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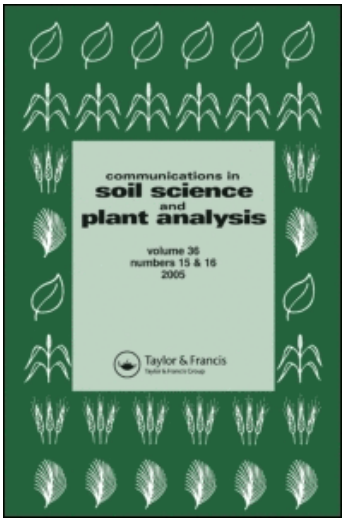

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Enzyme activities in hill land soils of the Appalachian region

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ENZYME ACTIVITIES IN HILL LAND SOILS OF THE APPALACHIAN REGION

Key Words: Organic and inorganic P and S, C, N, CEC, Phaseolus vulgaris L.

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ABSTRACT

The top two horizons of 14 major hill land soils of the Appalachian Region were evaluated for activities of acid phosphatase (AP), pyrophosphatase (PPi), arylsulfatase (AS) and urease (UR) enzymes. A relationship between enzyme activities and soil properties was examined. Surface horizons contained higher enzyme activities than the subsurface horizons. Overall, enzyme activities were positively correlated with soil moisture content, percent water-filled porosity, C, N, K, Mn and CEC. Activities of AP and PPi were negatively correlated with soil pH. The AP and UR activities were positively related to various forms of P. Enzyme activities were positively related to total and organic S. Pot trial was performed in green house conditions to evaluate the relationship between enzyme activities and snapbean (Phaseolus vulgaris L.) growth and N, P, and S uptake. With a few exceptions, activities of AP, AS and UR were positively related to snapbean shoot wt. and shoot content of N, P, and S. The PPi activities of subsurface horizons were positively related to shoot wt. and mineral content. Enzyme activities varied from one soil horizon to another. The effects of various soil

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properties and their interacting factors on activities of the four enzyme systems are discussed.

INTRODUCTION

Nutrient cycling in soil is mediated by biochemical, chemical and physicochemical reactions. Enzymes in soil catalyze biochemical reactions, and thereby mediate the transformation of organically bound nutrients into inorganic plant available forms (18, 19, 21,22). A large portion of the total soil P and S is in organic forms (4,22,27). Phosphatase and arylsulfatase enzymes are known to hydrolyze these organic forms into plant available inorganic forms (18,19,21,22). Yields and nutrient contents of crops have been related to various enzyme activities (18,19,20, 21,31). Hydrolase enzymes, such as phosphatase, urease, and arylsulfatase have been studied in various soils and ecosystems. Their activities have been related to various soil properties (1,10,18,19,21).

In various soils, enzyme activities are directly related to soil organic C, but their relationships with other soil properties such as pH, texture, exchangeable cations and anions have been a matter of controversey (1,18,19,21). Air drying and storage of soil samples is known to reduce phosphatase and pyrophosphatase acitivity in soils (18,21,29). In some soils, higher phosphatase activities were recorded in air dried soil samples than samples kept at field moist conditions (6). Urease and sulfatase activities are less influenced by air drying and storage of soils (1,18,21).

In recent years the use of urea as N fertilizer has increased throughout the world. The efficiency of added urea in many soils is dependent upon urease activity. High urease activities might result in excessive hydrolysis of urea and subsequent loss of ammonia by volatilization. On the other hand, low urease activities might cause urea to be lost by leaching (1,10). Inorganic

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pyrophosphatase is the enzyme that catalyzes the hydrolysis of pyrophosphate to orthophosphate (5,29). Understanding of pyrophosphatase activity in soils is important mainly because pyrophosphate is used as a phosphate fertilizer.

Soils of the Appalachian region are mostly acidic and infertile. Many soils of the region are situated on steep terrain. Surface horizons are known to contain a high organic matter content, while, subsurface horizons generally have finer texture and a lower organic matter content. Enzymes in these soils would play a dominant role in transformation of organically bound nutrients into plant available inorganic forms. The objectives of the present report were to (1) evaluate the magnitude of enzyme activities in the major hill land soil of Appalachia, (2) relate enzyme activities to soil physical and chemical properties, and (3) by means of pot-trial, evaluate the relationship between enzyme activities and snap bean (*Physeolus vulgaris* L.) mineral content and growth.

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MATERIALS AND METHODS

Soils

The top two horizons from 14 major hill land soils of the Appalachian region were collected from 4 states for the determination of enzyme activities. Selected properties of the soils are given in Table 1. With the exception of Watauga and Upshur soils, the soil samples were collected from woodland locations. Soil samples for Watauga soils were collected from pasture lands and samples for Upshur were obtained under the grass meadow. Bulk samples from the top two horizons of each soil were collected in the late spring and passed through a 2 mm sieve, air-dried and stored (20 $\pm$ 5°C) in plastic containers for two years before the determination of enzyme activities.

Soil Analysis

Soils were analyzed for pH (soil to solution ratio 1:1),

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TABLE 1
Classification and selected properties of soils studied.

Soil Classification	Horizon	WFP	pH	Total C	Total N	Phosphorous Total	Phosphorous Organic	Phosphorous Extract.	Sulfur Total	Sulfur Organic	K	CEC†	Mn
		%	H_2O										
				--g kg^{-1}--		----------mg kg^{-1}----------					--cmol(+)kg^{-1}--		mg kg^{-1}
North Carolina													
Ashe (Typic Dystrochrept)	A	0.67	4.4	15.2	0.9	105.5	73.8	9.5	57.2	28.9	0.10	2.29	1.0
	Bw	0.51	4.6	3.7	0.7	91.3	62.4	14.4	39.8	0.1	0.04	1.04	0.5
Hayesville (Typic Hapludult)	Ap	0.47	5.0	13.5	1.2	178.9	153.1	9.3	83.7	49.0	0.14	1.96	5.9
	Bw	2.65	5.2	5.9	0.1	275.3	251.5	3.4	176.0	0.8	0.22	2.45	2.1
Watauga (Typic Hapludult)	Ap	1.93	6.3	21.4	1.6	516.5	358.3	24.5	219.5	191.9	0.25	8.11	0.4
	Bt	1.83	6.6	7.6	0.2	328.8	279.4	5.1	53.6	34.3	0.35	4.44	0.3
South Carolina													
Edneytown (Typic Hapludult)	A	0.98	4.0	49.3	3.1	108.8	87.3	19.9	199.5	162.3	0.26	4.64	17.8
	E	0.55	4.6	8.6	0.1	38.5	28.3	7.9	20.1	0.1	0.05	1.77	0.5
Tennessee													
Dandridge (Lithic Ruptic Alfic Eutrochrepts)	A	5.15	4.7	110.4	11.2	625.0	339.6	58.5	373.0	321.1	0.80	12.27	34.6
	E	2.84	4.5	40.5	3.5	611.8	247.2	39.0	228.0	180.9	0.55	8.25	19.7
Dunmore (Typic Paleudults)	A	1.21	3.9	88.9	4.5	187.6	142.8	22.3	342.5	315.4	0.43	4.83	55.5
	E	0.44	4.6	11.6	0.6	99.8	78.0	9.7	56.9	23.1	0.08	1.73	1.6
Porter (Umbric Dystrochept)	A	3.98	3.4	220.9	14.4	556.2	454.3	31.4	842.5	771.9	0.36	12.15	11.0
	Bw	1.07	4.4	5.9	0.2	132.9	96.3	3.7	98.4	7.4	0.08	4.61	1.5
Tate (Typic Hapludult)	A	2.53	4.0	130.5	7.6	653.9	483.5	21.0	701.0	630.3	0.50	10.31	35.9
	BA	2.25	4.3	94.4	8.4	632.0	522.2	17.8	527.0	463.4	0.32	7.37	8.6
West Virginia													
Berks (Typic Dystrochrept)	A	8.07	3.8	171.6	6.4	371.2	309.0	34.0	593.0	540.4	0.49	10.46	33.4
	E	1.32	4.2	18.0	0.7	124.9	96.3	8.4	82.6	41.2	0.14	6.29	1.9
DeKalb (Typic Dystrochrept)	A	2.38	3.9	71.4	3.6	304.5	246.2	46.1	477.0	434.9	0.31	7.17	157.2
	E	0.83	4.4	22.0	1.3	234.4	195.5	21.8	169.5	128.7	0.17	4.16	98.6
Gilpin (Typic Hapludult)	A	3.33	5.1	103.7	8.1	516.1	432.0	33.7	383.0	336.1	0.76	11.11	56.8
	BA	1.71	4.9	22.5	0.9	347.4	283.8	10.2	129.0	85.8	0.40	6.39	17.9
Lily (Typic Hapludult)	A	2.46	3.9	84.0	4.4	326.4	264.0	53.4	440.5	347.0	0.46	7.32	61.5
	BA	1.07	4.6	25.0	0.5	138.9	108.9	16.4	131.0	48.0	0.13	3.32	6.9
Upshur (Typic Hapludult)	A	2.11	5.2	25.1	3.0	289.9	232.7	13.2	203.0	164.3	0.39	8.53	3.4
	Bt	2.56	4.7	5.5	0.1	141.8	111.5	3.2	58.8	18.5	0.18	13.27	3.4
Westmoreland (Typic Hapludalfs)	A	2.33	4.7	65.4	6.2	523.3	426.9	38.3	46.6	0.1	0.61	7.11	102.5
	E	1.75	4.3	19.8	0.5	533.9	475.9	12.3	22.4	0.1	0.14	4.83	19.4

† CEC = Σcmol(+)$\cdot kg^{-1}$ of K + Na + Ca + Mg + Al + H.

exchangeable bases (30), exchangeable acidity and Al (33), and DTPA extractble Mn (11). Extractable P and S were determined by extracting soil with Bray-1 reagent (0.025M HCl + 0.03M NH_4F). The P and S in the extract were detected by inductively coupled plasma emission spectroscopy (ICP). Organic P was estimated by the method of Olsen and Sommers (15) and represents the difference between P in the ignited (total) and unignited (inorganic) samples. Organic S was computed by taking the differences between total S from Leco (Leco SC 132 Model, Leco Corp., St. Joseph, MI) and extractable S from Bray-1 extractant. Total C and N were determined using Leco CHN 600. The NH_4^+-N and NO_3^--N were determined in 1 M KCl extractant of soils by Technicon Autoanalyzer II (Technicon, Terrytown, NY). The moisture content of samples at collection was determined by drying soils for 48 hours at 105°C. The percentage water content was multiplied by bulk density (BD) to obtain volumetric water content. Bulk density was estimated by taking 60 mm diameter soil cores of known volume. The percent water filled porosity (% WFP) was determined according to Linn and Doran (12).

Assay of Enzymes

Pyrophosphatase activity was determined by the method of Dick and Tabatabai (5) and Tabatabai (24). Acid phosphatase activity was assayed according to Eivazi and Tabatabai (6) and Tabatabai and Bremner (25). Arylsulfatase and urease activities were assayed as previously described (24,26,28). Ammonium released in urease activity was determined by Technicon Auto Analyzer II. Assays were performed in duplicate soil samples with an appropriate control.

Snapbean Studies

In order to assess the relationships between soil enzyme activities and growth and nutrient uptake by plants, a pot culture experiment was conducted in the greenhouse. In this study, an Al-tolerant snapbean, cv. Dade, was used as the test plant. Soil samples of each horizon received a blanket application of 89 mg N as NH_4NO_3, 89 mg P and 113 mg K as KH_2PO_4 per kg

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of soil. The lime requirement (LR) for each horizon was estimated from the relationship of LR (Mg ha^{-1}) = 2 Al + [2- (Ca + Mg)] where Al, Ca and Mg are in cmol(+)kg^{-1}. Dolomitic lime was used and soils were moistened to a moisture content corresponding to 33 kPa tension. Snapbeans were seeded directly into pots containing 1 kg of soil. After germination, the plants were thinned to two plants per pot. There were three replications for each soil horizon. During the growth period, the pots were watered daily to bring the soil moisture to a level corresponding to 33 kPa tension. After 5 weeks, plants were harvested and shoot samples were oven dried at 65°C for 4 days, ground to pass a 60 mesh screen and digested in HNO_3:$HClO_4$ (1:4) mixture. Inductively coupled argon plasma emission spectroscropy was used to determine P and S. The C and N content of shoots were determined by a Leco CHN 600 analyzer.

Statistical Analysis

Statistical Analysis System (SAS) programs were used to calculate the following: (i) comparison of activities in different horizons usings Duncan's Multiple Range Test (DMR), (ii) simple correlation coefficient (r) relating enzyme activities to soil properties and snapbean nutrient contents and growth, and (iii) multiple regression equations relating enzyme activities to soil properties.

RESULTS AND DISCUSSION

Acid phosphatase

Among surface horizons, Porter A recorded the highest acid phosphatase (AP) activity (Table 2). On an average, surface horizons recorded 4.9 fold higher AP activities than the subsurface horizons. A decline in AP activities with soil depth has been attributed to a decrease in microbiological activity and reduction in C, N and organic P content of the soil (9,18,19, 21). Surface horizon of Porter A contained the highest amounts of C, N, and relatively high amount of total and organic S and P. Ashe soil contained moderately low amounts of C, N and

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TABLE 2
Enzyme activities in various soils of Appalachia.†

Soils	Acid Phosphatase		Pyrophosphatase		Arylsulfatase		Urease	
	S‡	SS‡	S	SS	S	SS	S	SS
Ashe	103h*	36i	127e	40d	28e	14fg	75d	4h
Hayesville	184h	122f	137e	47d	82e	15fg	36eg	1h
Watauga	414g	94g	463d	49d	353b	28ef	114c	14gh
Edneytown	812f	80gh	2630a	51d	35e	23eg	6gh	22fg
Dandridge	980cf	446b	762c	244b	295c	217b	114c	186b
Dunmore	827f	69h	1131b	46d	183d	33ef	49df	46de
Porter	2173a	157e	1278b	37d	67e	4g	21fh	9gh
Tate	1063cd	636a	399d	152c	425a	423a	216b	235a
Berks	1951b	133f	2849a	155c	56e	41e	24fh	12gh
DeKalb	1158c	289c	2676a	517a	163d	32ef	1h	32ef
Gilpin	934df	229d	852c	265b	332b	146c	610a	50d
Lily	1028cd	119f	1360b	46d	191d	73d	38eg	65c
Upshur	423g	95g	295de	47d	211d	38ef	64de	8gh
Westmoreland	863cf	156e	848c	72d	316bc	93d	111c	33ef
Mean	922	190	1129	126	195	84	105	51
LSD 0.05	178	21	226	31	53	22	29	14

†Pyrophosphatase activity as μg of ortho-P released•g soil^{-1}• 5h^{-1}; Acidphosphnatase and arylsulfatase activities are expressed as μg of P-nitrophenol released•g soil^{-1}•h^{-1}; Urease activity as μg of NH_4-N released•g soil^{-1}•2h^{-1}.
‡S = Surface horizons, SS = subsurface horizons.
*Means in each column not followed by the same letter differ at the 0.05 levels of probability by DMR Test.

organic P and S and gave the lowest AP activities among the surface and subsurface horizons.

The AP activities in surface and subsurface horizons gave a positive significant correlation with original moisture by volume (OMV), and the original moisture by wt. (OMW) (Table 3). The AP activities were positive related to the water filled pore space (%WFP). Linn and Doran (12) reported a close correlation between % WFP and microbial activities. In the current study, % WFP accounted for 22 to 56% of the soil to soil variability in AP activities.

Positive significant relationships were observed between AP activity and C, N, and total and organic S. The AP activities were positively related to to NH_4^+-N, NO_3^--N, Na, K, Mn, H, and CEC. (Table 3). Such relationships are well documented in several other soil types (7,8,9,18,21).

Speir (20) recorded a positive relation between AP activity and adsorbed S in Tongan soils and a negative relationship in Cook Island soils. The Tongan soils had relatively less adsorbed S than Cook Island soils. In the current study, AP activities gave a negative nonsignificant correlation with extractable S of subsurface horizons and positive significant relationships with extactable S of surface horizons.

The AP activities were positively related to different forms of P. Phosphatase activities are known to be directly related to the organic P content of soils (21). Linear, inverse and no relationships between AP activities and inorganic P content have been reported (9,21). In the current study, we found a positive relationship between AP activities and extractable P (EP). It appears that the extent of inorganic P content of soils determines whether the relation between inorganic P and AP activity is positive or negative. In the current study, 20 out of 28 horizons had EP less than 25 mg kg^{-1} soil (Table 1). The EP levels of many of the soils in our study were low enough that AP activity was induced, not repressed, by inorganic P.

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TABLE 3
Correlation coefficient (r) betweensoil physical and chemical properties and various enzyme activities in different Appalachian soil horizons.

Soil Properties		Acid Phosphatase S	Acid Phosphatase SS	Pyrophosphatase S	Pyrophosphatase SS	Arylsulfatase S	Arylsulfatase SS	Urease S	Urease SS
Orig. Moist Wt.	(OMW)	0.84**‡	0.88**	0.18NS	0.16NS	0.22NS	0.93**	0.19NS	0.82**
Orig. Moist Vol.	(OMV)	0.85**	0.75**	0.40NS	0.16NS	0.10NS	0.76**	0.14NS	0.67**
WFP %		0.75**	0.47NS	0.43NS	0.03NS	0.03NS	0.46NS	0.08NS	0.41NS
BD		-0.40NS	-0.75NS	-0.06NS	-0.40NS	-0.26NS	-0.73**	-0.20NS	0.66**
pH H_2O		-0.66*	-0.29NS	-0.57*	-0.24NS	0.47NS	-0.25NS	0.33NS	-0.27NS
C		0.95**	0.93**	0.38NS	0.30NS	-0.01NS	0.97**	0.08NS	0.93**
N		0.76**	0.93**	0.11NS	0.26NS	0.19NS	0.95**	0.23NS	0.93**
NH_4-N		0.53NS	0.94**	-0.04NS	0.33NS	0.34NS	0.91**	0.35NS	0.98**
NO_3-N		0.20NS	0.77**	-0.23NS	0.03NS	0.53NS	0.85**	0.13NS	0.75**
Ignited P	(IP)	0.44NS	0.79**	-0.19NS	0.29NS	0.74**	0.79**	0.43NS	0.75**
Organic P	(OP)	0.52NS	0.66**	-0.12NS	0.20NS	0.68**	0.71**	0.48NS	0.56*
Ext. P	(EP)	0.48NS	0.53NS	0.39NS	0.55*	0.27NS	-0.08NS	0.05NS	0.60*
Total S	(TS)	0.85**	0.92**	0.36NS	0.32NS	0.07NS	0.88**	0.04NS	0.85**
Organic S	(OS)	0.84**	0.92**	0.36NS	0.40NS	0.06NS	0.89**	0.04NS	0.88**
Ext. S	(ES)	0.56*	-0.05NS	0.12NS	-0.28NS	0.21NS	-0.07NS	0.04NS	0.13NS
Exchangeable									
Na		0.70**	-0.01NS	0.06NS	0.14NS	0.02NS	0.06NS	-0.01NS	0.01NS
K		0.37NS	0.63*	0.04NS	0.38NS	0.59*	0.59*	0.56*	0.61*
Ca		-0.05NS	0.11NS	-0.21NS	0.04NS	0.62*	0.12NS	0.50NS	0.09NS
Mg		-0.04NS	-0.08NS	-0.18NS	-0.07NS	0.63*	-0.04NS	0.53NS	0.11NS
Mn		0.23NS	0.31NS	0.46NS	0.90**	0.21NS	0.02NS	0.04NS	0.07NS
Al		0.82**	0.48NS	0.34NS	0.18NS	-0.18NS	0.47NS	-0.18NS	0.38NS
H		0.90**	0.56*	0.71**	0.62*	-0.35NS	0.39NS	-0.25NS	0.43NS
Ex. Bases	(EB)††	-0.02NS	0.11NS	-0.20NS	0.03NS	0.67**	0.12NS	0.55*	0.08NS
CEC		0.69**	0.39NS	0.14NS	0.17NS	0.46NS	0.38NS	0.37NS	0.31NS
Mg/(Mg + Ca)	(Mg-Ca)	-0.05NS	0.11NS	-0.21NS	0.04NS	0.62*	0.12NS	0.50NS	0.09NS

†S = Surface Horizon, SS = Subsurface Horizon.
*, **Significant at 0.05 and 0.01 levels of probability.
‡NS = Not significant.
††EB = $\Sigma cmol(+) \cdot kg^{-1}$ of K + Na + Ca + Mg.

Stepwise regression equations were used to predict the AP activity from several soil variables (Table 4). In surface horizons, 97% of the variability in AP activity was accounted for by C, NH_4^+-N, and Mn. However, 98% of the significant variance in subsurface horizons were attributable to NH_4^+-N, Mn and OMW.

Pyrophosphatase

Pyrophosphatase (PPi) activity varied among the soil horizons studied and declined markedly with depth (Table 2). The PPi activity in surface horizons averaged about 9 fold higher than the activity in subsurface horizons. Tabatabai and Dick (29) in many of the Iowa soils recorded a 1.3 to 3.6 fold decrease in PPi activities from depth of 0-15 cm to 15-30 cm. Among surface horizons Dekalb A, Berks A and Edneytown A recorded the highest, and Ashe A and Hayesville Ap gave the lowest PPi activities. Among subsurface horizons, Porter Bw recorded the lowest activities.

The PPi activities were negatively correlated with soil pH in surface horizons (Table 3). These findings agree with results reported for several Iowa soils by Tabatabai and Dick (29). Further, they also observed a positive relationship between PPi activities and % clay, % organic C and molar ratios of Mg/(Mg + Ca). However, they noted that the relationship between PPi and organic C was pH dependent. In soils with pH $\geq$ 7, they observed a very low, positive relationship (r = 0.28). Whereas in soils with pH < 7.0, they recorded a high positive relationship (r = 0.90**) between organic C and PPi activities. In our study, the ratio of Mg/(Mg + Ca) was not significantly related to PPi activity in surface or subsurface horizons.

Positive nonsignificant relationships were observed between PPi activities and OMW, OMV, % WFP, forms of S and K. The positive relationships were observed between PPi activities and EP and Mn. The PPi activities gave significant positive relations with exchange acidity (H) in both horizons. The PPi activities gave a negative, nonsignificant relation with Ca and Mg in surface horizons. It has been reported that activity of yeast

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TABLE 4
Regression equations relating enzyme activities (Y) in different soil horizons to soil properties.†

Soil Horizon	Regression Equation	R^2
	Acid phosphatase	
A	$Y = 107.6 + 113.1\ C - 1.6\ NH_4^+\text{-}N + 1.7\ Mn$	0.97**
B	$Y = 46.1 + 1.5\ NH_4^+\text{-}N + 1.5\ Mn + 80.8\ OMW$	0.98**
	Pyrophosphatase	
A	$Y = -553.2 + 3511.9\ H + 192.9\ CEC - 799.1\ OMW$	0.83**
B	$Y = -18.7 + 4.1\ Mn + 205.4\ K + 184.2\ H$	0.94**
	Arylsulfatase	
A	$Y = 28.6 - 22.0\ C + 0.6\ NH_4^+\text{-}N + 0.9\ OP$	0.88**
B	$Y = -28.2 + 43.3\ C - 0.5\ Mn + 142.4\ K$	0.97**
	Urease	
A	$Y = -41.9 - 5.6\ EP + 599.2\ K + 91.2\ Mg$	0.61*
B	$Y = -3.1 + 20.0\ C + 0.9\ NH_4^+\text{-}N - 0.3\ OS$	0.98**

†Abbreviations refer to Table 3.
*,** Significant at the 0.05 and 0.01 level of probability.

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pyrophosphatase decreased by addition of divalent cations in the order of: $Mg^{2+} > Zn^{2+} > Co^{2+} > Mn^{2+} >> Ca^{2+}$ (2). However, the exact role of Ca^{2+} on PPi activities is still a controversial one (29). The PPi activities of Iowa soils was inhibited due to higher amounts of Ca^{2+} (29). Stott et al. (23) report inhibitory effects of 25 μmol Mn•g $soil^{-1}$ on PPi activities. In our study, an increase in native Mn content enhanced PPi activities. The Mn levels (0.3 to 157 mg•kg^{-1}) in our soils were far lower than the levels adapted by Stott et al. (23). By reducing added Mn from 25 to 5 μmole•g $soil^{-1}$ the percent inhibition in one Iowa soil dropped from 25 to 3% (25).

In the current study, 83% of the variance in surface soil PPi activity was accounted for by exchange acidity (H), CEC and OMW

and 94% of the variance in subsurface PPi activity was related to Mn, K and H (Table 4).

Arylsulfatase

Arylsulfatase (AS) activity was different in various soil horizons. The Tate soil recorded the highest AS activities. Similar to AP and PPi activities, the AS activities also declined with depth (Table 2). Surface horizons had 2.3 times higher AS activities than subsurface horizons. In six Iowa soils, Tabatabai and Bremner (27) found that decreases in AS activity with depth were highly correlated (r = 0.78**) with organic-C content of the profiles. In the current study (Table 3), AS activities of subsurface horizons were highly correlated with organic-C (r = 0.97**) and N (r = 0.95**). However, C and N content of surface horizons had very little effects on AS activities. Even though surface horizons had higher organic C, it appears that the nature of organic matter controls AS activity rather than quantity of organic matter. The organic C content in subsurface horizons are similar to those in the 27 Iowa soils used by Tabatabai and Bremner (27) wherein they reported positive correlations (r = 0.51**) between organic C and AS activities. Speir (20) also observed the absence of significant relationships between AS activities and organic C content (r = 0.42) of Cook Island soils with soil organic C content in the range of 3.3 to 5.9%. However, he found a significant relationship (r = 0.76*) between organic C and AS activities in Tongan soils with organic C contents from 2.1 to 6.1%. Such a difference in the two soils is believed to be related to types of vegetation of the two sites.

In both surface and subsurface horizons AS activities were significantly related to K. However, a significant relationship between AS activities and Ca and Mg observed only in surface horizons. In both horizons AS activities gave a significant relation to total and organic P content; however, AS activities were only significantly related to total S and organic S of subsurface horizons.

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Approximately 88% of the variance in AS activities of surface horizons was related to organic C, NH_4^+-N and organic P (Table 4), but 97% of the variance of AS activities of subsurface horizons was accountable to organic C, Mn and K.

Urease

Urease (UR) activity was different among various soils (Table 2). Variations in UR activities within and between soil groups of different climatic zones of the world have been reported (3, 13,32,34). Such variations in UR activities have been related to soil properties, type of vegetation and cultural practices. In the current study, surface horizons had more than 2 fold greater UR activities than subsurface horizons. Among surface horizons, Gilpin A had the highest and Dekalb A the lowest UR activities.

In surface horizons, UR activities showed a direct positive relation to K and exchangeable bases. In subsurface soil samples, UR activities gave a positive and significant relation with OMW, OMV, C, forms of N, P and S, and K. A high degree of correlation (3,13,14,32,34) and no relations (17) between UR activities and organic C have been recorded in various types of soils. The UR activities are known to be related to total N and CEC (32,34). There are reports of UR activity relating positively or negatively to soil pH (3,13,16,20,34).

In surface horizons, 61% of the variance in UR activities could be accountable for by EP, K, and Mg (Table 4), however, more than 98% of the variance in UR activities of subsurface horizons could be related to C, NH_4^+-N and organic S. Zantua et al. (34) and O'Toole (16) have also adapted multiple regression model to relate various soil properties to UR activities. O'Toole et al. (16) showed that 96 to 97% of the variabilities in UR activities of pasture and tilled soils were related to pH dependent and effective CEC, total N, pH, silt and C:N ratios. Approximately 83% of the variance in UR activities of 21 Iowa soils was also related to pH, total N, surface area and their interactions (34).

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TABLE 5
Correlation coefficient (r) between enzyme activities and Dade snapbean shoot wt. (g/2 plants) and N, P, and S content of shoot (mg/2 plants).

Enzyme	Soil Horizon	Shoot Dry wt.	Shoot Content N	P	S
Acid phosphatase (AP)	A	0.21NS†	0.07NS	0.31NS	-0.29NS
	B	0.16NS	0.37NS	0.19NS	0.17NS
Pyrophosphatase (PPi)	A	-0.17NS	0.35NS	0.19NS	-0.01NS
	B	0.59*	0.77**	0.56*	0.61*
Arylsulfatase (AS)	A	0.15NS	0.72**	0.16NS	0.27NS
	B	0.17NS	0.54*	0.02NS	0.11NS
Urease (UR)	A	0.33NS	0.61*	-0.15NS	0.20NS
	B	0.34NS	0.58*	0.23NS	0.19NS

†NS = Not significant.
*,** Significant at 0.05 and 0.01 level of probability.

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Relationships between Enzyme activities and Growth and Nutrient Content of Snapbeans

Neither snapbean shoot dry weight nor nutrient content was significantly correlated with AP activities (Table 5). Verstraete and Voets (31) have reported a positive relation between phosphatase activity and yield of winter wheat. However, various degrees of relationships between AP activities and growth of crops have been reported (21). The PPi activities of subsurface horizons were significantly correlated with shoot content of P, S, N and shoot wt of snap beans. In surface horizons, PPi was not significantly correlated with any of the growth or mineral content parameters. The AS activities in both horizons were positively related to shoot content of N, P and S, and shoot wt., but significant correlations were only observed for N content. The UR activities in both horizons were significantly correlated to N content only. Recently, Speir (20) related enzyme activities to green panic (switchgrass) yield in two diverse groups of soils. In Tongan soils, a positive relationship between yield

and urease, phosphatase and sulfatase activities was noted when soils received all nutrients except S. However, under similar soil treatments, enzymes gave a negative relation to green panic yields in Cook Island soils. In both the soils groups, Speir (20) observed a positive or negative relationships between enzyme activities and green panic parameters depending upon whether soils received N, P, or S.

CONCLUSIONS

Fourteen hill land soils from 4 states of the Appalachian region were sampled for determination of enzyme activities. The enzyme activities were related to growth and N, P, and S content of snapbeans. Surface horizons showed higher enzyme activities than subsurface horizons. Enzyme activities in surface and subsurface horizons were positively related to moisture content, percent water filed porosity, C, N, K, Mn, CEC, and total and organic P and S content of the soil. With some exceptions, activities of AP, AS, and UR were positively related to snapbean, shoot wt., and shoot content of N, P, and S. Each soil type has its own inherant level of enzyme activities.

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