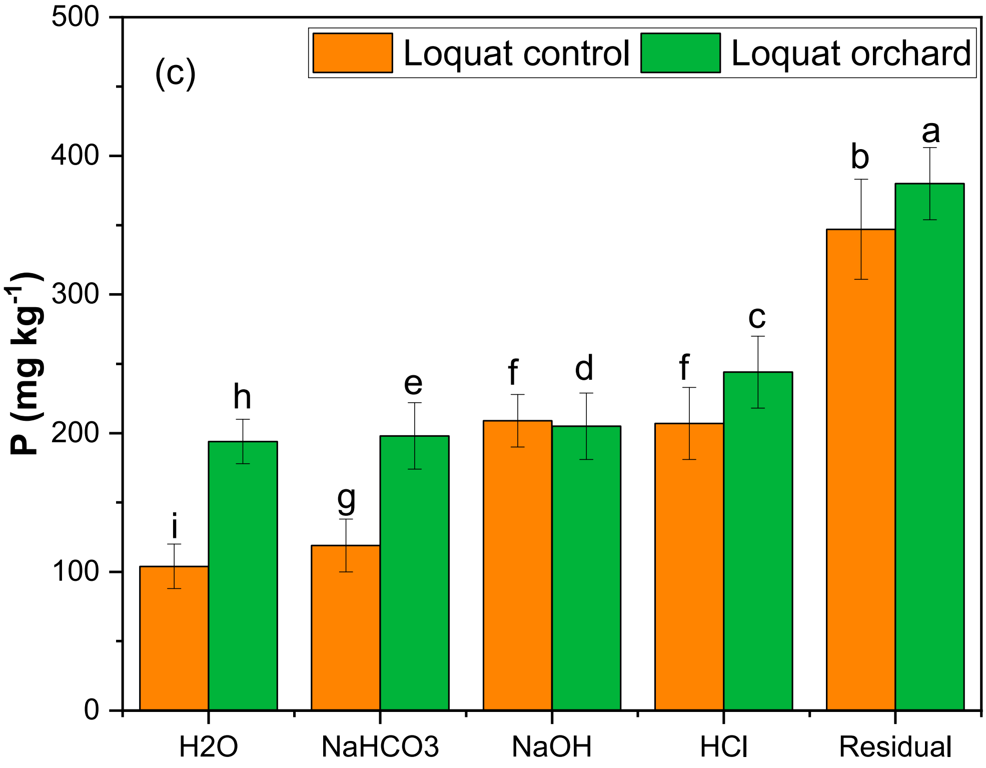

Figure 2. Phosphorus fractionation in topsoil (**a**), citrus (**b**) guava (**c**) loquat orchards. The bars are displayed as means (n = 10), ±values are standard errors. Small letters indicate significant differences at $p < 0.05$ between different treatment types.

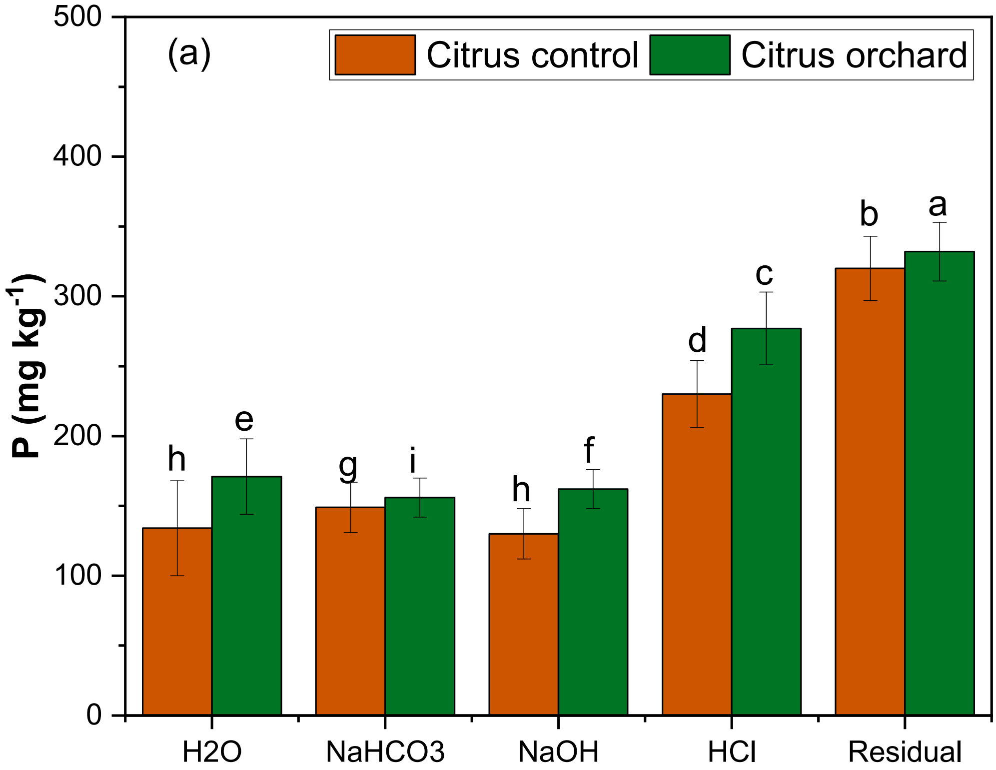

Figure 3. *Cont.*

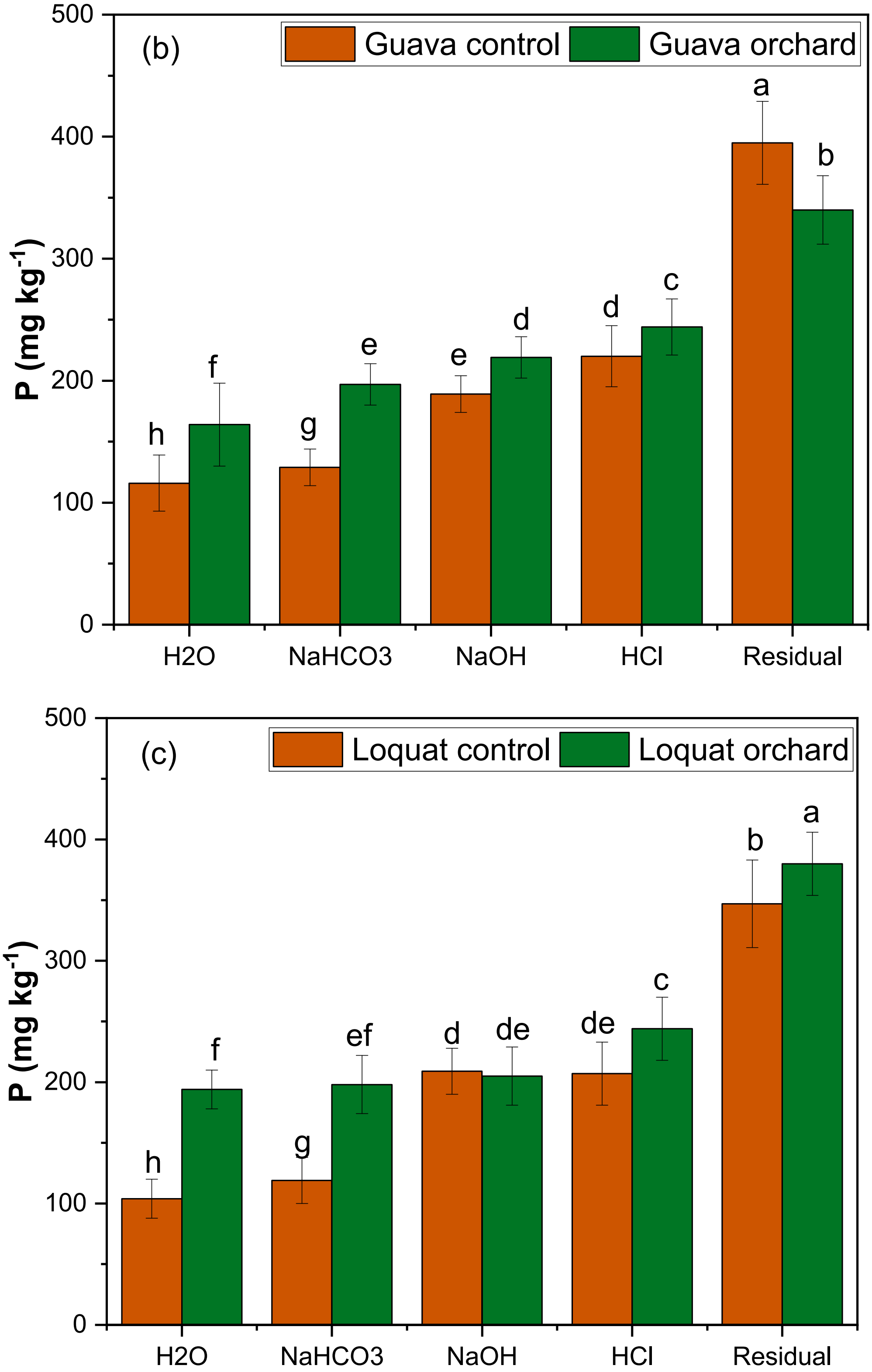

Figure 3. Phosphorus fractionation in subsoil (**a**) Citrus, (**b**) Guava, and (**c**) Loquat orchards. The bars are displayed as means ($n = 10$), ±values are standard errors. Small letters indicate significant differences at $p < 0.05$ between different treatment types.

The average amount of extractable P was found significantly higher ($p < 0.05$) in those soils of fruit orchards where the total amount of P was higher. Overall, the P fractions were higher in all types of orchard soils and lowered in the respective control soils. The residual P was higher in the loquat orchard in the subsoil sample. The lowest and highest amounts of H_2O-P fraction were found as 94 and 217 mg kg^{-1}. In the case of $NaHCO_3$-P, the highest measured value was 236 mg kg$^{-1,}$ and the lowest value was 119 mg kg^{-1}. HCl extraction reproduced a maximum extracted P, i.e., 291 mg kg^{-1}, and the minimum value was 207 mg kg^{-1}. The narrow range was observed for the residual P, where the maximum P was 382 mg kg^{-1}, and the minimum P content was 320 mg kg^{-1}. Higher accumulation of P in the soil as compared to control may be attributed to the litter falls of the orchards.

3.3. Soil Properties versus P Fractions

Soil properties (SOM content, clay content and CEC) greatly influenced the quantity and distribution of plant-available P in the orchard soils. Phosphorus fractions were significantly associated with SOM content in soil at both depths (Table 3). The quantity of P fraction was highly correlated with the SOM, soil texture and CEC of soils. The coefficient of determination (r^2) explaining the relationship of P fractions (y) and soil properties (x) are shown in Table 3. The higher values of r^2 for SOM, clay percentage, and CEC showed that P fractionation was substantially influenced by the soil properties. The sequential P fractions, namely H_2O, $NaHCO_3$, NaOH, HCl and residual, were related to SOC by the following r^2 values, i.e., 0.65, 0.86, 0.69, 0.66 and 0.77, respectively. These fractions were related to clay contents of soils by the r^2 values of 0.56, 0.57, 0.60, 0.57 and 0.63, respectively. The proportion of P increased with the increasing contents of clay in the soil. The interrelations of P fractions were largely shown with CEC by the r^2 values of 0.56, 0.77, 0.65, 0.59 and 0.68, respectively. During the study, a weak and negative relation of P fractions with a soil pH was noticed, irrespective of the sampling site and soil depth. At a depth of 0–25 cm, the increase in P fraction was mainly caused by increasingly finer soil texture. The higher r^2 values between P fractions and SOM indicated that all Hedley fractions increased strongly and significantly with increasing SOM contents in soils.

Table 3. Coefficient of determination (r^2) for P fractions versus soil properties under fruit orchards (n = 30).

P Fractions (mg kg^{-1})	**SOM**	**Clay**	**CEC**	**pH**
	(%)	**(%)**	**(meq/100 g)**	... ...
H_2O	0.65	0.56	0.56	−0.34
$NaHCO_3$	0.86	0.57	0.77	−0.47
NaOH	0.69	0.60	0.65	−0.27
HCl	0.66	0.57	0.59	0.13
Residual	0.77	0.63	0.68	0.36

3.4. Soil P Fractions versus Foliar P Contents

Nitrogen contents in the leaves of loquat and guava trees were relatively higher as compared to citrus plants (Figure 4). Phosphorus contents in the leaves were achieved as loquat > citrus > guava. Potassium (K) and Ca contents in leaves were appeared to be higher in citrus and lower in the guava species. Regardless of the plants, micronutrients were found in the order of Fe > Zn > Mn > Cu (Figure 5).

These microelements except Fe were found higher in the leaves of loquat when compared with citrus and guava species. The differences in the foliar contents of the plant nutrients could be attributed to the innate soil fertility and nutrient transformation in the orchard soils depending on the quantity and quality of tree litter. The results of the regression models showed a sufficient relationship between Hedley P fractions and the foliar P content of orchard trees. The coefficient of determination (r^2) showed changes in the extent of the relationship of foliar P contents with soil P fractions. Leaf contents of P were associated with soil P fractions extracted via H_2O, $NaHCO_3$, NaOH, HCl and residual P by the r^2 values of 0.50, 0.66, 0.89, 0.85 and 0.74, respectively (Figure 6). These results indicated that NaOH and HCl extractable P contents were strongly related to P bioavailability in orchards.

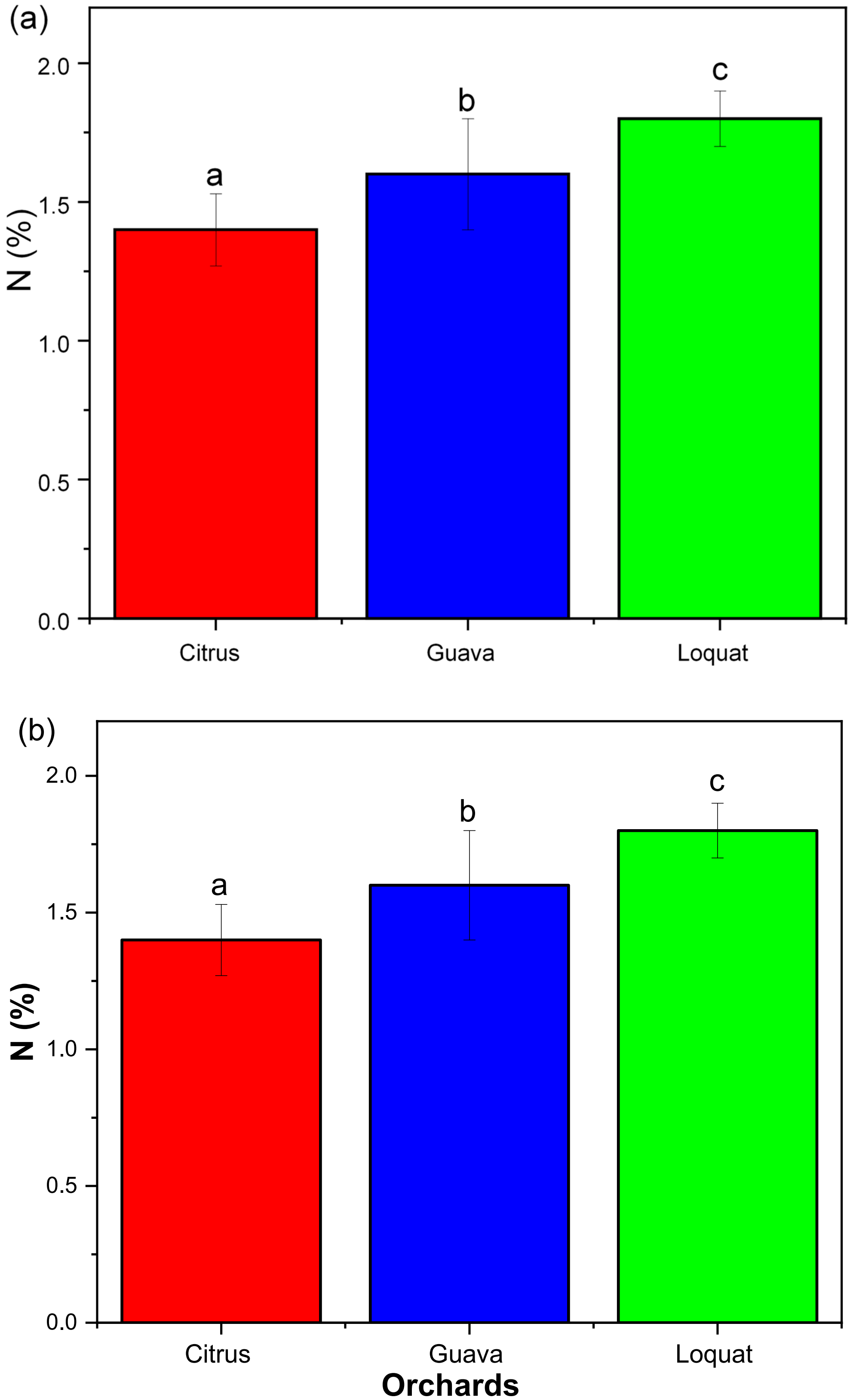

Figure 4. Comparison of foliar contents of N (**a**) and P (**b**) among fruit orchards. The bars are displayed as means (n = 10), ±values are standard errors. Small letters indicate significant differences at $p < 0.05$ between different treatment types.

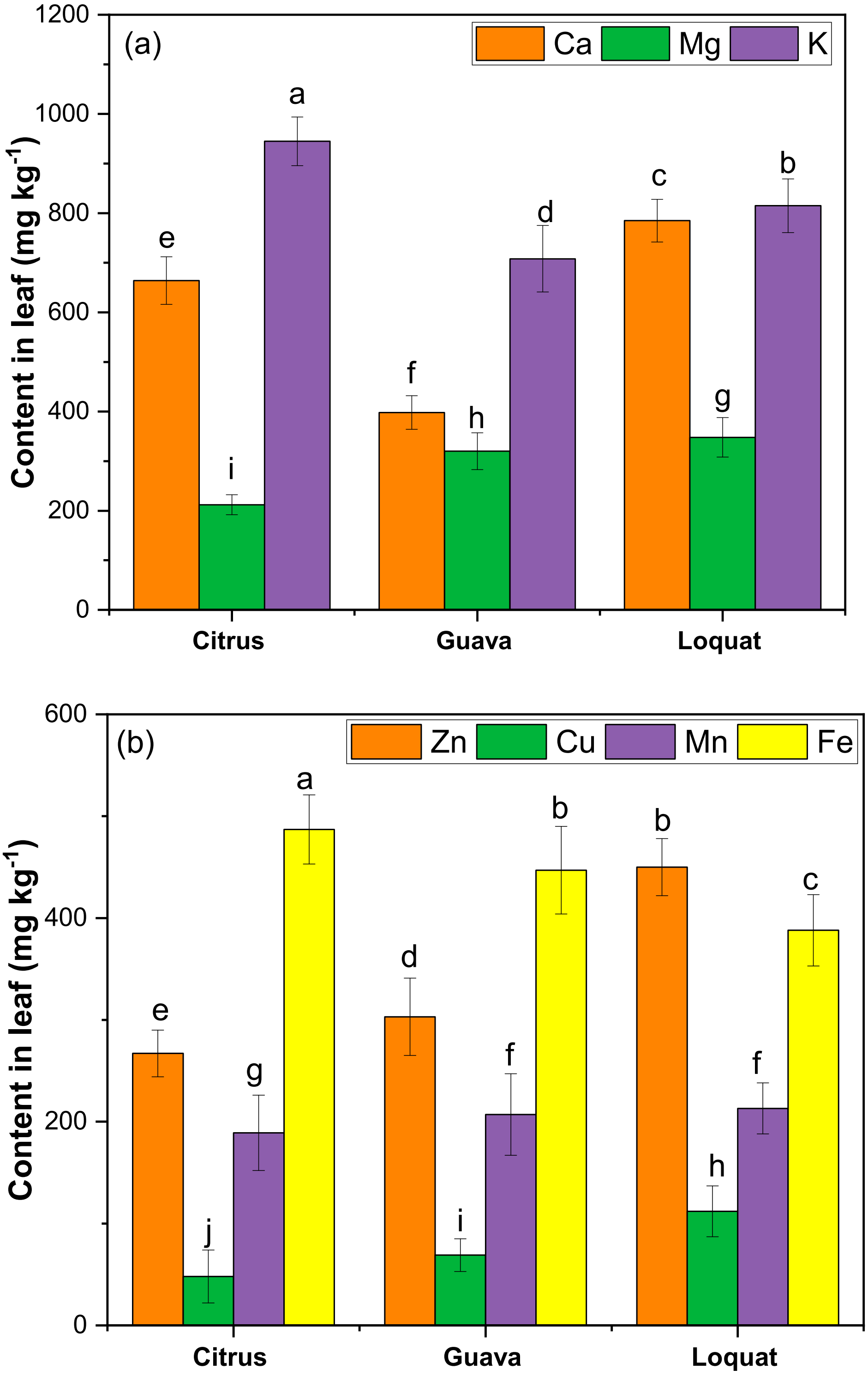

Figure 5. Comparison of foliar contents of nutrients among fruit orchards (**a**) foliar contents of Ca, Mg, and K, (**b**) foliar contents of Zn, Cu, Mn, and Fe. The bars are displayed as means (n = 10), ± values are standard errors. Small letters indicate significant differences at $p < 0.05$ between different treatment types.

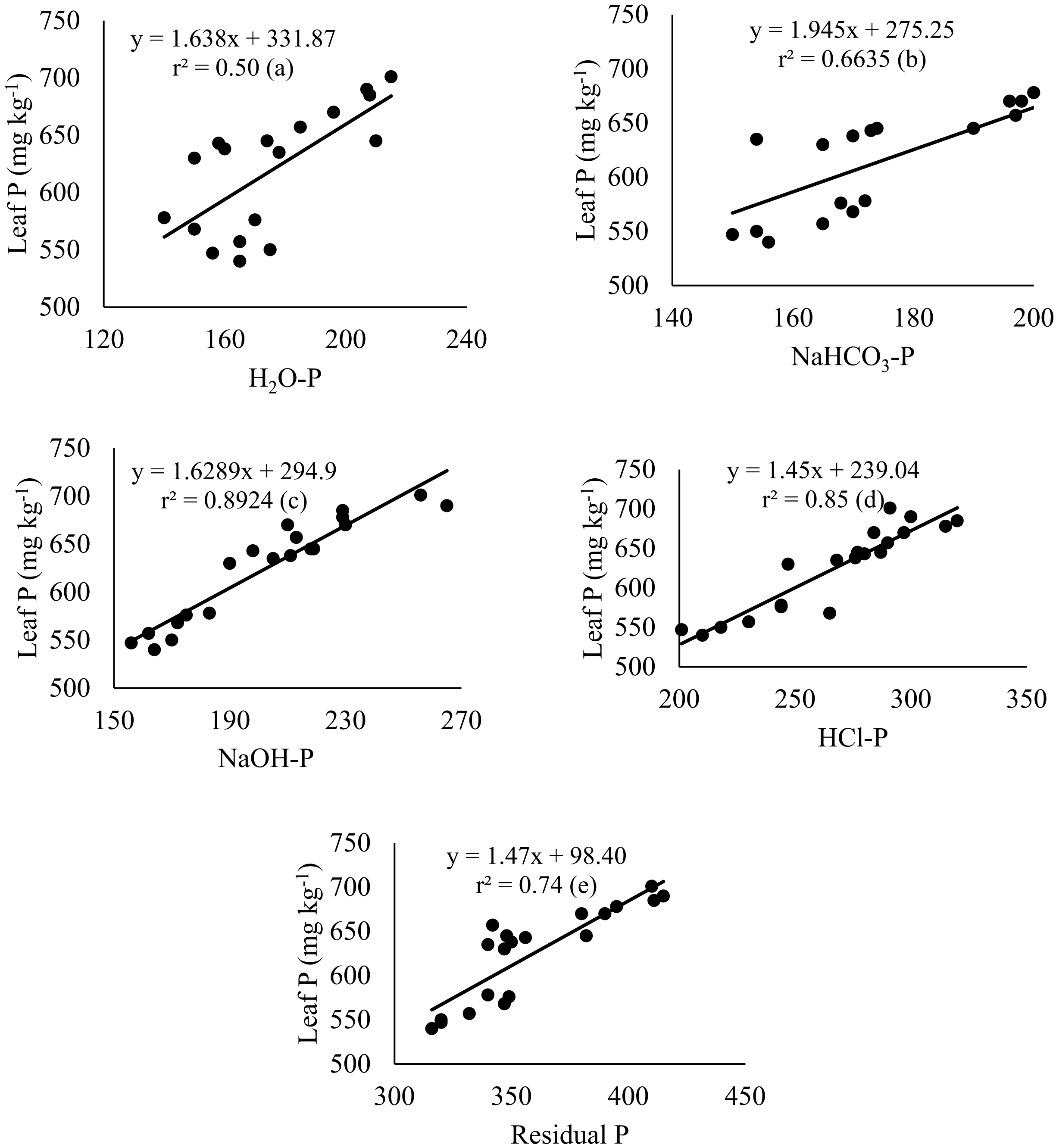

Figure 6. Regression plot for leaf P contents with soil P fractions (mg kg^{-1}) (**a**) leaf P vs. H_2O-P, (**b**) leaf P vs. $NaHCO_3$-P, (**c**) leaf P vs. NaOH-P, (**d**) leaf P vs. HCl-P, (**e**) leaf P vs. residual P.

4. Discussion

There were significant variations in soil properties after the establishment of orchards as compared to the respective control field. Higher amounts of SOM, CEC and major plant nutrients were achieved under orchard conditions. Loquat and citrus trees sequestered more amount of organic C. The orchard species exhibited slightly higher pH values in both surface and sub-surface soils. Micronutrients were inconsistently found among tree species, i.e., higher values of Mn, Cu, Zn, and Fe were found in citrus, loquat and guava species, respectively. Extractable micronutrients in soils have been reported to be closely interrelated with the amount and distribution of P in soil fractions [36].

Phosphorus fractionation is the validation of the nature, solubility and relative bioavailability of different inorganic and organic P fractions. Soil P fractions with different availability varied considerably by orchard tree species. These fractions were appeared to be higher in the residual P, HCl-P and NaOH-P forms and lower in the $NaHCO_3$ and H_2O extractable P forms. Soil P fractions showed comparative differences at both soil depths. The contents were higher in the surface soil as compared to the subsurface soil. The quantity of extractable P was found higher ($p < 0.05$) with a higher amount of total P contents in soils. Phosphorus fractions were varied among orchards as loquat > citrus > guava. All forms of P were lower in the respective control soil of each orchard. The higher amounts of extractable P forms could be predicted based on the quantity and quality of fallen leaf litter of trees. These litters may have affected the decomposition rate and played a key role in P dynamics in soils. The differences in the P fractions in this study could be largely attributed to the growth pattern of trees, soil fertility and controlling mechanisms of P transformation in soils. Since higher levels of inorganic P were found under loquat and citrus trees, therefore, the quantity and quality of fallen leaf litter of these trees may be responsible for the accumulation of a substantial amount of inorganic P in soils. The narrow range of P contents was observed for the residual P, where the maximum extracted P was 382 mg kg^{-1}, and the minimum P value was 320 mg kg^{-1}. The accumulation of P in orchard soils could be attributed to the litterfalls of trees. In soils, the residual P pool represents a significant proportion of total soil P, and several findings suggested that residual P is far from recalcitrant with respect to bioavailability over the longer period [37]. Zhao et al. [38] reported mineralization of organic P and decomposition of litter were the main sources of available P, and associated biological processes controlled the P transformation in soil. The soil P cycle is related to soil genesis and land management [12]. A significant decrease in the $NaHCO_3$ and NaOH extractable P fractions was reported with soil depth [39]. Each extracting agent has a different ability to extract the amount of soil P because the reagent is targeted for a different pool of soil P [40]. Jobbágy and Jackson [41] reported a strong influence of microbial activity on organic P accumulation in the topsoil layers and a concomitant decrease of organic P and SOC with soil depth. Changes in environmental conditions and pollutants have caused a major shift in the SOM and biological activity in the soil, destabilized the soil ecosystem, and reduced the nutrient pools in soils. The changes in the major nutrient dynamics in soils in relation to climate change have been reported by Bungau et al. [42]. The effects of climate change on the biological cycle of the trees, vegetative rest period of the trees, blooming period, and quantity of production have been reported by Gitea et al. [43]. Soil enzymes activities have been considered as viable indicators for the fertility and quality of soil [44].

4.1. Relationship of Soil Properties and P Fractions

The properties of soils substantially influenced the P contents in soils. The magnitude of P fractions was correlated with the SOM, soil texture, CEC and pH of soils. A sufficient relationship of P fractions in soils was noticed with soil properties. This relation has been markedly signified by the r^2 values. Phosphorus contents in soil are enhanced with the clay contents of soils. Soil texture affects the chemical characteristics of soil, including the formation of Al-organic matter bonded stable P and leaching of P from soils [45], which may be related to the available P. The relationship of P fractions with soil pH was either weak or negative in soils. The higher r^2 values between P fractions and SOM predicted that all Hedley fractions increased strongly and significantly with increasing SOM content in soils. Changes in the organic P indicated that OM inputs associated with the tree growth influenced the P dynamics in soil [46]. Zheng and Zhang [47] reported that soil texture and distribution of particle size markedly influenced soil P extraction in soils. Land cover changes invariably affected soil properties and biogeochemical processes [18] and altered soil P transformation by modifying the amount of plant P demand, litter quality and quantity, and soil properties [16]. The P extraction from soils has been associated with soil properties under different land uses by Augusto et al. [48] and Zederer and Talkner [49]. Predicting soil P fractions is not consistently related to a single soil variable. A strong positive correlation between SOC and total organic P content ($r^2 = 0.77$) in mineral soils has been reported [50]. A close relationship between SOC and P fractions suggested that these fractions in soil may be forecasted by the SOC content [25]. The optimum availability of P to plants typically occurs around pH 6.5. At a pH value below 6, P is fixed as Fe or Al phosphates or adsorbed to oxide surfaces [24,51], and above a pH value of 7, P is fixed in the form of Ca phosphates [24]. It has been shown that there are considerable changes in the relative importance of P fractions with pH, even if there is only a minor influence of pH on total P [52].

4.2. Phosphorus Fractions and Foliar P Contents

Fractionation of P in soils is important to predict the foliar P contents of plant species. Soil P fractions were differentiated among soil samples in all orchard species. The linear regression models for foliar P contents varied considerably amongst the tree species. Phosphorus contents in the leaves of loquat and citrus trees were relatively higher than guava. A lower amount of K and Ca contents in leaves of guava and a higher amount of these nutrients were achieved in citrus leaves. Iron and Zn contents were higher in the leaves than Mn and Cu, irrespective of the type of orchard. The differences in the foliar contents of these nutrients could be attributed to the relative soil fertility and nutrient transformation in the orchard soils depending on the quantity and quality of litter production. The Hedley P fractions were found related to the foliar P contents of orchard species. The coefficient of determination (r^2) was higher for NaOH, HCl and residual P fractions than H_2O and $NaHCO_3$. Variations in foliar nutrient contents among tree species can be attributed to the changes in the nutrient cycling processes linked with tree species and fallen leaf litter. Several reports have related the P extraction methods to the foliar P contents [43,44]. Prietzel and Stetter [44] reported citric acid extractable P in the soil as an important predictor to explain foliar P contents in a forest species. Manghabati et al. [53] reported that P contents in *Pinus abies* were related to the citric acid and $NaHCO_3$ extractable soil P. Manghabati et al. [53] reported total soil P as a predictor of the P nutrient in *Fagus sylvatica*. Soil P pools or fractions may not accurately simulate the P availability in the forest ecosystem due to the complex processes for P nutrition [54]. A recent study in tropical trees showed that foliar P contents may have limited indication ability for the physiological performance of leaves [55,56].

This study indicated that the fractionation of P in soils could relevantly predict the foliar P contents in plants. This has also indicated that soil organic matter inputs and turnover associated with the orchard plants exhibited a substantial amount of extractable P in soils. Predicting available P in relation to the bioavailability using more determination methods in contrasting soils under diversified land uses is further required. Moreover, the interrelation of P availability driven by microbial activities in soils with climate change under field conditions also needs to be investigated.

5. Conclusions

It is concluded that orchard species significantly influenced the P availability in soil. The largest proportion of P was associated with the residual fraction and fractions more resistant to extraction via NaOH and HCl. Among orchards, the P contents were found in the soils as loquat > citrus > guava. Loquat and citrus trees contributed to the soil quality in terms of SOM, CEC, and plant nutrients than guava species. The higher r^2 values between P fractions versus SOM, clay and CEC of soils predicted a strong interrelationship among these soil variables. This study signifies the promotion of P reserves in afforested soils. This may help address issues related to P fertility and environmental management.

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