Innovative Farming
-A Quarterly International Journal of Agriculture

Research Article
Article: SAAI/IF/430

Consequences of Different Organic Resources on Microbial Community in Rice-Mustard Cropping Sequence

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KEYWORDS:

FYM, Humic acid, MBC, Microbial population, Organic carbon, Soil

ARTICLE INFO

Received on:
11.02.2021
Revised on:
12.07.2021
Published on:
19.07.2021

ABSTRACT

In Typic *Fluvaquent* soils of the Old Alluvial zone in West Bengal, India, an investigation was carried out to study the significance of organic matter, particularly humic acid, on the microbial community throughout the paddy cultivation (Variety MTU 1010), followed by mustard (Variety B-9). The soil has been allocated with fertilizers having recommended doses for rice field ($N:P_2O_5:K_2O$::60:30:30) and mustard ($N:P_2O_5:K_2O$::80:40:40), following the application of farmyard manure (FYM) @ 5.0 and 2.5 t ha^{-1}, respectively. Additionally, commercial humic acid and FYM-extracted humic acid were applied @ 0.5 and 0.25 kg ha^{-1}, respectively, according to the treatment arrangements. The experiment was carried out using a Randomized Block Design (RBD). Surface soil (0-15 cm) samples were gathered in definite interval to analyse organic carbon, microbial biomass carbon and microbial population. The application of extracted humic acid (EHA) demonstrated a significant positive correlation with increased organic carbon and microbial biomass carbon during cultivation of paddy, followed mustard. Hormonal behaviour of EHA, in combination to root exudation process, enhanced the microbial population at rhizosphere soil, regardless of the crop grown.

How to Cite:

Paul, N., Roy, G., Giri, U., Saha, D., 2021. Consequences of different organic resources on microbial community in rice-mustard cropping sequence. *Innovative Farming* 6(3), 87-96.

INTRODUCTION

Carbon is the fundamental constituent of all life and its cycle represents the story of life on this planet. The presence of carbon in organic and microbial biomass form is the major prerequisite of soil organic substance and biosphere serves as the source of organic matter of soil. Through photosynthesis, plants assimilate carbon, oxygen and hydrogen and as a part of ecological niche animals acquire carbon directly or indirectly from plants. After death, decomposition and/or burning of living body return

www.biospub.com
ISSN: 2455-6521 (Online)

these elements in the form of CO_2 and H_2O to nature. The intermediate C-based products of decomposition are actual precursors of the carbon present in the soil. Microbial biomass carbon (MBC) is an index for comparing natural and degraded system of microbial activity in soil. This is actually microbial body carbon, developed with microbial decomposition in soil and act as major source of energy to rhizosphere required for aggregate formation and nutrient conservation (Fahramand *et al.*, 2014).

In soil different organic ameliorates, especially compost, FYM, green manure, synthetic polymers, *viz*. polyacrylamides and polyvinyl alcohols are disposing to microbial degradation (Nyyssola and Ahlgren, 2019). Many rhizosphere soil microbes of different taxonomic and functional groups respond on application of humic colloids in soil (Vallini *et al.*, 1993). During composting, by aerobic biological decomposition, all easily decomposable, semi-resistant and resistant materials are gradually converts to a stable mature compost (Goyal *et al.*, 2005), recommended for direct application in cultivated soil to enhance soil fertility (Suarez-Estrella *et al.*, 2008).

Various workers study importance of humic acid (HA) for enhancing crop productivity and soil fertility. The functional groups (both aromatic and aliphatic) and amines cause HA to be biologically active as well as increase the CEC of the soil (Fahramand *et al.*, 2014). HA additionally has positive influence on microbial population ensuing in plant enlargement and biomass production (Suarez-Estrella *et al.*, 2008).

Present study compares FYM and HA (both commercial and extracted) on the changes in the status of SOC, MBC, soil microbial population using field experiments carried out with rice mustard cropping pattern.

MATERIALS AND METHODS

Site of Study

In rice-mustard cropping sequence, two field experiments were conducted in succession (*Kharif* followed by *Rabi*) at Adaptive Research Farm, India (23.95° N and 88.03° E), to examine the effect of different organic sources on microbial community. Throughout the experiment (Figure 1), the climate was humid subtropical, with a rainfall of 1481 mm and temperature ranging from 34.4 °C (maximum) and 11.0 °C (minimum). Table 1 represents the physical and chemical characteristics of the soil (Typic *Fluvaquent*).

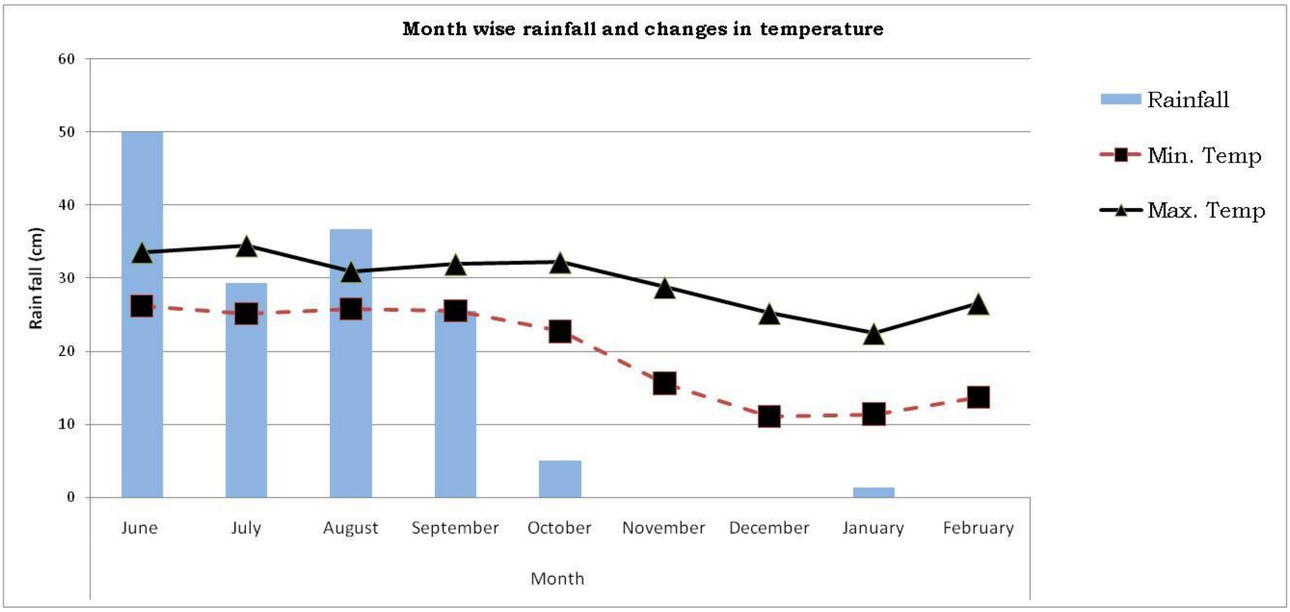

Figure 1: Meteorological changes during the experimental seasons

Table 1: Physico-chemical characteristics of the soils the study location

Sl. No.	Properties	Unit	Surface soil
1	Category of the soil	-	Typic *Fluvaquent*
2	Texture of the soil	-	Sandy Clay Loam
3	Oxidizable organic carbon	g per 100 g	1.16
4	pH	Soil:water = 1:2.5	6.34
5	Microbial biomass carbon	$\mu g\ g^{-1}$	99.85
6	Bacterial population	($cfu \times 10^6$)	23.04
7	Actinomycetes population	($cfu \times 10^5$)	95.02
8	Fungal population	($cfu \times 10^4$)	26.12

Description of Treatments

Humic acid was extracted from farmyard manure (FYM) using the process of Kononova and Belchikova (1961) and purchased from open market. The commercial humic acid was characterised with an 8% ash content. The properties of the FYM and humic acid used in the study are illustrated in table 2.

Table 2: Properties of farmyard manure and humic acids from various sources

Sl. No.	Properties	FYM	Extracted Humic acid from FYM (EHA)	Purchased humic acid (CHA)
1	Oxidizable organic carbon (%)	32.56	29.77	43.36
2	Aggregate nitrogen (%)	1.014	2.20	1.29
3	C:N ratio	32.016	13.53	33.61
4	Viscosity (Ubelhode Viscometer)	-	133.10	139.00
5	E_4:E_6	-	3.193	3.41
6	Functional group (Dragunova, 1958) (meq Ba)	-	6.803	6.803
7	Ash-free carboxylic group (Kononova, 1966) (meq)	-	628.3	415.9

Urea, SSP and MOP were applied at the recommended doses ($N:P_2O_5:K_2O$ :: 60:30:30) for paddy (Variety MTU-1010) during the *kharif* season, irrespective to treatments. Half of the external nitrogen was used as a basal dose, while the remaining nitrogen was split into two applications, *viz.*, tillering stage and flowering stage of rice. A Randomized Block Design (RBD) was followed, with 3 replications. Mustard (B-9) was cultivated as a *rabi* crop after paddy, with the following nutrient doses ($N:P_2O_5:K_2O$ :: 80:40:40 kg ha^{-1}).

These treatments were applied in the first experiment, followed by the second experiment consecutively.

Treatments adopted in the first experiment with rice:

T_1 = Control

T_2 = Basal application of FYM @ 5 tons ha^{-1}

T_3 = Basal application of CHA @ 0.5 kg ha^{-1}.

T_4 = Basal application of EHA @ 0.5 kg ha^{-1}.

Treatments adopted in the second experiment with mustard:

T_1' = Control

T_2' = Basal application of FYM @ 2.5 tons ha^{-1}.

T_3' = Basal application of CHA @ 0.25 kg ha^{-1}.

T_4' = Basal application of EHA @ 0.25 kg ha^{-1}.

Collection and Assessment of Soil and Plant Samples

Surface soil samples (0-15 cm) were gathered from each experimental site at key growth stages: tillering, panicle initiation, flowering and harvesting of rice, followed by branching, flowering and harvesting stages of mustard.

Oxidizable organic carbon and MBC were determined using the Walkley and Black (1934) method and the chloroform fumigation direct extraction (CFDE) method (Joergensen, 1995). The biomass of microorganisms in the rhizosphere soil were estimated using Thornton's method (Thornton, 1922), Jensen's method (Jensen, 1930) and Martin's rose bengal streptomycin agar medium (Martin, 1950).

Statistical Assessment

The findings of the trials were statistically evaluated using analysis of variance (ANOVA), and the critical differences were calculated at a 5% level of significance to assess the significance of treatment methods. This evaluation followed the guidelines established by Jackson (1973) and Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Organic Carbon

The effects of farmyard manure (FYM) applied at 5.0 and 2.5 t ha^{-1}, as well as commercial and extracted humic acid applied at 0.5 and 0.25 kg ha^{-1}, respectively, on the organic carbon (OC) content in the soil, following the paddy cultivation and the mustard cultivation, are presented in table 3.

Table 3: Changes in the content of organic carbon (g/ 100 g) in soil treated with FYM and humic acid in rice-mustard cropping sequence

	Rice					Mustard		
Treatments	Days after transplanting of rice				Treatments	Days after sowing of mustard		
	Tillering	Panicle initiation	Flowering	Harvesting		Branching	Flowering	Harvesting
T_1	11.07	10.47	10.20	9.90	T_1'	10.38	9.55	8.78
T_2	12.07	11.90	10.57	10.37	T_2'	11.42	10.74	10.61
T_3	11.13	10.83	10.23	9.63	T_3'	11.53	10.48	7.86
T_4	12.00	11.30	11.20	11.00	T_4'	12.97	10.48	9.56
SEm (±)	0.2093	0.1846	0.1808	0.1244	SEm (±)	0.0856	0.0649	0.2843
CD (5%)	0.7241	0.6387	0.6255	0.4302	CD (5%)	0.2962	0.2245	0.9836
CV%	3.1338	2.8739	2.9681	2.1064	CV%	1.2809	1.0896	5.3501
SEm (±)	0.1387				SEm (±)	0.4568		
CD (5%)	0.4437				CD (5%)	1.5806		

[SEm = Standard Error of mean, CD = Critical Difference, CV = Coefficient of Variation]

In paddy, FYM serves as the richest source of organic carbon, resulting in increases of 9% and 13.7% at tillering and panicle initiation (PI) stages, respectively, followed by EHA (8.4% and 8.0%). This enhancement might be due to the synergistic effect of applied fertilizers and soil organic matter (SOM) (Table 1) (Korschens, 2002). In soil EHA gripped the highest position through raising the content of organic carbon at flowering (9.8%) and harvesting stages (11.1%) as equated to that of control. EHA affects the root exudation status of the soil (Trevisan *et al.*, 2010) which might be helpful for improving the biochemical and microbial activity in root zone (da Silva Lima *et al.*, 2014).

The effect of EHA was further reflected in mustard, cultivated followed by paddy and jointly with applied EHA at mustard increased the content of OC by 24.9% followed by CHA (11.0%) and FYM (10.0%) at branching stage as compared with control in soil. This result was further justified by Chouriya (2016). On the contrary at harvesting stage of mustard FYM take lead role in increasing the content of OC (20.8%) than EHA (8.8%) as compared with control in rhizosphere soil.

Higher microbial proliferation on easily decomposed followed by semi-resistant and resistant organic substances might be the reason of the availability of organic carbon (Michel Jr. *et al.*, 1996). The declining trend of OC was much higher with CHA than EHA and FYM might be rise in aerobic microbial inhabitants and their activity on added organic sources (Kumari *et al.*, 2011).

Microbial Biomass Carbon

Application of FYM, CHA and EHA on paddy followed by mustard field brought different influence on the microbes' body carbon, derived from organic sources in soil by the chemo-heterotrophic microorganisms (Table 4). Similar observation was also reported by Sellamuthu and Govindaswamy (2003). Among all the treatments in soil, EHA imparted significant increase from 51.4% (tillering) to 78.2% (PI) and 15.2% (flowering) to 34.6% (harvesting phase) of rice in comparison to that respective control. Addition of humic acid enhanced the microbial incubation period under semi-aerobic conditions of paddy cultivation.

Table 4: Changes in the content of microbial biomass carbon (µg g^{-1}) in soil treated with FYM and humic acid in rice-mustard cropping sequence

Rice					Mustard			
Treatments	Days after transplanting of rice				Treatments	Days after sowing of mustard		
	Tillering	Panicle initiation	Flowering	Harvesting		Branching	Flowering	Harvesting
T_1	101.41	145.02	189.27	159.98	T_1'	142.20	177.97	153.79
T_2	151.00	169.25	221.05	198.34	T_2'	189.60	205.03	206.91
T_3	140.29	252.52	229.50	161.49	T_3'	166.00	222.43	205.03
T_4	153.55	258.42	218.01	215.31	T_4'	284.40	358.80	335.89
SEm (±)	1.3760	3.7970	3.8847	3.0891	SEm (±)	4.3871	5.5321	1.4255
CD (5%)	4.7610	13.1372	13.4409	10.6881	CD (5%)	15.1790	19.1406	4.9321
CV%	1.7452	3.1878	3.1375	2.9114	CV%	3.8858	3.9749	1.0954
SEm (±)	13.3920				SEm (±)	7.9732		
CD (5%)	42.8370				CD (5%)	27.5868		

[SEm = Standard Error of mean, CD = Critical Difference, CV = Coefficient of Variation]

Additionally EHA raised the content of MBC from 100 to 118.4% during the period between branching phase and harvesting stage of mustard.

This result substantiate the findings of Filip and Kubat (2004) manifesting the application of EHA serves as a provider of nitrogen and carbon for enhancing the metabolic activity of micro-organisms in rhizosphere soil (Suarez-Estrella *et al.*, 2008). Moreover, dead cells of susceptible organisms might be the good source of MBC in soil (Alexander, 1977). The residual effect of added EHA during paddy cultivation was also reflected in mustard justified the findings of Demkina and Zolotareva (1997).

Jones *et al.* (2007) reported that CHA brought about declining trend from PI (74.1%) to harvesting (0.9%) stage in the content of MBC as compared with control in soil. On the contrary, CHA exhibited similar significant increasing trend as like EHA from branching (16.7%) to harvesting (33.3%) during mustard cultivation as compared with control in soil (Costa *et al.*, 2008). Fate of FYM have significant effect on MBC status resulting in significant declination from tillering (48.9%) and branching (33.3%) to flowering (16.8% and 15.2%) of paddy and mustard respectively. This might be due to positive correlation between soil organic carbon and MBC, as reported by Singh *et al.* (1989). The level of MBC was increased at harvesting stage of both the crops; and this might be due to highest root exudation during flowering stage (Islam and Borthakur, 2016).

Micro-Organism

Humic substances persuade the expansion curve of soil microbial population. Soil micro-entities of diverse taxonomic and functional groups exhibit exhibit positive reactions to the presence of humic acid in *in-vivo* experiments (Suarez-Estrella *et al.*, 2008). Changes in microbial population at rhizosphere with the application of FYM, CHA and EHA during cultivation of paddy followed by mustard were tabulated in table 5, 6 and 7 for bacteria, actinomycetes and fungi, respectively. The pH (6.34) and climatic condition (Figure 1) of the experimental field also develop favourable climatic conditions of microbial growth.

EHA inclusion in soil resulted highest significant boost in population of bacteria (36.7%) followed by CHA (22.2%) and FYM (17.3%) at tillering stage of paddy as compared to control. A parallel pattern was also observed at harvesting stage of paddy and throughout the entire incubation period of mustard. FYM established highest increase of 60.6% in bacteria population at flowering stage of paddy, followed by EHA (57.6%) and CHA (34.7%) respectively in comparison with control.

During paddy cultivation stagnant water and or swampy condition in rhizosphere soil was observed which might be responsible for lower bacterial growth. Aerobic climatic condition with optimum moisture percent is favourable for bacterial growth and this might be the actual reason of more than one fold increase in bacterial population during mustard cultivation across all treatments compared to the control in soil, as well as cultivation of paddy. EHA was responsible for increasing the activity and population of nitrogen fixing bacteria (Suarez-Estrella *et al.*, 2008) and this might be the reason of highest bacterial growth with EHA after that CHA and FYM as equated to that of control in soil.

Table 5: Changes in number of total bacteria (CFU×10^6) in soils treated with FYM and humic acid in rice-mustard cropping sequence

Rice					Mustard			
Treatments	Days after transplanting of rice				Treatments	Days after sowing of mustard		
	Tillering	Panicle initiation	Flowering	Harvesting		Branching	Flowering	Harvesting
T_1	23.34	30.58	23.30	19.84	T_1'	24.60	30.95	28.16
T_2	27.37	31.40	37.42	30.23	T_2'	49.20	71.32	60.75
T_3	28.51	35.97	31.38	27.03	T_3'	55.92	75.36	67.25
T_4	31.90	37.05	36.71	30.76	T_4'	62.62	87.46	75.93
SEm (±)	0.3464	0.7773	0.4006	0.7605	SEm (±)	2.3570	1.4436	1.5218
CD (5%)	1.1984	2.6892	1.3861	2.6313	CD (5%)	8.1552	4.9947	5.2652
CV%	2.1595	3.9890	2.1549	4.8853	CV%	8.4904	3.7730	4.5428
SEm (±)	1.3040				SEm (±)	2.3724		
CD (5%)	4.1711				CD (5%)	8.2084		

[SEm = Standard Error of mean, CD = Critical Difference, CV = Coefficient of Variation]

Table 6: Changes in number of actinomycetes (CFU×10^5) in soils treated with FYM and humic acid in rice-mustard cropping sequence

Rice					Mustard			
Treatments	Days after transplanting of rice				Treatments	Days after sowing of mustard		
	Tillering	Panicle initiation	Flowering	Harvesting		Branching	Flowering	Harvesting
T_1	96.57	104.55	105.90	63.88	T_1'	98.40	113.02	99.75
T_2	144.85	185.15	211.80	186.34	T_2'	219.18	226.05	216.94
T_3	127.10	152.90	136.85	95.83	T_3'	174.42	204.52	177.89
T_4	173.80	273.70	217.33	179.87	T_4'	223.64	247.58	221.28
SEm (±)	2.8900	6.0651	0.3296	0.3279	SEm (±)	0.2897	1.8102	0.7957
CD (5%)	9.9991	20.9847	1.1405	1.1344	CD (5%)	1.0024	6.2633	2.7530
CV%	3.6920	5.8663	0.3399	0.4319	CV%	0.2805	1.5852	0.7701
SEm (±)	11.5913				SEm (±)	3.2783		
CD (5%)	37.0768				CD (5%)	11.3427		

[SEm = Standard Error of mean, CD = Critical Difference, CV = Coefficient of Variation]

Table 7: Changes in number of fungi (CFU×10^4) in soils treated with FYM and humic acid in rice-mustard cropping sequence

Rice					Mustard			
Treatments	Days after transplanting of rice				Treatments	Days after sowing of mustard		
	Tillering	Panicle initiation	Flowering	Harvesting		Branching	Flowering	Harvesting
T_1	26.62	40.25	60.37	63.88	T_1'	33.55	40.37	27.12
T_2	40.25	80.50	120.75	207.64	T_2'	111.82	139.94	119.32
T_3	106.37	111.12	88.25	155.31	T_3'	78.27	94.19	92.20
T_4	120.80	161.00	152.93	196.98	T_4'	162.14	181.65	178.98
SEm (±)	0.1060	0.1094	0.1884	3.1569	SEm (±)	1.7913	1.9202	1.2740
CD (5%)	0.3666	0.3784	0.6518	10.9227	CD (5%)	6.1978	6.6437	4.4079
CV%	0.2497	0.1929	0.3091	3.5061	CV%	3.2170	2.9165	2.1135
SEm (±)	10.6577				SEm (±)	3.8389		
CD (5%)	34.0908				CD (5%)	13.2825		

[SEm = Standard Error of mean, CD = Critical Difference, CV = Coefficient of Variation]

Total population of actinomycetes in soil was significantly affected with EHA and FYM in paddy followed by mustard. Highest increase in population was recorded with EHA throughout the entire growth cycle of paddy and mustard except harvesting of paddy. Fungal population with EHA was significantly and gradually increased upto more than four and a half fold and five and half fold at harvesting stages of paddy and mustard, respectively, compared to the respective control in the soil. This increment was supplementary followed by FYM (more than 3 fold) in both the crop as compared with control.

Humic substances in soil have a very good nutritive value (Potter and Meyer, 1990) and have enzymatic activation of nutrient uptake (Tejada *et al.*, 2006).

Spectrometric study established hormonal effect of humic substances and usually higher in rhizosphere soil, probably because of acceleration in microbial population or of a speed up metabolism that results from the presence of root exudates (Trevisan *et al*., 2010).

CONCLUSION

Irrespective of chemical fertilizers in their respective recommended doses, imputation of extracted humic acid (EHA) and commercial humic acid (CHA) increase the availability of organic carbon and microbial body carbon into utilizable form for soil microorganisms. In spite of higher competition among bacteria, actinomycetes and fungi for the utilizable form of organic carbon, presence of humic substances increases the metabolic rate as well as populace of these living entities especially during physical growing period of paddy followed by entire life cycle of mustard.

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

Alexander, M., 1977. Introduction to Soil Microbiology, 2nd Edition. John Wiley & Sons, Inc., New York, NY. p. 467.

Chouriya, S., 2016. Residual effect of different rabi crops on succeeding rice under irrigated condition in Kymore Plateau and Satpura Hills agroclimatic zone of Madhya Pradesh. *M.Sc. Thesis* (Agronomy), Jawaharlal Nehru Krishi Vishwavidyalaya (JNKVV), Jabalpur, Madhya Pradesh.

Costa, G., Labrousse, P., Bodin, C., Lhernould, S., Carlue, M., Authier, F., Krausz, P., 2008. Effects of humic substances on the rooting and development of woody plant cuttings. Acta *Horticulturae* 779, 255-261.

da Silva Lima, L., Olivares, F.L., de Oliveira, R.R., Vega, M.R.G., Aguiar, N.O., Canellas, L.P., 2014. Root exudate profiling of maize seedlings inoculated with *Herbaspirillum seropedicae* and humic acids. *Chemical and Biological Technologies in Agriculture* 1, 23. DOI: https://doi.org/10.1186/s40538-014-0023-z.

Demkina, T.S., Zolotareva, B.N., 1997. Determination of the rate of mineralization of humic substances in soil. *Eurasian Soil Science* 30(10), 1085-1089.

Dragunova, A.F., 1958. A rapid method for determining functional groups in humic acids. Nauch Trudy, Mosk. I in Zh. Chonon Inst. Ser. Khinprioz-vod. p. 544.

Fahramand, M., Panahi, F., Omara, M.O., Keshtehgar, A., Mobasser, H.R., Rigi, K., 2014. Influence of earthworms and humic acid on some microbial indices in a Pb contaminated soil. *Journal of Biodiversity and Environmental Sciences* 5(6), 213-231.

Filip, Z., Kubat, J., 2004. Microbial processing of humic acids extracted from soils of a long-term field trial. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* 52(4), 137-146. DOI: https://doi.org/10.11118/actaun200452040137.

Gomez, K.A., Gomez, A.A., 1984. *Statistical Procedures for Agricultural Research*, 2nd Edition, John Wiley and Sons, New York. p. 680.

Goyal, S., Dhull, S.K., Kapoor, K.K., 2005. Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bioresource Technology* 96(14), 1584-1591. DOI: https://doi.org/10.1016/j.biortech.2004.12.012.

Islam, N.F., Borthakur., 2016. Effect of different growth stages on rice crop on soil microbial and enzyme activities. *Tropical Plant Research* 3(1), 40-47.

Jackson, M.L., 1973. *Soil Chemical Analysis*, 1st Edition. Prentice Hall of India Pvt. Ltd., New Delhi. p. 498.

Jensen, H.L., 1930. Actinomycetes in Danish soil. *Soil Science* 30, 59-77.

Joergensen, R.G., 1995. Microbial biomass. In: *Methods in Applied Microbiology and*

Biochemistry. (Eds.) Alef, K. and Nannipieri, P. Academic press, London. pp. 382-386.

Jones, C.A., Jacobsen, J.S., Mugaas, A., 2007. Effect of low-rate commercial humic acid on phosphorus availability, micronutrient uptake, and spring wheat yield. *Communications in Soil Science and Plant Analysis* 38(7-8), 921-933. DOI: https://doi.org/10.1080/00103620701277817.

Kononova, M.M., Belchikova, N.P., 1961. Accelerated methods for determining the composition of humus in mineral soils. *Soil Science* 10, 75-87.

Kononova, M.M., 1966. *Soil Organic Matter; Its Nature, Its Role in Soil Formation and in Soil Fertility* [in Russian]. Pergamon Press Ltd., Oxford, New York. p. 544.

Korschens, M., 2002. Importance of soil organic matter (SOM) for biomass production and environment (a review). *Archives of Agronomy and Soil Science* 48(2), 89-94. DOI: https://doi.org/10.1080/03650340214162.

Kumari, G., Mishra, B., Kumar, R., Agarwal, B.K., Singh, B.P., 2011. Long-term effect of manure, fertilizer and lime application on active and passive pools of soil organic carbon under maize-wheat cropping system in an alfisol. *Journal of the Indian Society of Soil Science* 59(3), 245-250.

Martin, J.P., 1950. Use of acid, Rose Bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science* 69(3), 215-232. DOI: https://doi.org/10.1097/00010694-195003000-00006.

Michel Jr., F.C., Forney, L.J., Huang, A.J.F., Drew, S., Czuprenski, M., Lindeberg, J.D., Reddy, C.A., 1996. Effects of turning frequency, leaves to grass mix ratio and windrow vs. pile configuration on the composting of yard trimmings. *Compost Science and Utilization* 4(1), 26-43. DOI: https://doi.org/10.1080/1065657X.1996.10701816.

Nyyssola, A., Ahlgren, J., 2019. Microbial degradation of polyacrylamide and the deamination product polyacrylate. *International Biodeterioration & Biodegradation* 139, 24-33. DOI: https://doi.org/10.1016/j.ibiod.2019.02.005.

Potter, C.S., Meyer, R.E., 1990. The role of soil biodiversity in sustainable dryland farming systems. In: *Advances in Soil Science*. (Eds.) Singh, R.P., Parr, J.F. and Stewart, B.A. Advances in Soil Science, Volume 13. Springer, New York. pp. 241-251. DOI: https://doi.org/10.1007/978-1-4613-8982-8_12.

Sellamuthu, K.M., Govindaswamy, M., 2003. Effect of fertiliser and humic acid on rhizosphere microorganisms and soil enzymes at an early stage of sugarcane growth. Sugar Tech 5, 273-277. DOI: https://doi.org/10.1007/BF02942484.

Singh, J.S., Raghubanshi, A.S., Singh, R.S., Srivastava, S.C., 1989. Microbial biomass acts as a source of plant nutrients in dry tropical forest and savanna. *Nature* 338, 499-500. DOI: https://doi.org/10.1038/338499a0.

Suarez-Estrella, F., Vargas-Garcia, M.C., Lopez, M.J., Moreno, J., 2008. Effect of humic substances extracted from compost to plant growth and soil microorganisms. *Dynamic Soil, Dynamic Plant* 2(Special Issue 1), 96-102.

Tejada, M., Garcia, C., Gonzalez, J.L., Hernandez, M.T., 2006. Use of organic amendment as a strategy for saline soil remediation: Influence on the physical, chemical and biological properties of soil. Soil Biology and Biochemistry 38(6), 1413-1421. DOI: https://doi.org/10.1016/j.soilbio.2005.10.017.

Thornton, H.G., 1922. On the development of standardized agar medium for counting soil bacteria, with special regard to the repression of spreading colonies. *Annals of Applied Biology* 9(3-4), 241-274. DOI: https://doi.org/10.1111/j.1744-7348.1922.tb05958.x.

Trevisan, S., Francioso, O., Quaggiotti, S., Nardi, S., 2010. Humic substances biological activity at the plant-soil interface: From environmental aspects to molecular factors. *Plant Signaling and Behavior* 5(6), 635-643. DOI: https://doi.org/10.4161/psb.5.6.11211.

Vallini, G., Pera, A., Avio, L., Valdrighi, M., Giovannetti, M., 1993. Influence of humic acids on laurel growth, associated rhizospheric microorganisms, and mycorrhizal fungi. *Biology and Fertility of Soils* 16, 1-4. DOI: https://doi.org/10.1007/BF00336506.

Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* 37(1), 29-38. DOI: https://doi.org/10.1097/00010694-193401000-00003.

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