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Vertical distribution of phosphorus fractions in soils of different land use systems of northern transect, Bengaluru

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Abstract
Phosphorus dynamics in soil is a complex process, influenced by cultivation practices and land-use patterns. The knowledge regarding the forms of phosphorus, and conditions controlling their availability is of importance in the appraisal of their status in soil. Phosphorus fractions in soil profile samples of various land use systems in northern transect of Bengaluru were studied in relation to soil properties. The results indicated that soil texture of the surface horizons was varying from sandy clay to sandy clay loam while for subsurface horizons it varied from sandy clay to clayey in soil profiles of different land uses. The soil pH varied from moderately acidic to slightly acidic in surface horizons and moderately acidic to slightly alkaline in subsurface horizons. Soils were non saline in nature under different land uses and EC followed increasing trend with soil depth in all profiles. OC decreased with soil depth in all the soil profiles with higher values recorded in surface horizons of forest (20.10 and 21.70 g kg^{-1} in profile 5 and 6, respectively) and organic farming (13.10 and 12.40 g kg^{-1} in profile 9 and 10, respectively) land uses. Saloid P, Al-P and Fe-P contents decreased with increasing soil depth in soil profiles of different land uses with higher values recorded in surface horizons of agriculture (15.37, 121.63 and 145.83 mg kg^{-1}, respectively) and horticulture land uses (16.78, 146.25 and 157.02 mg kg^{-1}, respectively). Reductant soluble P was recorded higher in surface horizons of forest (112.29 mg kg^{-1}) and horticulture (102.61 mg kg^{-1}) land uses. Organic-P was recorded higher in soil profiles of forest (93.65 to 265.11 mg kg^{-1}) and organic farming (72.35 to 220.89 mg kg^{-1}) land uses while lowest values of organic P were recorded in fallow land use (27.19 to 80.25 mg kg^{-1}). Total-P ranged from 173.17 to 628.59 mg kg^{-1}, 161.26 to 717.68 mg kg^{-1}, 152.83 to 376.42 mg kg^{-1}, 199.27 to 569.83 mg kg^{-1}, 186.46 to 482.42 mg $kg^{-1}$and 76.52 to 221.77 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, sericulture, forest, organic farming and fallow land uses, respectively.

Keywords: Soil profile, land use systems, organic carbon, phosphorus fractions

Introduction

Rapid urban expansion of Bengaluru city has transformed agricultural practices, particularly along its fringes and peri-urban areas. Diverse dryland farming systems are increasingly replaced by intensive, irrigated, multi-cropping systems, often relying heavily on chemical fertilizers, urban compost and sometimes waste water irrigation. These shifts while boosting crop yield, have significantly altered soil physical, chemical and biological properties, especially phosphorus (P) dynamics-a crucial nutrient required for plant growth and development. Phosphorus in soil exists in both organic and inorganic forms. The major inorganic forms are particularly those bound to aluminium, iron and calcium which make up the bulk of total P in soils and directly affect P availability to plants. However, the transformation and availability of these forms vary widely based on soil characteristics and management practices. The excessive and inefficient use of mineral fertilizers pose risks of environmental pollution and disrupt the natural cycling of nutrients. Phosphorus is an essential major nutrient required. for optimal plant growth and development. In crops, its total concentration typically ranges from 0.2 to 0.5 percent (Chandrakala *et al.*, 2017) [5]. In plants, it plays a crucial role in several physiological and biochemical processes, including energy transfer (ATP synthesis), photosynthesis, conversion of sugars and starches, movement of nutrients within the plant, genetic information transfer across generations, root initiation, and cell elongation. On an average, Indian soils contain 44 to 3580 mg per kg of total P and 2160 mg per kg of organic P (Kaistha *et al.*, 1999) [16]. Soil phosphorus occurs in two primary forms *ie.* inorganic and organic forms. Organic form, which is mainly confined to the surface layer, gets mineralized into inorganic forms. But the plants mainly depend on inorganic P forms for their P requirements. Inorganic P makes up the majority, accounting for 30 to 95 percent. of the total P. A large proportion of soluble inorganic phosphate added to soil is rapidly fixed as insoluble form and becomes unavailable to the plants. Chemical fractionation of phosphorus in soil provides knowledge regarding proportion of phosphorus distributed in various forms of phosphorus, which includes labile form such as saloid P, moderately labile form such as aluminium (Al-P), iron (Fe-P) and calcium bound P (Ca-P) and less labile form like reductant soluble P and occluded P. The forms of phosphorus are influenced by soil characteristics such as soil reaction (pH), organic matter, free calcium carbonate content and soil texture. The various inorganic P pools are interrelated and jointly contribute to plant available P (Hao *et al.*, 2008) [13]. Variation in phosphorus fractions is the function of pedogenic manifestation (Walker and Syers, 1976) [36], stage of soil development (Chang and Jackson, 1958; Smeck, 1976) [6, 30] and age of soils (Birkland, 1984) [4]. The proportion of different forms of phosphorus including organic-P which govern the response to applied phosphorus (Singh *et al.*, 2003) [27]. A thorough understanding of distribution of these forms in soil gives greater insight into phosphorus dynamics. Land use systems play an important role in nutrient transformation and hence their availability. Changes in land use systems affect soil properties, which may alter the availability and forms of nutrients in soil. Besides parent material, climatic factors and natural vegetation, land use pattern plays a vital. role in governing the nutrient dynamics and fertility of soils (Chavan *et al.*, 1995) [8]. Soil quality mainly depends on the management practices undertaken in different land use systems, which may modify the soil properties and hence the soil productivity. Land use pattern also has a profound influence on the chemical nature of soils which in turn governs the dominance of P fractions in soil. Such information is meager particularly in the soils of northern transect of Bengaluru and therefore the present study is a step in that direction.

Materials and Methods

From the northern transect of Bengaluru, six major land use systems were identified *viz.*, agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems. Two soil profiles from each land use system were excavated (2 soil profiles × 6 land use systems = total 12 soil profiles). Horizon wise soil samples were collected. Soil samples were dried, sieved through 2 mm sieve and stored for chemical analysis. Particle size analysis was carried out by International Pipette Method as described by Jackson (1973) [15]. Soil pH was determined in 1:2.5 soil water suspension using pH meter. The clear supernatant of soil water suspension was taken out and EC was measured using conductivity bridge (Jackson, 1973) [15]. Organic carbon was determined by wet oxidation method as described by Walkley and Black (1965) [37]. Fractionation of soil phosphorus was carried out by using the standard procedure as outlined by Peterson and Corey (1966) [21].

Results and Discussion

Soil texture

Texture of soil profiles in different land use systems of northern transect of Bengaluru is detailed in Table 1. Irrespective of land use systems, in almost all the soil profiles, sand content was decreased and clay content was increased with soil depth. But silt showed irregular trend in most of the soil profiles. Sand content varied from 34.91 to 59.37 percent, 30.88 to 51.76 percent, 34.06 to 53.24 percent, 30.13 to 57.03 percent, 39.54 to 57.81 percent and 39.55 to 56.12 percent in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Maximum sand content was recorded in surface horizon and minimum in sub surface horizons. Silt content ranged from 12.31 to 22.16 percent, 13.38 to 21.34 percent, 6.79 to 14.70 percent, 3.24 to 18.89 percent, 4.18 to 14.40 percent and 6.70 to 16.40 percent in agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Clay content ranged from 26.87 to 43.84 percent, 28.94 to 51.24 percent, 37.46 to 52.30 percent, 33.42 to 53.64 percent, 33.75 to 54.50 percent and 32.47 to 52.71 percent in agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Maximum clay content was recorded in sub surface (Bt) horizons and minimum in surface horizon (Ap) which may be due to illuviation of clay particles. Soil texture of the surface horizon was sandy clay in profiles 5 and 6, sandy clay loam in profiles 7, 9, 10, 11 and 12, gravelly clay loam in profile 3, sandy loam in profile 2 and gravelly sandy clay loam in profiles 1, 4 and 8. The soil texture of subsurface horizons ranged from sandy clay to gravelly clayey. Meena *et al.* (2014) [18] in their study reported that the sand content was recorded higher in surface horizons, whereas higher clay content was recorded in the sub-surface horizons because of the illuviation of fine fractions from the surface layers. Gebrelibanos and Assen (2013) [11] reported that lower clay and higher sand content were found in the surface layer and higher clay content was found in the subsurface layer of cultivated land than the adjacent natural forest, plantation forest and grazing lands. Decreasing trend of sand with soil depth indicates weathering of these fractions to finer particles as evidenced by increase in clay content with concomitant decrease in sand fraction (Patil and Dasog., 1999) [19]. Textural variations are mainly associated with type of parent material, degree of weathering, topography and time. Similar results were reported by Sitanggang *et al.* (2006) [29].

Chemical properties

The chemical properties of soil profiles in different land use systems are presented in Table 2.

Table 1: Texture of soil profiles in different land use systems of northern transect of Bengaluru

Horizon	Depth (cm)	Sand	Silt	Clay
			(%)	
Profile-1 (Agriculture land use system)				
Ap	0-10	59.37	12.31	28.32
Bt1	10-31	53.22	15.70	31.08
Bt2	31-46	51.06	12.80	36.14
Bt3	46-75	45.23	14.98	39.79
Bt4	75-106	46.78	14.04	39.18
Bt5	106-129	40.25	16.48	43.27
BC	129-152	38.19	21.43	40.38
Profile-2 (Agriculture land use system)				
Ap	0-11	55.38	17.75	26.87
Bt1	11-30	50.27	20.43	29.30
Bt2	30-64	45.66	19.82	34.52
Bt3	64-100	39.24	21.62	39.14
Bt4	100-128	37.73	22.16	40.11
Bt5	128-160	34.91	21.25	43.84
Profile-3 (Horticulture land use system)				
Ap	0-12	45.54	21.34	33.12
Bt1	12-41	42.15	16.48	41.37
Bt2	41-72	38.78	17.00	44.22
Bt3	72-108	38.02	13.93	48.05
Bt4	108-143	34.36	16.8	48.84
Bt5	143-175	30.88	19.94	49.18
Profile-4 (Horticulture land use system)				
Ap	0-12	51.76	19.30	28.94
Bt1	12-35	47.25	15.47	37.28
Bt2	35-82	40.08	16.47	43.45
Bt3	82-110	37.93	13.38	48.69
Bt4	110-144	36.50	14.39	49.11
Bt5	144-168	33.61	15.15	51.24

Horizon	Depth (cm)	Sand	Silt	Clay
			(%)	
Profile-5 (Forest land use system)				
Ap	0-14	50.93	11.61	37.46
Bt1	14-40	51.12	7.63	41.25
Bt2	40-72	46.55	7.12	46.33
Bt3	72-104	45.29	6.79	47.92
Bt4	104-140	34.06	14.7	51.24
Bt5	140-175	39.95	9.97	50.08
Profile-6 (Forest land use system)				
Ap	0-14	53.24	7.24	39.52
Bt1	14-46	48.54	10.8	40.66
Bt2	46-77	49.37	9.26	41.37
Bt3	77-115	43.49	8.03	48.48
Bt4	115-155	40.61	7.09	52.30
Profile-7 (Sericulture land use system)				
Ap	0-15	52.38	11.42	36.20
Bt1	15-33	49.68	13.11	37.21
Bt2	33-56	44.91	12.55	42.54
Bt3	56-84	37.34	18.89	43.77
Bt4	84-105	32.55	18.19	49.26
Bt5	105-135	30.13	16.23	53.64
Profile-8 (Sericulture land use system)				
Ap	0-16	57.03	9.55	33.42
Bt1	16-34	54.79	9.04	36.17
Bt2	34-65	50.96	9.71	39.33
Bt3	65-99	41.25	14.98	43.77
Bt4	99-132	44.11	9.61	46.28
Bt5	132-166	47.39	6.06	46.55
Bt6	166-180	46.12	3.24	50.64

Horizon	Depth (cm)	Sand	Silt	Clay
			(%)	
Profile-9 (Organic farming land use system)				
Ap	0-17	50.27	14.4	35.33
Bt1	17-48	52.39	13.86	33.75
Bt2	48-79	57.81	4.18	38.01
Bt3	79-116	49.91	7.92	42.17
Bt4	116-148	41.06	8.58	50.36
Bt5	148-170	48.99	9.38	41.63
Profile-10 (Organic farming land use system)				
Ap	0-10	55.18	7.77	37.05
Bt1	10-46	52.39	7.65	39.96
Bt2	46-71	48.22	8.94	42.84
Bt3	71-100	45.33	5.3	49.37
Bt4	100-124	41.07	5.67	53.26
Bt5	124-160	39.54	5.96	54.50
Profile-11 (Fallow land use system)				
Ap	0-16	56.12	11.41	32.47
Bw1	16-35	50.23	14.41	35.36
Bw2	35-71	45.37	16.40	38.23
Bw3	71-99	46.20	9.33	44.47
Bw4	99-134	39.55	7.74	52.71
Bw5	134-170	45.06	6.70	48.24
Profile-12 (Fallow land use system)				
Ap	0-14	50.05	14.97	34.98
Bt1	14-40	49.86	15.11	35.03
Bt2	40-71	47.46	11.27	41.27
Bt3	71-98	42.11	12.01	45.88
Bt4	98-132	40.86	9.88	49.26
Bt5	132-170	41.70	7.64	50.66

Soil reaction (pH)

The soil pH varied from moderately acidic to slightly acidic in surface horizons and moderately acidic to slightly alkaline in subsurface horizons. Soil pH showed increasing trend with soil depth in all the soil profiles which may be due to the removal of basic cations from surface soil horizons and their deposition in sub surface horizons by rainfall or irrigation. Soil pH ranged from 5.74 to 7.73, 5.92 to 7.39, 5.26 to 6.02, 5.78 to 7.48, 6.12 to 7.72 and 5.45 to 6.83 in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. The surface horizons were recorded acidic than subsurface horizons, which might be due to the release of organic acids by the decomposition of organic matter added to the surface soil layer and the presence of acidic parent materials such as granite and laterized granite (Harsha and Anil kumar, 2022) [14]. Similar results were reported by Vaidya *et al.* (2014) [33] in the soil pedons of pomegranate-growing areas.

Electrical conductivity (EC)

EC ranged from 0.12 to 0.36 dS m^{-1}, 0.29 to 0.37 dS m^{-1}, 0.10 to 0.24 dS m^{-1}, 0.19 to 0.64 dS m^{-1}, 0.18 to 0.49 dS m^{-1} and 0.09 to 0.26 dS m^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. The low EC values across different soil profiles indicates non saline nature of soils. The low EC values in the surface soil layer might be due to the removal of salts by the percolating water (Pramod and Patil, 2015) [23]. Except soil profile-3 (Horticulture land use system), in all other soil profiles, EC followed increasing trend with soil depth, which might be due to the leaching of soluble salts from the surface horizon and their subsequent accumulation in sub surface horizons (Chari, 2015; Pillai and Natarajan, 2004) [7, 22].

Organic carbon (OC)

OC showed decreasing trend with soil depth in all the soil profiles of different land use system. OC varied from 1.10 to 6.70 g kg^{-1}, 0.80 to 7.10 g kg^{-1}, 1.50 to 21.70 g kg^{-1}, 0.80 to 5.20 g kg^{-1}, 0.80 to 13.10 g kg^{-1} and 0.50 to 3.10 g kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Over all, surface horizons recorded higher OC content than sub-surface horizons due to increased amount of litter and crop residues at the surface and faster rate of their decomposition (Avinash *et al.*, 2019) [2]. Irrespective of land use systems, OC content decreased as moved down the soil profile (Shreshma and Subbarayappa, 2023) [26]. A similar trend was reported by Amara *et al.* (2015) [1] and Thangasamy *et al.* (2005) [31]. High OC was recorded in surface horizons of forest land use system followed by organic farming and low OC was recorded in fallow land use system.

Phosphorus fractions

Vertical distribution of phosphorus fractions in soil profiles of different land use systems are presented in Table 3.

Saloid P ranged from 0.30 to 15.37 mg kg^{-1}, 0.41 to 16.78 mg kg^{-1}, 0.82 to 5.45 mg kg^{-1}, 0.85 to 7.69 mg kg^{-1}, 0.65 to 5.37 mg $kg^{-1}$and 0.34 to 1.82 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Saloid P decreased with increasing soil depth in all the land use systems. Majumdar (2014) [17] reported that the surface horizons of red and black soils contain more amount of saloid-P compared to lower horizons. Among the different land use systems, the surface horizons of agriculture and horticulture land use systems had more saloid P content due to more intense crop management practices followed in these lands with high input of inorganic P fertilizers.

Al-P ranged from 7.10 to 121.63 mg kg^{-1}, 9.64 to 146.25 mg kg^{-1}, 11.33 to 88.31 mg kg^{-1}, 8.17 to 46.35 mg kg^{-1}, 9.60 to 58.15 mg kg^{-1} and 5.57 to 26.95 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively while Fe-P ranged from 8.43 to 145.83 mg kg^{-1}, 7.01 to 157.02 mg kg^{-1}, 6.2 to 70.24 mg kg^{-1}, 5.44 to 54.31 mg kg^{-1}, 9.18 to 64.85 mg kg^{-1} and 6.21 to 29.5 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Irrespective of different land use systems, in all the soil profiles, inorganic P fractions like saloid P, Al-P, Fe-P and reductant soluble P followed decreasing trend with soil depth. Similar trend of inorganic P fractions in soil profiles was also reported by Singh *et al.* (2014) [28], Dongale (1993) [9] and Trivedi *et al.* (2010) [32]. The higher content of saloid P, Fe-P and Al-P in the surface horizon is because of the effect of addition of inorganic fertilizers, manures and easily mineralizable organic P (Sheela, 2006) [25]. The surface horizons of agriculture and horticulture land use systems had high amount of Al-P and Fe-P whereas the same was very low in fallow land use system.

Reductant soluble P ranged from 32.18 to 90.86 mg kg^{-1}, 18.35 to 102.61 mg kg^{-1}, 32.21 to 112.29 mg kg^{-1}, 30.20 to 60.59 mg kg^{-1}, 23.52 to 75.16 mg kg^{-1} and 11.07 to 48.95 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. In all the soil profiles, reductant soluble P content was higher in surface horizons and the same decreased down the soil depth which may be due to dry environment at soil surface is conducive for its accumulation instead of prolonged moist condition prevailing in deeper soil layers (Singh *et al.*, 2014) [28]. High reductant soluble P values were recorded in surface horizons of forest land use system followed by horticulture. This may be attributed to higher OC input and undisturbed soil structure of forest land use system promoting reducing conditions. Similar results were also reported by Vishwanath and Doddamani (1991) [35], Bhavsar *et al.* (2018) [3], and Patil and Patil (2019) [20]. Reductant soluble P is strongly and positively correlated with OC (Veeresha and Patil, 2020) [34].

Occluded-P ranged from 29.97 to 45.67 mg kg^{-1}, 23.09 to 45.89 mg kg^{-1}, 23.97 to 43.8 mg kg^{-1}, 21.02 to 39.06 mg kg^{-1}, 18.57 to 37.82 mg kg^{-1} and 9.82 to 32.18 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. The distribution of occluded-P in soil profiles of different land use systems did not show definite trend, except in some soil profiles (Profile 1,3,8,10, and 12) where it decreased with soil depth. Similar results were also reported by Vishwanath and Doddamani (1991) [35] and Gajbhiye (2001) [10]. The highest occluded P was accumulated in the surface horizons of most of the soil profiles indicating non-mobility of P in soils down to lower layers (Bhavsar *et al.*, 2018) [3].

Ca-P ranged from 16.41 to 52.04 mg kg^{-1}, 26.17 to 73.16 mg kg^{-1}, 13.46 to 19.25 mg kg^{-1}, 12.37 to 47.62 mg kg^{-1}, 31.25 to 54.3 mg $kg^{-1}$and 10.33 to 16.23 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Ca-P content was recorded higher in subsurface horizons compared to surface horizons because of leaching of Ca ions from surface soil to lower soil layers through rainfall and irrigation. Similar results with respect to change in Ca-P content with soil depth was also reported by Singh *et al.* (2014) [28] and Trivedi *et al.* (2010) [32]. Among different P fractions, Ca-P fraction accounts the second lowest one after Saloid-P. This might be due to the low soil pH condition of study area (Sarkar *et al.*, 2014) [24].

Organic-P ranged from 39.66 to 181.94 mg kg^{-1}, 56.18 to 187.02 mg kg^{-1}, 93.65 to 265.11 mg kg^{-1}, 65.24 to 148.71 mg kg^{-1}, 72.35 to 220.89 mg $kg^{-1}$and 27.04 to 80.25 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, forest, sericulture, organic farming and fallow land use systems, respectively. Higher organic P content was recorded in surface horizons compared to sub surface horizons which may be due to continuous litterfall and FYM addition to the soil surface. The decrease in organic P content with increase in soil depth might be due to the decrease in organic matter content (Veeresha and Patil, 2020) [34]. Similar results were also reported by Bhavsar *et al.* (2018) [3]. Forest and organic farming land use systems showed high organic P content in the surface horizons compared to other land use systems due to high organic matter addition whereas fallow land use system showed low organic P content in surface horizons due to less organic matter input.

Table 2: Chemical properties of soil profiles in different land use systems of northern transect of Bengaluru

Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (g kg^{-1})
Profile-1 (Agriculture land use system)				
Ap	0-10	5.74	0.12	6.10
Bt1	10-31	5.81	0.14	5.80
Bt2	31-46	5.92	0.14	5.20
Bt3	46-75	5.99	0.19	4.70
Bt4	75-106	6.51	0.21	4.60
Bt5	106-129	6.97	0.22	3.30
BC	129-152	7.73	0.36	2.40
Profile-2 (Agriculture land use system)				
Ap	0-11	5.85	0.23	6.70
Bt1	11-30	5.78	0.22	6.10
Bt2	30-64	6.01	0.25	3.50
Bt3	64-100	6.23	0.24	2.20
Bt4	100-128	6.86	0.29	1.50
Bt5	128-160	7.58	0.34	1.10
Profile-3 (Horticulture land use system)				
Ap	0-12	6.01	0.36	6.40
Bt1	12-41	6.38	0.37	5.80
Bt2	41-72	6.62	0.29	5.10
Bt3	72-108	6.98	0.31	3.80
Bt4	108-143	7.01	0.32	2.70
Bt5	143-175	7.39	0.3	0.80
Profile-4 (Horticulture land use system)				
Ap	0-12	5.92	0.29	7.10
Bt1	12-35	6.22	0.31	4.80
Bt2	35-82	6.85	0.31	4.20
Bt3	82-110	7.23	0.34	3.50
Bt4	110-144	7.35	0.35	1.80
Bt5	144-168	7.36	0.37	1.10

Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (g kg^{-1})
Profile-5 (Forest land use system)				
Ap	0-14	5.42	0.12	20.10
Bt1	14-40	5.46	0.1	16.90
Bt2	40-72	5.51	0.14	9.60
Bt3	72-104	5.6	0.17	6.50
Bt4	104-140	5.75	0.22	4.10
Bt5	140-175	6.02	0.24	1.70
Profile-6 (Forest land use system)				
Ap	0-14	5.26	0.11	21.70
Bt1	14-46	5.31	0.12	18.40
Bt2	46-77	5.45	0.14	7.80
Bt3	77-115	5.80	0.19	4.60
Bt4	115-155	5.96	0.22	1.50
Profile-7 (Sericulture land use system)				
Ap	0-15	5.78	0.19	5.20
Bt1	15-33	6.12	0.19	4.40
Bt2	33-56	6.33	0.22	3.90
Bt3	56-84	6.45	0.27	2.60
Bt4	84-105	6.79	0.30	1.70
Bt5	105-135	6.91	0.29	0.80
Profile-8 (Sericulture land use system)				
Ap	0-16	5.91	0.25	4.80
Bt1	16-34	6.34	0.26	3.60
Bt2	34-65	6.51	0.17	2.20
Bt3	65-99	6.57	0.22	1.20
Bt4	99-132	6.73	0.33	1.0
Bt5	132-166	6.95	0.35	0.80
Bt6	166-180	7.48	0.64	0.80

Horizon	Depth (cm)	pH	EC (dS m^{-1})	OC (g kg^{-1})
Profile-9 (Organic farming land use system)				
Ap	0-17	6.58	0.18	13.10
Bt1	17-48	6.62	0.20	9.90
Bt2	48-79	6.79	0.24	7.40
Bt3	79-116	7.19	0.24	4.10
Bt4	116-148	7.43	0.31	2.70
Bt5	148-170	7.72	0.49	1.30
Profile-10 (Organic farming land use system)				
Ap	0-10	6.12	0.23	12.40
Bt1	10-46	6.83	0.24	8.70
Bt2	46-71	6.96	0.27	4.30
Bt3	71-100	7.07	0.31	2.10
Bt4	100-124	7.23	0.28	0.90
Bt5	124-160	7.49	0.36	0.80
Profile-11 (Fallow land use system)				
Ap	0-16	5.45	0.11	3.10
Bw1	16-35	5.87	0.12	2.70
Bw2	35-71	6.18	0.11	1.80
Bw3	71-99	6.47	0.15	1.50
Bw4	99-134	6.69	0.14	0.80
Bw5	134-170	6.83	0.21	0.50
Profile-12 (Fallow land use system)				
Ap	0-14	5.62	0.09	2.80
Bt1	14-40	6.05	0.10	2.10
Bt2	40-71	6.20	0.12	1.50
Bt3	71-98	6.38	0.18	1.10
Bt4	98-132	6.42	0.21	0.80
Bt5	132-170	6.65	0.26	0.60

The highest total P content of surface soil horizons in different land use systems followed the order Horticulture > Agriculture > Forest > Organic farming > Sericulture > Fallow. Total-P content ranged from 173.17 to 628.59 mg kg^{-1}, 161.26 to 717.68 mg kg^{-1}, 152.83 to 376.42 mg kg^{-1}, 199.27 to 569.83 mg kg^{-1}, 186.46 to 482.42 mg kg^{-1}and 76.52 to 221.77 mg kg^{-1} in different horizons of soil profiles of agriculture, horticulture, sericulture, forest, organic farming and fallow land use systems, respectively. The decrease in total P content down the soil depth might be due to the decrease in organic matter content. Similar results were also reported by Trivedi *et al.* (2010) [32]. The highest content of total P was recorded in surface soil layers of horticulture (717.68 mg kg^{-1}) and agriculture (628.59 mg kg^{-1}) land use systems which may be attributed to continuous addition of manures and P fertilizers in this layer (Singh *et al.*, 2014) [28]. The lower total P content in sub surface horizons may be due to continuous removal of P by plant roots from sub surface soil layers without subsequent replacement through organic matter or fertilizers (Gupta and Singh, 1972) [12]. Decrease in total P content with soil depth was also reported by Dongale (1993) [9], who worked on lateritic soils of coastal region.

Table 3: Vertical distribution of phosphorus fractions in soil profiles of different land use systems of northern transect of Bengaluru

Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Mineral-P	Organic-P	Total-P
		(mg kg^{-1})								
Profile-1 (Agriculture land use system)										
Ap	0-10	7.62	35.64	40.12	72.12	45.67	16.41	217.58	181.94	399.52
Bt1	10-31	3.81	35.07	37.12	79.38	40.59	19.62	215.59	169.44	385.03
Bt2	31-46	3.62	36.51	38.30	63.13	37.13	22.09	200.78	142.60	343.38
Bt3	46-75	2.97	17.29	23.20	49.20	37.28	25.74	155.68	112.57	268.25
Bt4	75-106	1.45	13.06	12.13	39.12	33.43	23.56	122.75	80.95	203.70
Bt5	106-129	1.22	7.10	8.77	36.23	34.16	24.47	111.95	76.36	188.31
BC	129-152	1.07	7.20	8.43	32.18	29.97	23.08	101.93	71.24	173.17
Profile-2 (Agriculture land use system)										
Ap	0-11	15.37	121.63	145.83	90.86	41.74	38.01	453.44	175.15	628.59
Bt1	11-30	8.51	91.52	102.41	82.23	39.36	44.25	368.28	152.34	520.62
Bt2	30-64	3.53	69.21	82.18	83.09	33.28	52.04	323.33	121.82	445.15
Bt3	64-100	1.23	27.60	41.30	62.08	43.05	51.56	226.82	101.41	328.23
Bt4	100-128	0.61	28.91	30.14	68.12	38.13	47.19	213.10	65.24	278.34
Bt5	128-160	0.30	15.53	12.13	49.28	39.36	50.03	166.63	39.66	206.29

Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Mineral-P	Organic-P	Total-P
		(mg kg^{-1})								
Profile-3 (Horticulture land use system)										
Ap	0-12	16.78	146.25	157.02	102.61	45.89	62.11	530.66	187.02	717.68
Bt1	12-41	8.26	103.83	109.56	84.38	42.84	61.62	410.49	156.21	566.70
Bt2	41-72	5.96	51.51	66.81	47.19	28.58	67.46	267.51	127.48	394.99
Bt3	72-108	3.89	25.28	38.36	25.46	23.09	73.16	189.24	105.25	294.49
Bt4	108-143	1.25	9.64	13.29	18.35	23.29	45.08	110.90	73.29	184.19
Bt5	143-175	0.86	9.97	10.98	18.77	24.17	40.33	105.08	56.18	161.26
Profile-4 (Horticulture land use system)										
Ap	0-12	8.76	51.52	53.12	72.97	32.28	27.25	194.38	169.35	363.73
Bt1	12-35	8.90	53.91	48.41	65.89	42.74	26.17	192.11	143.30	335.41
Bt2	35-82	5.53	39.60	49.36	65.93	39.36	34.78	194.96	122.23	317.19
Bt3	82-110	3.51	40.20	22.98	56.22	41.92	37.61	162.24	102.58	264.82
Bt4	110-144	1.65	15.19	18.17	58.82	36.28	36.48	151.40	98.04	249.44
Bt5	144-168	0.41	9.63	7.01	41.24	35.97	36.55	121.18	92.26	213.44

Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Mineral-P	Organic-P	Total-P
		(mg kg^{-1})								
Profile-5 (Forest land use system)										
Ap	0-14	5.45	83.37	61.10	112.29	29.05	13.46	304.72	265.11	569.83
Bt1	14-40	4.63	70.37	54.03	88.13	26.59	16.08	259.83	238.76	498.59
Bt2	40-72	3.07	59.68	43.29	64.79	23.97	18.31	213.11	183.95	397.06
Bt3	72-104	1.72	37.06	28.19	56.18	25.66	18.56	167.37	146.34	313.71
Bt4	104-140	0.95	25.75	29.03	40.21	28.20	19.25	143.39	101.83	245.22
Bt5	140-175	0.82	11.33	11.45	41.25	30.36	18.97	114.18	93.65	207.83
Profile-6 (Forest land use system)										
Ap	0-14	4.22	88.31	70.24	95.21	35.87	13.75	307.60	237.27	544.87
Bt1	14-46	3.99	90.78	54.33	68.72	36.59	13.94	268.35	220.56	488.91
Bt2	46-77	3.79	49.60	43.71	70.63	43.80	16.48	228.01	184.30	412.31
Bt3	77-115	2.07	38.98	17.41	49.40	40.28	18.33	166.47	121.41	287.88
Bt4	115-155	1.20	15.68	6.20	32.21	26.90	19.01	101.20	98.07	199.27

Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Mineral-P	Organic-P	Total-P
		(mg kg^{-1})								
Profile-7 (Sericulture land use system)										
Ap	0-15	7.69	46.35	54.31	60.59	37.36	23.22	229.52	146.90	376.42
Bt1	15-33	3.07	31.59	36.18	54.32	34.06	24.64	183.86	117.41	301.27
Bt2	33-56	1.84	17.30	13.29	57.21	34.44	27.02	151.10	100.52	251.62
Bt3	56-84	1.23	10.29	11.32	42.01	36.69	15.52	117.06	93.53	210.59
Bt4	84-105	0.92	8.98	8.41	45.97	35.24	12.37	111.89	78.21	190.10
Bt5	105-135	0.85	8.17	7.95	38.64	32.21	12.44	100.26	73.44	173.70
Profile-8 (Sericulture land use system)										
Ap	0-16	6.61	41.44	47.34	41.29	39.06	29.98	205.72	148.71	354.43
Bt1	16-34	3.75	35.83	43.18	43.81	31.74	28.59	186.90	137.67	324.57
Bt2	34-65	2.19	38.52	38.29	39.61	33.82	36.05	188.48	106.81	295.29
Bt3	65-99	2.84	27.59	30.30	35.12	28.74	47.62	172.21	94.61	266.82
Bt4	99-132	2.23	18.58	24.61	35.08	23.44	33.12	137.06	88.54	225.60
Bt5	132-166	1.72	18.63	16.92	31.35	26.08	24.61	119.31	73.17	192.48
Bt6	166-180	0.96	9.09	5.44	30.20	21.02	20.87	87.58	65.24	152.82

Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Mineral-P	Organic-P	Total-P
		(mg kg^{-1})								
Profile-9 (Organic farming land use system)										
Ap	0-17	4.95	58.15	64.85	75.16	36.29	31.25	270.65	211.77	482.42
Bt1	17-48	4.12	47.95	42.11	67.26	36.94	34.51	232.89	198.16	431.05
Bt2	48-79	3.41	26.64	31.51	54.25	34.58	46.69	197.08	145.37	342.45
Bt3	79-116	2.02	27.01	24.30	34.21	29.15	49.46	166.15	118.20	284.35
Bt4	116-148	0.92	14.45	16.95	36.14	30.86	54.30	153.62	96.23	249.85
Bt5	148-170	0.68	10.27	9.18	36.33	33.20	38.40	128.06	72.35	200.41
Profile-10 (Organic farming land use system)										
Ap	0-10	5.37	49.98	55.81	68.35	37.20	33.44	250.15	220.89	471.04
Bt1	10-46	3.34	39.37	63.12	63.27	37.82	37.24	244.16	183.76	427.92
Bt2	46-71	2.77	40.06	63.18	64.18	35.05	48.57	253.81	146.19	400.00
Bt3	71-100	2.15	25.75	43.33	52.74	34.74	47.19	205.90	114.82	320.72
Bt4	100-124	0.87	21.20	21.13	41.68	23.51	45.10	153.49	99.92	253.41
Bt5	124-160	0.65	9.60	12.80	23.52	18.57	40.98	106.12	80.34	186.46

Horizon	Depth (cm)	Saloid-P	Al-P	Fe-P	Reductant soluble-P	Occluded-P	Ca-P	Mineral-P	Organic-P	Total-P
		(mg kg^{-1})								
Profile-11 (Fallow land use system)										
Ap	0-16	1.82	24.48	25.77	48.95	30.17	10.33	141.52	80.25	221.77
Bw1	16-35	1.64	25.10	17.23	40.17	17.76	13.01	114.91	76.31	191.22
Bw2	35-71	1.10	16.24	13.79	31.22	17.94	13.12	93.41	63.28	156.69
Bw3	71-99	0.95	17.62	9.20	22.78	16.51	13.86	80.92	40.20	121.12
Bw4	99-134	0.66	6.15	7.68	11.26	20.06	15.99	61.80	33.25	95.05
Bw5	134-170	0.43	5.57	6.21	11.07	9.82	16.23	49.33	27.19	76.52
Profile-12 (Fallow land use system)										
Ap	0-14	1.21	26.95	29.50	43.21	32.18	10.83	143.88	68.36	212.24
Bt1	14-40	1.17	25.47	21.19	31.20	25.36	10.88	115.27	65.82	181.09
Bt2	40-71	0.72	13.02	14.77	23.17	14.98	10.96	77.62	63.24	140.86
Bt3	71-98	0.81	13.89	8.31	16.24	11.27	12.25	62.77	55.31	118.08
Bt4	98-132	0.68	10.18	8.51	16.47	10.32	13.74	59.90	42.12	102.02
Bt5	132-170	0.34	7.23	7.78	12.03	10.49	13.8	51.67	29.07	80.74

Concussion

The study revealed that soil properties varied significantly across different land use systems in the northern transect of Bengaluru. Sand content decreased while clay content increased with soil depth, indicating clay illuviation. Surface soils were generally acidic with low EC, showing non-saline nature. Organic carbon was higher in surface horizons, particularly under forest and organic farming systems, due to higher organic matter input. Among phosphorus fractions, saloid-P, Al-P, Fe-P, and organic-P were concentrated in surface layers, decreasing with depth. Overall, horticulture and agriculture soils recorded the highest total phosphorus, emphasizing the influence of intensive land use and fertilization practices.

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