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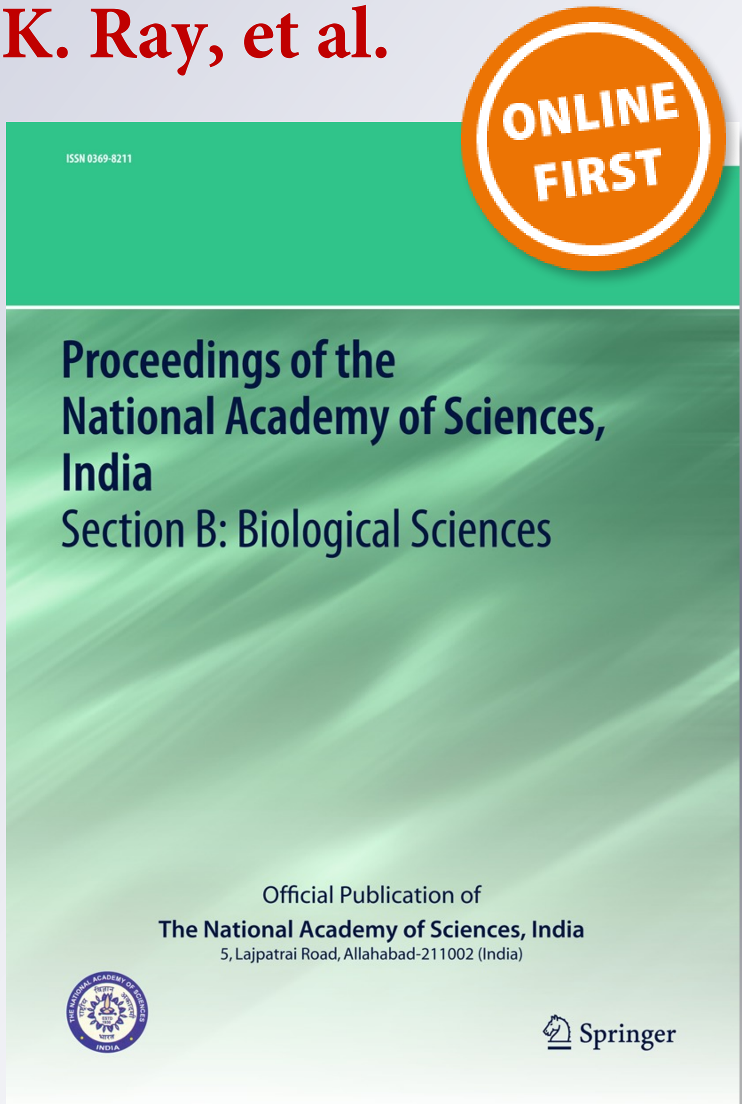

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RESEARCH ARTICLE

Urease Activity in Various Agro-ecological Sub-regions of Black Soil Regions of India

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Abstract A study was undertaken in the established benchmark soil series in different agro-ecological sub-regions of Black Soil Regions of India with the objective to assess the urease activity as a function of soil depth, bio-climate, cropping system and land use type. The urease activity declined with increase in soil depth. Maximum activity was restricted within 0–30 cm of soil depth. Cropping systems and bio-climates significantly ($p < 0.01$) influenced the urease activity in soil. The average urease activity in different bio-climates was in decreasing order viz. sub-humid (moist) > sub-humid (dry) > semi-arid (dry) > arid. The activity in different cropping systems was in decreasing order viz. legume- > sugarcane- > cereals- > cotton-based cropping system. Higher urease activity was observed in irrigated agro-systems as compared to the rainfed agricultural systems. High management practices increased urease activity as compared to low management. In physical properties, urease activity was negatively correlated with sand, fine clay, bulk density and available water content. Electrical conductivity, calcium carbonate and cation exchange capacity showed negative correlation in chemical properties at all the soil depths.

Keywords Urease activity · Bio-climates · Cropping systems · Agricultural land use · Principal Component Analysis

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Introduction

Soil enzymes have been suggested as one of the potential biological indicators of soil quality because of their relationship to soil biology, ease of measurement, and rapid response to changes in soil management [1]. Among various soil enzymes, urease (urea amidohydrolase EC 3.5.1.5: catalyzing the hydrolysis of urea to CO_2 and NH_3) is very widely distributed in nature, and has been detected in plants, animals, and microorganisms [2, 3]. Urease plays an important role in the efficient use of urea fertilizer in soil and the changes in urease activity can be used as an indirect indicator of the variation in the pool of potentially available N in a soil [4]. Urease activity influences the optimum use of urea fertilizer, N volatilization, N leaching and environmental pollution related to N [5, 6]. While, low urease activity might cause added urea to be lost by leaching; on the other hand, a higher activity might result in excessive hydrolysis of added urea and subsequently ammonia can be lost by volatilization [7]. Li et al. [8] reported that urease activity was closely related to soil nutrient conditions and recommended that urease should be considered as an important parameter for estimating the Soil Quality Index.

In India, though a few studies have been reported about the soil urease activity [9–11], information on the urease

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Table 1 Characteristics of selected BM spots in BSRs of India [13]

AESR	Bio-climates	MAR (mm)	Soil series	MSL (m)	Districts	States	Soil sub-group classification
6.1	Arid	520	Nimone	517	Ahmednagar	Maharashtra	Sodic Haplusterts
5.1	Arid	533	Sokdha	25	Rajkot	Gujarat	Calcic Haplusterts
8.1	SAd	612	Coimbatore	421	Coimbatore	Tamil Nadu	Vertic Haplustepts
3.0	SAd	632	Teligi	379	Bellary	Karnataka	Typic Haplusterts
6.4	SAd	638	Acchamatti	573	Dharwad	Karnataka	Sodic Haplusterts
7.1	SAd	650	Nandyal	212	Kurnool	Andhra Pradesh	Chromic Haplusterts
5.1	SAd	650	Bhola	76	Rajkot	Gujarat	Typic Haplusterts
8.3	SAd	660	Kovilpatti	81	Tuticorin	Tamil Nadu	Gypsic Haplusterts
8.2	SAd	661	Siddalaghatta	717	Kolar	Karnataka	Vertic Haplustepts
7.2	SAd	764	Kasireddipalli	538	Medak	Andhra Pradesh	Sodic Haplusterts
6.2	SAd	789	Vasmat	372	Hingoli	Maharashtra	Sodic Haplusterts
6.3	SAd	794	Paral	267	Akola	Maharashtra	Sodic Haplusterts
5.2	SHd	1053	Sarol	564	Indore	Madhya Pradesh	Typic Haplusterts
10.3	SHd	1100	Ghulguli	509	Shahdol	Madhya Pradesh	Typic Haplusterts
10.2	SHm	1127	Panjri	309	Nagpur	Maharashtra	Typic Haplusterts
10.1	SHm	1209	Nabibagh	501	Bhopal	Madhya Pradesh	Typic Haplusterts
7.3	SHm	1250	Tenali	15	East Godavari	Andhra Pradesh	Halic Haplusterts

AESR agro-ecological sub-regions, *MAR* mean annual rainfall (mm), *Arid* <550 mm, *SAd* semi-arid dry (850–550 mm), *SHd* sub-humid dry (1,100–1,000 mm), *SHm* sub-humid moist (>1,100 mm), *MSL* elevation above mean sea level

activity in the Black Soil Regions (BSRs) of India which covers about 76.4 M ha of total geographical area of the country is lacking. Hence, a survey was undertaken in the established benchmark (BM) soil series of BSR of India with the objective to assess the urease activity as a function of soil depth, bio-climate, cropping system and land use type. This is the first extensive report on urease activities in BSR of India and the information generated through this study will be highly useful for the refinement and management of nitrogen fertilization to crops and also for the assessment of land quality in BSR of India specifically.

Material and Methods

Site Description and Sampling

The characteristics of selected BM spots of BSR of India are summarized in Table 1 and the cropping systems and management practices adopted in the BM spots are presented in Table 2. The soil samples (approximately 1 kg each from different horizons of a pedon) were collected from the representative BM spots in the BSR of India (Fig. 1) covering specific bio-climatic systems in six AERs (agro-ecological regions) and 17 AESRs (agro-ecological sub-regions—3.0, 5.1, 5.2, 6.1, 6.2, 6.3, 6.4, 7.1, 7.2, 7.3, 8.1, 8.2, 8.3, 10.1, 10.2, 10.3, and 5.1) [12] accounting for 19 % (117 M ha) [13] of total geographical area of the country. The soil series were selected in such a way that in any agricultural system under a particular cropping pattern, two representative pedons/soil profile (under the same soil series) were included—one under low management (LM) which is characterized by application of low NPK, rarely applied manures, removal of residues and biomass, no soil moisture conservation practices and the other under high management (HM) which is characterized by application of higher NPK, regular application of organic manures, incorporation of residues, adoption of soil moisture conservation techniques (ridge furrows, bunding, broad bed and furrow).

Soil Physico-chemical and Microbiological Analysis

The international pipette method was applied for particle-size analysis for quantifying the sand, silt and clay fractions according to the size segregation procedure of Jackson [14]. Bulk density (BD) was determined by field-moist method using core samples (diameter 50 mm) of known volume (100 ml) [15, 16]. Hydraulic conductivity was measured by taking 200 g of soil, uniformly tapped and saturated overnight. It was measured by taking an hourly observation until three constant observations were obtained. It was measured in cm h^{-1} [17]. The chemical characteristics of soil were determined by standard procedures [18]. For microbiological analysis, soil samples collected at different soil depths from different BM spots were serially diluted in 90 ml Ringers solution up to 10^{-4} dilution and 1 ml of aliquot was pour plated in selective media (Nutrient Agar for bacteria [19], Martin's Rose Bengal Agar for fungi [20], Ken Knights and Munaier's

Table 2 Cropping systems and management practices adopted in selected BM spots in BSRs of India

BM spots	HM		LM	
	Cropping systems[a]	Agriculture	Cropping systems	Agriculture
Nimone	Soybean–wheat/chick pea	Irrigated	Soybean/pearl millet/chick pea	Irrigated
Sokdha	Cotton + green gram/pearl millet	Rainfed	Cotton + green gram/pearl millet/sorghum	Rainfed
Coimbatore	Maize–chick pea	Irrigated	Single cropping of chick pea	Rainfed
Teligi	Triple cropping of rice	Irrigated	Maize/sorghum–chick pea	Rainfed
Acchamatti	Cotton–wheat/safflower/sorghum	Irrigated	Maize–chick pea	Rainfed
Nandyal	Rice–rice	Irrigated	Cotton/sunflower	Rainfed
Bhola	Cotton–wheat	Irrigated	Cotton–wheat	Irrigated
Kovilpatti	Single cropping of sorghum	Rainfed	Single cropping of cotton/sunflower/chick pea	Rainfed
Siddalaghatta	Fruits crops + sunflower/sorghum	Irrigated	Rice–maize–tomato	Irrigated
Kasireddipalli	Soybean + pigeon pea/maize–sunflower	Rainfed	Chick pea/sorghum	Rainfed
Vasmat	Sugarcane	Irrigated	Rice-fallow	Irrigated
Paral	Cotton + soybean/green gram + sorghum	Irrigated	Cotton + black gram/chick pea + sorghum	Irrigated
Sarol	Soybean–wheat	Irrigated	Soybean–chick pea	Irrigated
Ghulguli	Pigeon pea/mustard/green gram	Rainfed	Rice–wheat/chick pea	Irrigated
Panjri	Single crop of cotton/soybean	Rainfed	Soybean–wheat/soybean–chick pea	Rainfed
Nabibagh	Soybean–wheat/soybean–chick pea	Irrigated	Soybean–wheat/soybean–chick pea	Irrigated
Tenali	Rice–rice	Irrigated	Rice–rice	Irrigated

HM practices	LM practices
Application of higher NPK	Application of low NPK
Regular application of organic manures	Manures rarely applied
Incorporation of residues	Removal of residues and biomass
Adoption of soil moisture conservation techniques (ridge furrows, bunding, broad bed and furrow)	No soil moisture conservation practices

[a] Cropping systems: '/' = or; '+' = intercropping; '–' = followed by

Agar [19] for actinomycetes and Buffered Yeast Agar for yeast). The plates were incubated at optimum temperature (28 ± 1 °C for bacteria and yeast; 30 ± 1 °C for fungi and actinomycetes) in triplicates. The microbial colonies appearing after the stipulated time period of incubation (3 days for bacteria and yeast; 5 days for fungi; 7 days for actinomycetes) were counted and expressed as total culturable colony forming units (Cfus)/g of the sample.

Assay of Urease Activity in Soil

Urease (EC 3.5.1.5) activity in selected BM soils (air-dried, crushed and sieved through a 2-mm mesh screen) was assayed in duplicate by the method described by Tabatabai and Bremner [21], which involves the determination of the ammonia released by urease activity when 5 g of soil was incubated with 9 ml of 0.05 M Tris (hydroxymethyl) aminomethane buffer (pH 9.0), 1 ml of 0.2 M of urea solution and toluene at 37 °C for 2 h. The ammonia released was determined by a procedure involving treatment of the incubated soil sample with 2.5 M KC1 containing a urease inhibitor (Ag_2SO_4) and steam distillation of an aliquot of the resulting soil suspension with MgO for 4 min.

Statistical Analysis

The data pertaining to BSR coming under different bioclimates, soil depths, cropping systems, land use, soil subgroups [22], and management practices were pooled together and analysed for descriptive statistics, ANOVA, and principal component analysis using statistical software's SAS version 9.2 and JMP-8.

Results and Discussion

Variations in Urease Activity in BM Spots of BSR of India: Soil Depth Influence

The urease activity was found to decline in all the BM spots studied with increase in soil depth (Table 3). The maximum urease activity was recorded in the surface

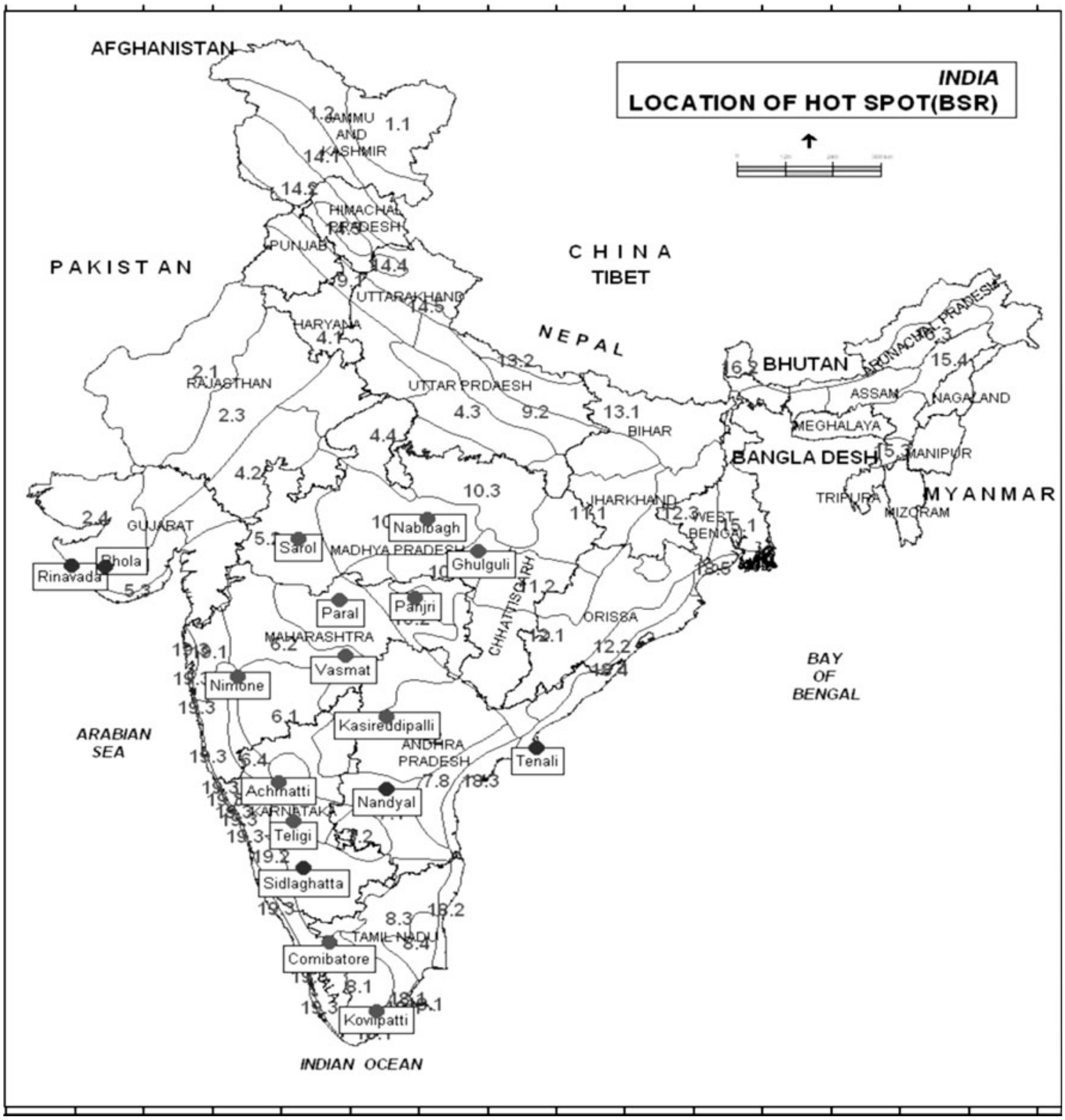

Fig. 1 Agro-ecological sub-regions of India and the locations of BM spots in BSRs of India

horizon (0–15 cm) and almost 50 % of urease activity was found to be restricted within 0–30 cm in all the BM spots. Higher urease activity was recorded in HM BM spots as compared to LM spots and the urease activity differed significantly ($p < 0.01$) between the BM spots. Among the BM spots in HM, highest urease activity was recorded in Nimone soil series of Maharashtra (47.5 μg NH_4^+-N g^{-1}), while the lowest urease activity was recorded in Bhola series of Gujarat (2.6 μg NH_4^+-N g^{-1}) at 15 cm soil depth. In LM, highest urease activity was recorded in Vasmat soil series of Maharashtra (44.7 μg NH_4^+-N g^{-1}), while the lowest urease activity was recorded in Nandyal series of Andhra Pradesh (2.0 μg NH_4^+-N g^{-1}) at 15 cm soil depth. The major reason for increased urease activity in the surface soil as compared to the deeper soil depths was the result of greater availability of urea, organic C, nutrients and stimulated microbial activity in the surface soil [23–25]. Depth of root penetration and nitrogen exhaustive characteristics of crops may also be another reason for the decline of urease activities in deeper soil layers. The low content of total nitrogen in soil due to cultivation of high-exhaustive crops together with low soil organic carbon content was also reported as one of the reasons for lesser urease activity in sub-surface [26]. Urease activity was reported to be proportional to organic C distribution in each soil profile. Its maximum activity was concentrated in the surface soil which decreased with depth [23, 24]. The sharp decline in urease activity with increasing soil depth have

Table 3 Urease activity (μg NH_4^+-N g^{-1} dry soil) in selected BM spots of BSR of India

BM soil series	Soil depth (cm)									
	0–15		15–30		30–50		50–100		100–150	
	HM	LM	HM	LM	HM	LM	HM	LM	HM	LM
Nimone	47.5	42.4	48.0	30.4	39.6	23.4	26.6	18.1	20.8	13.6
Sokdha	8.00	5.40	7.10	5.10	5.60	4.70	4.40	4.00	–	–
Coimbatore	38.4	25.8	30.0	23.1	26.2	20.9	18.9	15.2	16.0	11.4
Telgi	13.0	9.60	8.50	8.30	6.30	6.80	4.20	5.20	3.00	4.00
Acchamatti	14.6	2.30	12.7	7.70	11.4	11.3	7.80	11.3	5.70	9.10
Nandyal	3.40	2.00	3.20	2.40	2.90	2.50	2.20	2.10	1.70	1.60
Bhola	2.60	ND	2.20	ND	2.10	ND	1.80	ND	–	ND
Kovilpatti	10.7	5.90	9.90	4.80	8.80	3.70	6.20	2.30	4.50	1.70
Siddalghatta	16.4	17.6	16.6	15.5	15.7	12.1	11.4	7.40	8.90	5.40
Kasireddipalli	25.6	21.8	11.2	16.7	9.30	14.0	6.50	10.4	–	–
Vasmat	13.6	44.7	16.4	32.9	14.1	26.8	9.60	16.8	7.60	12.1
Paral	20.6	10.0	12.9	6.10	11.0	5.20	8.60	4.20	6.30	3.90
Sarol	38.9	34.2	20.2	24.7	14.3	17.9	8.50	12.5	6.40	10.1
Ghulghuli	8.60	8.30	7.50	9.00	6.90	8.20	6.60	–	5.90	–
Panjari	16.1	15.9	15.5	14.9	13.1	12.3	9.10	8.10	6.50	5.80
Nabibagh	42.5	35.3	39.7	29.0	29.6	24.5	19.3	18.8	15.0	15.3
Tenali	3.60	2.20	3.40	1.90	2.90	1.80	2.50	1.80	2.20	1.50
Standard deviation	14.4	14.6	12.7	10.5	10.2	8.27	6.73	6.01	5.58	4.83
Coefficient of variation	75.6	82.9	81.7	72.3	78.9	67.5	74.2	65.3	70.7	65.8
Standard error of mean	3.49	3.67	3.09	2.62	2.47	2.06	1.63	1.55	1.49	1.34
p value	0.003**	0.001***	0.002**	0.005**	0.001**	0.006**	0.005**	0.003**	0.002**	0.009**

HM high management, *LM* low management, *ND* not determined

, * *p* values significant at 0.01 and 0.001 probability level respectively

Table 4 Bio-climates and soil sub-groups on urease activity (μg NH_4^+-N g^{-1} dry soil) in BSRs of India

	Soil depth (cm)				
	0–15	15–30	30–50	50–100	100–150
Bio-climates					
SHm	19.3^{b}	17.4^{a}	14.0^{a}	9.9^{a}	7.7^{a}
SHd	22.5^{a}	15.3^{b}	11.8^{b}	6.9^{c}	5.6^{c}
SAd	15.7^{c}	12.7^{c}	11.1^{b}	8.0^{b}	6.4^{b}
Arid	6.7^{d}	6.09^{d}	5.14^{c}	4.2^{d}	2.9^{d}
Soil sub-groups					
Vertic Haplustepts	24.6^{a}	21.3^{a}	18.7^{a}	13.2^{a}	10.5^{a}
Sodic Haplusterts	24.3^{a}	19.5^{b}	16.6^{b}	12.0^{b}	7.90^{b}
Typic Haplusterts	18.8^{b}	14.9^{c}	11.8^{d}	7.80^{d}	6.00^{c}
Gypsic Haplusterts	16.6^{c}	14.6^{c}	12.5^{c}	8.50^{c}	6.20^{c}
Calcic Haplusterts	13.4^{d}	12.2^{d}	10.3^{e}	8.40^{c}	–
Halic Haplusterts	5.80^{e}	5.30^{e}	4.70^{g}	4.30^{e}	3.70^{d}
Chromic Haplusterts	5.40^{f}	5.50^{e}	5.40^{f}	4.30^{e}	3.30^{d}

Bio-climate and soil sub-groups with the same letter in the columns are not significantly different following Tukey HSD (0.01)

been reported due to either the lower microbial activity [25], and limited availability of organic substrates [27]. Application of higher nitrogenous fertilizers and cultivation of legumes are also reported to be the important factors which increase the mineral nitrogen in soil resulting in increased urease activity in the surface horizon [26].

Table 5 Cropping systems on urease activity (μg NH_4^+-N g^{-1} dry soil) in BSRs of India

Cropping systems	Crops	Soil depth (cm)				
		0–15	15–30	30–50	50–100	100–150
Legume-based system	Chick pea	47.4[a]	40.1[a]	35.1[a]	26.0[a]	11.6[b]
	Soybean	35.4[c]	27.4[c]	21.5[c]	14.9[c]	12.6[a]
	Pigeon pea	8.8[f]	7.5[f]	7.2[f]	6.7[f]	0.0
Sugarcane-based system	Sugarcane	44.3[b]	33.1[b]	26.9[b]	17.0[b]	12.3[a]
Cereal-based system	Maize	22.3[d]	19.2[d]	17.7[d]	13.7[d]	11.3[b]
	Sorghum	13.7[e]	13.5[e]	12.5[e]	9.0[e]	6.8[c]
	Rice	8.7[f]	7.8[f]	6.7[fg]	4.7[g]	3.7[e]
Cotton-based system	Cotton	9.3[f]	7.6[f]	6.6[g]	5.0[g]	4.5[d]

Cropping systems with the same letter in the columns are not significantly different following Tukey HSD (0.01)

Table 6 Land use types and management levels on urease activity (μg NH_4^+-N g^{-1} dry soil)

	Soil depth (cm)				
	0–15	15–30	30–50	50–100	100–150
Agricultural land use					
Irrigated	24.0[a]	19.0[a]	15.3[a]	10.8[a]	8.7[a]
Rainfed	12.5[b]	10.3[b]	9.1[b]	7.0[b]	5.6[b]
Management level					
HM	19.1[a]	15.7[a]	12.9[a]	9.0[ns]	7.9[ns]
LM	17.6[b]	14.5[b]	12.3[b]	9.2[ns]	7.3[ns]

ns non significant

Land use types and management levels with the same letter in the columns are not significantly different following Tukey HSD (0.01)

Bio-climates and Soil Sub-groups on Urease Activity

The pooled analyses of urease activity in different bio-climates and soil types of BM spots (inclusive of cropping systems, management, and land use effects) indicated significant differences ($p < 0.01$) between the bio-climate, soil type as well as the soil depth (Table 4). At the surface layer (0–15 cm) higher urease activity was recorded in sub-humid (dry) (SHd) (22.5 μg NH_4^+-N g^{-1}) with a range between 8.6 and 38.9 μg NH_4^+-N g^{-1} followed by sub-humid (moist) (SHm) (19.3 μg NH_4^+-N g^{-1}, range = 3.6–42.5 μg NH_4^+-N g^{-1}) and the least urease activity was recorded in arid regions (6.7 μg NH_4^+-N g^{-1}). The average urease activity in different bio-climates declined with the depth in decreasing order of SHm > SHd > semi-arid (dry) (SAd) > arid. In soil sub-groups, Vertic Haplustepts recorded higher urease activity (24.6 μg NH_4^+-N g^{-1}) followed by Sodic Haplusterts (24.3 μg NH_4^+-N g^{-1}), while the lowest urease activity was observed in Halic Haplusterts (5.8 μg NH_4^+-N g^{-1}) and Chromic Haplusterts (5.4 μg NH_4^+-N g^{-1}) at the surface soil (0–15 cm). The average urease activity in different soil sub-groups were in decreasing order of Vertic Haplustepts > Sodic Haplusterts > Typic Haplusterts > Gypsic Haplusterts > Calcic Haplusterts > Halic Haplusterts > Chromic Haplusterts.

It is well known that the hydrolyzing activity of urease follows the Michaelis–Menten kinetics, and it is influenced by several factors including the soil type, organic matter content, temperature, soil moisture, pH and the amount of added nitrogen [28–31]. Urease activity was related to seasonal changes in soil temperature and moisture [32] and reported to show considerable sensitivity to water availability [33], however, the activity of urease has not always been reported as correlated with soil water availability [34]. Urease activity is also reported to increase as the temperature rises [35]. The variation in urease distribution in different soil types is reported to be influenced by physical and chemical properties of the soil [9, 36, 37].

Cropping Systems on Urease Activity

Among the cropping systems effects at the surface layer (0–15 cm) (inclusive of bio-climates, soil types, management, and type of agriculture effects), legume-based cropping system (chick pea/soybean/pigeon pea) recorded higher urease activity (Table 5). In legume-based system, chick pea (47.4 μg NH_4^+-N g^{-1}) followed by soybean (35.3 μg NH_4^+-N g^{-1}) recorded higher urease activity and sugarcane-based cropping system 44.2 μg NH_4^+-N g^{-1})

Table 7 Correlation matrix for urease activity and soil parameters

Variables	0–15 cm	15–30 cm	30–50 cm	50–100 cm	100–150 cm
Sand (%)	−0.308	−0.233	−0.235	−0.222	−0.068
Silt (%)	0.343	**0.363**	0.158	0.247	0.189
Clay (%)	0.083	0.013	0.155	0.059	−0.067
Fine clay (%)	−0.163	−0.050	0.011	−0.102	−0.076
BD (Mg m^{-3})	−0.229	−0.243	−0.195	**−0.405**	**−0.395**
1/3 bar	0.017	−0.128	−0.049	−0.117	**−0.409**
15 bar	0.088	0.090	−0.153	−0.150	−0.308
1 bar	−0.111	−0.259	−0.091	−0.086	−0.334
3 bar	−0.163	−0.282	−0.128	−0.055	−0.292
HC (cm h^{-1})	**0.455**	0.204	0.131	−0.091	**0.461**
Water pH (1:2)	0.115	0.001	−0.142	−0.230	−0.158
KCl pH (1:2)	0.213	0.170	0.202	0.119	−0.024
EC (1:2) (dS m^{-1})	−0.267	−0.031	0.241	0.228	−0.133
Organic carbon (%)	0.003	0.125	−0.100	−0.219	−0.123
Calcium carbonate (%)	−0.019	−0.084	−0.057	−0.043	0.072
CEC	−0.164	−0.250	−0.198	−0.223	−0.123
Base saturation (%)	0.148	0.007	−0.013	−0.049	−0.151
Exchangeable sodium percentage	0.325	**0.381**	0.267	0.188	0.068
Exchangeable magnesium percentage	−0.163	0.097	0.182	0.257	0.162
Nitrogen (kg/ha)	−0.072	0.085	0.050	0.243	0.109
Phosphorus (kg/ha)	−0.132	0.166	−0.190	−0.203	0.049
Potassium (kg/ha)	0.159	−0.039	−0.043	0.028	−0.241
Microbial population (total Cfu)	0.154	0.030	0.064	0.087	0.019

In bold, significant values at the level of significance $\alpha = 0.050$ (two-tailed test)

followed the legume system. The lowest urease activity was recorded in cotton-based cropping system (9.2 µg NH_4^+-N g^{-1}). The urease activity showed significant difference ($p < 0.01$) between the cropping systems and the soil depths in all the BM spots. The average urease activity in different cropping systems was in decreasing order of legume- > sugarcane- > cereal- and cotton-based cropping systems.

The higher urease activity in legume-based system showed the contribution of legumes towards the greater availability of organic C and N and stimulated microbial activity [38, 39]. Crop growth characteristics such as root growth, nitrogen fixation and utilization pattern were also governing higher urease activity in legume-based system. Availability of higher MN by way of huge nitrogenous fertilizer application and HM in sugarcane-based systems reflected the impact of N fertilization on urease activity. The lesser urease activity in cereal- and cotton-based cropping systems is mainly because of the crop characteristics (deep rooted and nutrient exhaustiveness) and management level (mostly rainfed with low inputs). The alteration of soil enzymatic activities resulting from cultivation or differences in cropping system has been demonstrated by several researchers [40]. Khan [38] noted significantly higher soil enzymatic activity in rotation of grains and legumes than in wheat fallow system. Urease was also affected by plant types or plant species combinations [41].

Agricultural Land Use and Management Practices on Urease Activity

The pooled analysis of soil urease data indicated significant differences ($p < 0.01$) between the land use and the soil depth. The data clearly indicates the dominance of irrigated agro-systems over the rainfed agricultural systems on the urease activity (Table 6). The average urease activity in irrigated system was found to be 24 µg NH_4^+-N g^{-1}, while in rainfed systems it was recorded as 12.5 µg NH_4^+-N g^{-1} at the surface soil (0–15 cm). The pooled data on urease distribution indicated significant differences ($p < 0.01$) between the management practices and the soil depth. HM recorded higher urease activity (19.1 µg NH_4^+-N g^{-1}) as compared to the LM (17.6 µg NH_4^+-N g^{-1}).

The average urease activity in irrigated system was found to be almost 50 % higher than that of rainfed systems. It is also clear that, the lesser urease activity under rainfed system is also contributed by the crops grown under

Table 8 Contributions of the variables (%) after Varimax rotation

Variable	0–15 cm				15–30 cm				30–50 cm	
	F1	F2	F3	F4	F1	F2	F3	F4	F1	F2
Sand	10.33	2.71	5.43	0.05	9.35	5.05	1.96	0.00	11.06	0.30
Silt	0.29	14.12	10.71	0.69	0.56	14.98	9.13	0.18	0.07	1.27
Clay	13.02	1.66	0.00	0.22	12.85	0.04	0.42	0.10	12.68	0.03
Fine clay	4.75	0.00	10.29	0.16	6.04	1.45	0.13	2.02	6.18	0.09
BD	1.01	1.64	7.95	1.23	0.57	19.70	0.17	1.48	0.03	4.68
1/3 bar	12.02	2.87	0.01	0.98	12.60	0.03	0.18	0.26	13.19	0.71
15 bar	12.85	1.60	0.06	0.42	12.78	0.13	0.02	0.00	2.63	0.01
1 bar	12.83	1.13	1.18	0.81	13.16	0.30	0.13	0.82	14.37	0.00
3 bar	12.25	1.23	2.21	1.11	12.27	0.20	0.02	0.43	13.69	0.04
HC	0.07	0.66	16.71	0.44	0.56	0.96	0.54	27.00	1.69	0.21
Water pH	0.05	18.11	1.71	3.08	0.02	1.10	21.81	2.05	0.38	20.26
KCl pH	1.16	11.54	1.28	3.97	0.68	0.40	25.06	0.34	0.41	24.17
EC	1.16	0.06	14.03	14.73	0.04	3.51	8.60	1.51	0.22	1.92
OC	0.36	11.77	0.00	11.20	0.82	9.63	1.86	7.27	2.37	6.82
$CaCO_3$	0.17	4.60	2.40	11.60	0.28	0.60	6.29	26.10	0.77	5.18
CEC	8.76	0.81	0.14	0.00	11.34	1.09	0.75	0.16	13.04	0.00
BS	3.53	5.67	3.99	0.26	2.24	1.98	3.51	0.85	3.63	0.22
ESP	0.17	0.34	0.85	13.28	0.01	9.40	10.15	4.13	0.06	13.83
EMP	0.00	0.00	0.01	2.93	0.11	0.24	2.69	0.36	0.25	0.48
N	0.03	15.73	0.22	7.04	0.06	10.70	1.25	2.59	0.39	14.51
P	0.06	1.77	0.26	22.07	0.22	0.00	1.09	21.20	0.05	0.94
K	1.59	0.02	1.54	1.28	1.94	0.44	0.09	0.95	1.77	3.19
Urease	0.02	0.00	18.98	0.00	0.15	16.73	0.35	0.06	0.02	1.08
Total Cfu	3.49	1.94	0.05	2.43	1.35	1.33	3.81	0.14	1.06	0.06
Percent variance (after Varimax rotation)										
Eigenvalue	6.94	3.67	2.62	2.11	7.06	3.09	2.28	1.82	6.71	3.68
Variance (%)	27.75	15.26	11.32	9.59	28.80	10.25	11.73	8.57	26.14	13.18
Cumulative (%)	27.75	43.01	54.33	63.92	28.80	39.05	50.78	59.35	26.14	39.32

Variable	30–50 cm		50–100 cm				100–150 cm			
	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
Sand	0.02	3.50	9.39	1.16	0.14	0.46	10.02	1.19	0.04	1.99
Silt	1.67	22.14	0.72	3.83	0.02	1.65	0.02	1.71	0.49	6.20
Clay	1.13	1.32	12.63	0.04	0.08	0.03	10.94	0.03	0.09	0.12
Fine clay	6.01	4.51	8.91	0.30	1.45	1.02	7.46	0.46	0.83	0.00
BD	5.06	0.94	0.03	0.76	5.08	0.10	1.85	2.02	3.97	8.17
1/3 bar	0.46	0.01	12.34	0.95	0.00	1.55	10.06	1.25	1.66	4.25
15 bar	10.70	0.50	2.81	0.20	6.69	0.17	11.56	0.15	0.76	1.68
1 bar	0.49	0.49	13.04	1.54	0.01	1.95	10.38	1.60	3.86	1.87
3 bar	0.40	0.86	12.27	1.91	0.02	2.57	10.26	2.37	2.94	1.50
HC	12.22	0.55	4.51	1.16	9.31	3.33	2.05	3.47	5.07	15.13
Water pH	0.84	0.01	0.85	20.92	0.79	0.01	0.46	19.62	4.27	1.32
KCl pH	0.11	0.23	0.77	23.05	0.00	1.54	0.52	22.82	0.75	0.01
EC	0.12	15.68	0.11	0.83	0.32	27.28	0.03	0.93	30.09	0.04
OC	9.20	0.51	2.14	6.19	12.00	0.07	5.68	1.92	0.69	10.00
$CaCO_3$	20.69	0.29	2.03	6.60	17.62	0.16	0.02	20.35	0.04	2.22
CEC	1.56	0.70	9.07	0.01	6.35	0.60	8.89	0.89	0.03	0.05

Table 8 continued

Variable	30–50 cm		50–100 cm				100–150 cm			
	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
BS	1.62	14.35	3.95	0.21	0.59	14.59	1.25	0.15	19.12	1.16
ESP	2.32	0.18	0.02	12.24	0.81	11.92	0.16	8.38	0.92	0.80
EMP	2.92	8.39	1.04	3.41	9.77	0.41	7.38	0.41	0.70	0.05
N	0.32	2.76	0.58	13.04	0.33	4.31	0.00	5.48	2.93	11.87
P	20.98	0.23	0.48	0.10	23.00	0.35	0.08	3.92	4.55	5.10
K	0.00	0.27	1.07	0.75	1.17	0.69	0.10	0.41	2.95	10.44
Urease	1.14	0.34	0.32	0.23	4.33	2.07	0.14	0.10	2.49	15.90
Total Cfu	0.02	21.24	0.92	0.57	0.12	23.18	0.69	0.36	10.78	0.12
Percent variance (after Varimax rotation)										
Eigenvalue	2.78	2.03	6.87	3.26	2.84	2.11	7.50	3.24	2.50	1.92
Variance (%)	12.08	11.95	27.04	11.61	12.00	12.15	28.90	13.42	11.27	9.57
Cumulative (%)	51.39	63.35	27.04	38.65	50.65	62.80	28.90	42.33	53.59	63.17

such system. Rainfed system is dominated either by cereal- or cotton based which is managed with low inputs, while the irrigated system (sugarcane- and legume based) is managed with high inputs. In BSR poor management coupled with low organic content makes the soil biologically inactive. Nourbakhsh and Monreal [42] reported increased soil urease activity under irrigated cultivation and concluded that urease activity was deeply influenced by water and heat factors. Impact of management practices on soil urease activity has been reported by several workers. Integrated application of vermicompost and nitrogen fertilizers significantly increased soil urease activity [43].

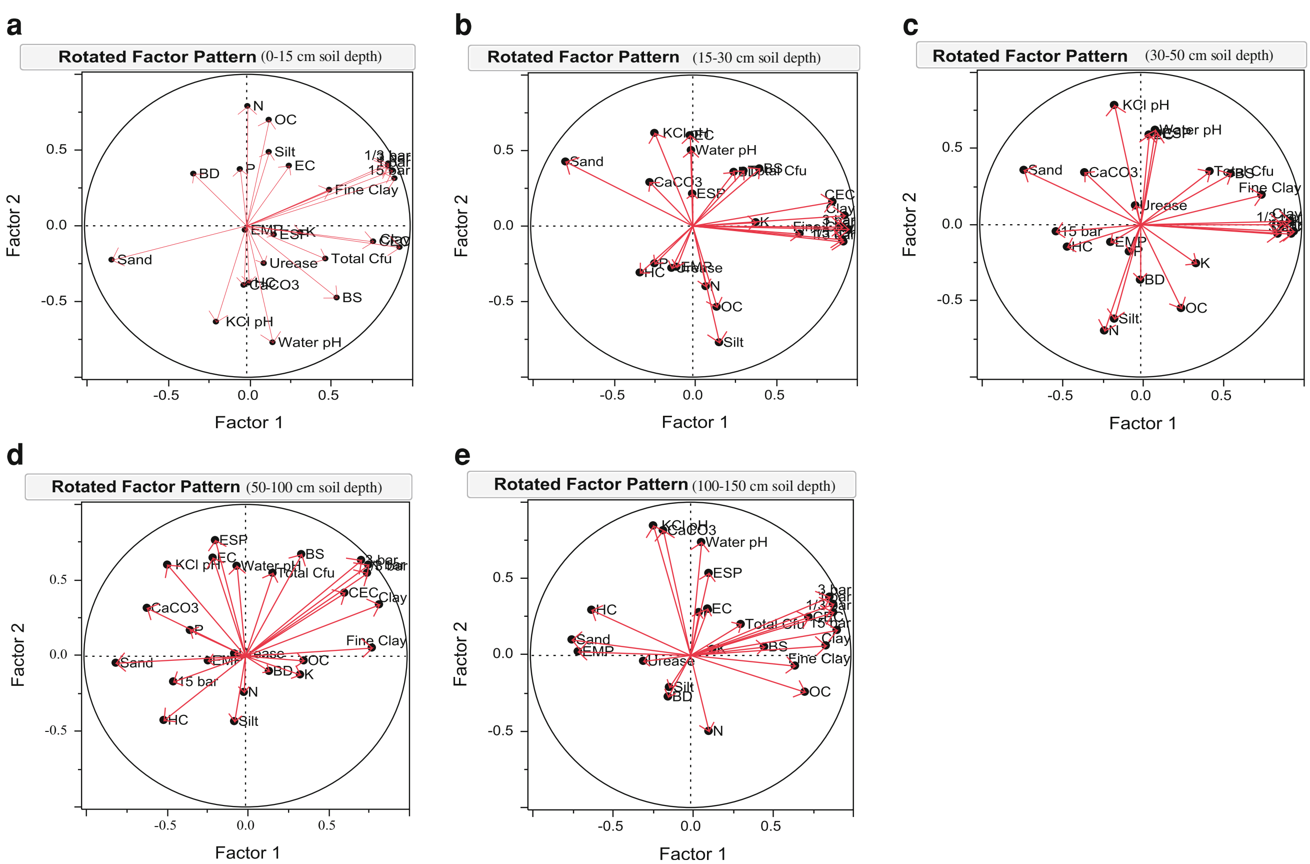

Fig. 2 Principle Component Analysis and factor rotation at different soil depths

Tillage practice influenced urease activity in the Ap horizon [44]. Nautiyal et al. [45] reported higher urease activity in organically cultivated field which practiced no tillage and no removal of crop residues. Plant protection activities such as fungicide contamination of the soil are also reported to significantly inhibit the urease activity [46].

Impact of Soil Properties on Urease Activity

In the present study, though significant positive correlation was observed between urease activity and hydraulic conductivity at 0–15 and 100–150 cm, silt (15–30 cm) and ESP (15–30 cm), urease activity was negatively correlated with sand, fine clay, bulk density (BD) and available water content in soil, electrical conductivity (EC), calcium carbonate and cation exchange capacity (CEC) at all the soil depths (Table 7). While physical parameters like clay and silt content showed positive correlation for urease activity in soil at all the depths, chemical parameters such as water pH, organic carbon and base saturation showed positive correlation only for the surface horizon (0–30 cm). In major nutrients, available nitrogen showed negative correlation for the surface and positive correlations for the sub-surface horizons, while phosphorus and potassium does not follow any pattern. A weak positive correlation was observed between the total microbial population and urease activity at all the depths. At all the soil depths, soil physical factors (water availability, sand, clay) were found to influence the urease activity most followed by soil chemical factors (pH, organic carbon and nitrogen) (Table 8; Fig. 2a–e). CEC, base saturation and microbial activity also influenced urease activity at all the depths.

The increase in soil water content favoured the microbiological activity and subsequent increase in soil enzyme activities [47–49]. The difference in temperature and rainfall results in the variation of soil pH and EC [50], which show impacts on soil enzyme activity. In the present study, soil pH was positively correlated with urease activity. The close relationship between soil pH and enzyme activity were reported by Deng and Tabatabai [51] and Wang and Lu [52]. Rao and Ghai [2] reported non-significant correlation between urease activity and EC, CEC, clay, silt and sand. In the present study, urease activity was positively correlated with silt and clay but not with calcium carbonate and EC. However, urease activity was correlated with nitrogen content in sub-surface horizons and organic carbon in surface soil (0–30 cm). Similar results were reported by Fawaz et al. [53]. In this study, urease activity was weakly but positively correlated with total culturable microbial population at all the depths. This is likely due to the fact that plate counts only reveal a small proportion of the ureolytic bacteria. A better correlation between urease activity and ureolytic bacteria can probably be obtained by measuring unculturable bacteria, as it is not possible with the plate count technique. Similar results were previously reported by Frankenberger and Dick [54] and by Reynolds et al. [55].

Conclusion

Urease activity declined with increase in soil depth in all the BM spots of BSR. The maximum urease activity was found to be in the surface horizon (0–15 cm) and almost 50 % of urease activity was restricted within 0–30 cm soil depth. Cropping systems and bio-climates significantly influence the urease activity in soil. The average urease activity in different bio-climates was in decreasing order of SHm > SHd > SAd > arid, while its activity in different cropping systems was in decreasing order of legume > sugarcane > cereals > cotton. Higher urease activity was observed in irrigated agro-systems as compared to the rainfed agricultural system and HM practice found to increase urease activity as compared to LM. On one hand India is spending huge capital on the import of nitrogenous fertilizers while on the other hand enormous nitrogenous fertilizers are lost by N volatilization, N leaching and environmental pollution. Hence better understanding of the urease enzyme activity in soil of BSR will help in better management of nitrogenous fertilizers to avoid soil pollution and increased cost of cultivation. This study will be highly useful for the refinement and management of nitrogen fertilization to crops and also for the assessment of land quality in BSR of India specifically.

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