Effect of Water Hyacinth (*Eichhornia crassipes*) Mulch on Soil Microbial Properties in Lowland Rainfed Rice-Based Agricultural System in Northeast India

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Abstract Most water bodies in the humid tropical areas of Arunachal Pradesh are infested with gregarious *Eichhornia crassipes* (Mart.) Solms. Over a period of time, with death and decay, the water bodies are eutrophicated. This natural phenomenon gave forth the idea of using *E. crassipes* biomass as a compost in agricultural fields for soil nutrients management, using microbial characteristics as potential indicators. The study indicating that water hyacinth as a potential organic substrate can stimulate the growth of diversity of microbial population in agricultural soils. In general, soil respiration and microbial population were significantly ($p < 0.05$) greater in mulched plots compared to control. Among treatments, vermicompost mulched plots recorded for higher bacterial ($74.31 \text{ CFU} \times 10^4$) and fungal counts ($31.09 \text{ CFU} \times 10^3$) at both surface and sub-surface soil layers. The present study provides baseline information for ecofriendly approach to management of *E. crassipes*, especially for the countries where it poses a huge threat to the wetland ecosystems. Nonetheless, nutrient deficient soils in the present study site due mainly to conventional farming practices and nutrient runoff could however be checked by mulching soils with naturally and abundantly growing *E. crassipes* locally.

Keywords Water hyacinth · Microbial biomass · Mulching · Soil respiration

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Introduction

Water hyacinth [*Eichhornia crassipes* Mart. (Solms.)], aptly known as the worst aquatic weed, grows abundantly in almost all types of wetlands vary from small fish ponds ('Beels') to big riverine lakes, posing severe threat to the local livelihood as well as to pristine wetland ecosystems in northeast India. Further, there is a huge risk that it can invade the high altitude lakes in Arunachal Pradesh. Water hyacinth is capable of growing in nutrient rich water and accumulating very high concentration of N, P and K [10], and upon decomposition it also releases accumulated nutrients rapidly. This qualifies water hyacinth as a potential mulching material in soil nutrient management in rainfed agroecosystems of humid tropics, where high rainfall leaches the soil nutrients. Thus, easily decomposable water hyacinth compost and or vermicompost can accelerate growth and activity of microorganism and eventually register higher microbial biomass. For example, increased microbial populations in soil with organic amendment than in soils without amendments has been reported by Girvan et al. [15]. Hence,

exogenous application of adequate amount of organic matter to the soil is vital to sustainable soil nutrient management practices in the humid tropics.

Soil microbial biomass is considered as a ‘source’ and ‘sink’ of plant available nutrients, and hence organic inputs stimulate microbial nutrient immobilisation/mineralisation. Reportedly, microbial biomass even though represents only a small fraction of the total C, N, and P contents of soil, it has relatively a rapid turnover [3]. The decay rate of organic matter is considered to be an important factor in controlling microbial activity and nutrients in the soil. Thus, any alteration in the soil management practices will adversely affect the microbial activities/communities, which in turn lead to the imbalance in organic matter availability in the soil.

Several studies have been conducted using various plant resources to assess the mulching effects on soil physico-chemical properties [12, 29]. On the contrary, there were no reports on mulching effects of aquatic macrophytes on soil properties in general and microbial parameters in particular, which is otherwise the main factor behind nutrient turnover in soil. Therefore, the present study was carried out to assess the influence of different forms of water hyacinth mulching on soil microbial biomass (C, N and P) in the soils of lowland paddy fields in Arunachal Pradesh, northeast India.

Materials and Methods

Field Site and Experimental Design

The experimental design was a randomized complete block (RCB) with four treatments including control and three replications each. The field trials were carried out in Emchi village (27°5′3.09″N and 93°47′48.50″E) located in Doimukh circle of Papum Pare district of Arunachal Pradesh, India. The field experiments were conducted repeatedly for three consecutive years, i.e. 2008–2010 (cropping period being April to October). All the plots (9 × 5 m) were treated with three different forms of water hyacinth mulch and the one without mulching served as control. Different forms of water hyacinth (WHGM, WHCM and WHVcM) were mulched at the rate of 5 t ha⁻¹ (as recommended by the Assam Agricultural University, Assam, India) in the respective experimental plots and ploughed under before 14 days of transplantation of rice seedlings from nursery.

Preparation of Different Forms of Water Hyacinth Mulches

Green Mulch

Fresh water hyacinth growing in wetlands nearby the paddy fields was harvested and rinsed very thoroughly with saline

water (1 M NaCl) initially, and later with tap water and distilled water in order to free it from adhering microflora, fauna and sediment debris. The excess water was drained and the plants were chopped into leaves, petioles and roots, air-dried for 7–10 days prior to incorporation in the soil as mulch.

Compost

Compost was prepared in the low-cost vermicompost unit [6] established at the North Eastern Regional Institute of Science and Technology, Itanagar, India. The compost heaps consisted setting up successive layers, 10, 5 and 3-cm thick, respectively of water hyacinth, cow dung and paddy straw in composting tanks (2.5 × 1.5 × 1.5 m) made out of local bamboo. The layers were repeated until the compost heaped to about 1 m high. Water was sprinkled at every layer of the compost heap in order to maintain moisture content of 60 %. Finally, the compost heaps were plastered with the cow dung slurry and covered with plastic sheet. The heaps were frequently turned upside down, which continued for 12 weeks. The completion of composting was indicated when mixing the contents and keeping them undisturbed after covering did not lead to a rise in temperature. Further paddy straw and cow dung were added to water hyacinth compost in order to avoid or equalise the loss of N in the form of volatile ammonia during composting process.

Vermicompost

Fresh water hyacinth plants and paddy straw were thoroughly mixed with the cow dung (8:2:1). The mixtures were allowed to decompose for 2 weeks in bamboo made composting tank as described above. Then pre-decomposed water hyacinth materials were transferred to vermicomposting beds, wherein around 1,000–2,000 earthworms (*Eisenia foetida* Savigny) introduced. The average moisture content of ~45 % was maintained in all the vermicomposting beds by periodic monitoring. After 90 days, the vermicompost was ready for applications.

Nutrient Analysis of Mulch

The finished compost and vermicompost (cocoon removed) were air-dried, ground and sieved through a 2-mm mesh screen. The subsamples (5 replicates) were taken for analysis of nutrient quality of the composts. Green water hyacinth, compost and vermicompost were analysed for carbon (C), organic matter, nitrogen (N), phosphorus (P) and potassium (K) contents. Carbon was determined according to modified Walkley and Black [35] method. Nitrogen (N) was determined by Kjeldhal procedure [1]. Phosphorus (P) was determined according to molybdenum

blue method [19] and potassium (K) using the flame photometer [1].

Soil Samplings and Analysis

Soil samples (in 5 replicates) were collected randomly from each experimental plot, mulched with different forms of water hyacinth mulch, using a steel corer (6.5 cm inner diameter) from two depths (0–15 and 15–30 cm) for consequent seven sampling periods ('7', '14', '35', '56', '77', '98' and '112' days after mulching) throughout the cropping period. The replicate samples of each depth were thoroughly mixed to obtain a composite sample. The samples were sieved through a 2-mm mesh screen to remove coarse material and then through another 0.5 mm mesh. Sub samples (5 replicates) were taken for further soil chemical and microbiological analyses.

Soil moisture content was determined gravimetrically and pH (1:2.5 w/v H₂O) was analysed using a digital pH meter (SYSTRONICS). Soil organic C (SOC) was determined following rapid titration method [35], total nitrogen (N) by using a semi-micro Kjeldhal apparatus and available P was determined according to molybdenum blue method [4].

Soil microbial biomass C, N and P were determined in field moist soil by chloroform fumigation–extraction procedures [4, 11, 20, 33]. Fungal and bacterial populations in the soil were estimated by soil plate method [36] and serial dilution technique [22] using rose bengal agar medium [26] and solidified nutrient agar medium, respectively, as explained by Arunachalam et al. [9]. Soil respiration was measured by MacFadyen [25], as described in Arunachalam et al. [9].

Statistical Analysis

All the data were analysed statistically using STATISTICA 6.0 and ORIGIN 7.0. Three-way analysis of variance (ANOVA) was used to compare the variations in soil properties amongst different treatments, soil depth and sampling days. Simple correlation matrix was performed to understand the relationship amongst different soil properties [38]. The level of significance (p) in all the cases was held at 0.05.

Results

Mulching on Soil Chemical Properties

Three-way ANOVA showed that pH differed significantly ($p < 0.05$) across the treatments ($F = 6645.09$), soil depth ($F = 12.61$), days ($F = 2806.23$). Soil organic matter (SOM) was significantly higher (135.59 %) in mulched plots over control (without mulch). Organic matter was higher (30.10 %) in upper soil layer (0–15 cm)

in all the mulching treatments including control plots (Fig. 1). SOM showed an inclining pattern throughout the cropping period in all the mulched plots. Soil organic matter ranged from 1.52 to 4.17 % in green mulched (WHGM) plot, 0.64–3.57 % in compost mulched (WHCM) plot and 0.91–3.79 % in vermicompost mulched (WHVcM) plot irrespective of soil depth and days (Fig. 1). Three-way ANOVA revealed that soil organic matter significantly ($p < 0.05$) varied with mulching treatments ($F = 5259.81$), soil depth ($F = 20824.06$) and days ($F = 15047.64$) (Fig. 1).

Total N in the experimental plots ranged from 0.097 to 0.314 % across three mulching treatments. Total N was higher (12.64 %) in surface soil layer (0–15 cm) than the lower 15–30 cm soil layer in all the treatment plots and also in the control plot. Amongst the three treatments, total nitrogen was significantly greater (29.56 %) in water hyacinth vermicompost (WHVcM) mulched plots followed by water hyacinth compost (WHCM) mulched plots and green water hyacinth (WHGM) mulched plots (Fig. 1). Three-way analysis of variance showed that the total nitrogen (N) was significantly ($p < 0.05$) varied across various mulching treatments ($F = 13032.11$), soil depth ($F = 1098.05$) and days ($F = 3190.67$) (Fig. 1).

The soil available P was significantly influenced by all three forms of water hyacinth mulching (Fig. 1). Available P concentration was comparatively higher (33.33 %) in the top soil layer (0–15 cm) in all the treatment plots including control plots. It ranged from 0.0097 to 0.0728 % across the three mulching treatments. However, available P increased gradually after mulching of different forms of water hyacinth till the harvesting stage. Three-way ANOVA showed that the available P was significantly different across various mulching treatments ($F = 37471.47$, $p < 0.05$), soil depth ($F = 69459.13$) and days ($F = 38096.01$). The interactions amongst mulch treatment, soil depth and days were also found to significantly influence the soil chemical properties (Fig. 1).

Mulching on Soil Microbial Biomass (C, N and P)

Microbial C inclined in all the water hyacinth mulched plots till the harvesting phase (Fig. 2). The microbial biomass C (MBC) ranged from 191.32 to 350.76 $\mu\text{g g}^{-1}$ in control plot, 156.04–992.95 $\mu\text{g g}^{-1}$ in green water hyacinth (WHGM) mulched soil, 185.59–463.04 $\mu\text{g g}^{-1}$ in water hyacinth compost (WHCM) mulched plot and from 376.88 to 980.21 $\mu\text{g g}^{-1}$ in water hyacinth vermicompost (WHVcM) mulched plots. Spatially, microbial C was significantly higher (63.40 %) in the top-soil 0–15 cm layer and lower in subsurface-soil 15–30 cm layer (Fig. 2). Three-way ANOVA showed that microbial C was significantly ($p < 0.05$) different among treatments, soil depth and days (Table 1).

Fig. 1 Soil organic matter, total N and available P under different forms of water hyacinth mulches. *d* Days, CON control, WHGM green mulch, WHCM compost mulch, WHVcM vermicompost Mulch).

Vertical error bars represents standard error ($\pm$, $n = 20$). T treatments, SD soil depth (cm), D days. Values in parenthesis are degree of freedom (df). *Significant at $p < 0.05$

Microbial N was also greater (53.98 %) at top-soil (0–15 cm) than in the sub-soil layer (15–30 cm). Among treatments, the microbial nitrogen (MBN) was greater in

compost (60.36 %) and vermicompost (56.09 %) mulched plots compared to green mulched (WHGM) soils (Fig. 2). Three-way factorial analysis of variance (Table 1) revealed

Fig. 2 Soil microbial biomass C, N and P under different forms of water hyacinth mulches. *d* Days, CON control, WHGM green mulch, WHCM compost mulch, WHVcM vermicompost mulch. Vertical error bars represents standard error ($\pm$, $n = 20$)

that microbial nitrogen (MBN) significantly varied across treatments ($F = 2586.38$), along soil depth ($F = 6727.76$) and days ($F = 4035.79$).

Microbial P was significantly ($p < 0.05$) higher (45.91 %) in the soil mulched with different forms of water hyacinth over the control (without mulch). Microbial P (MBP) ranged

Table 1 Three-way factorial ANOVA of impact of different forms of water hyacinth mulching treatments, soil depth, sampling days and interaction (treatment $\times$ soil depth $\times$ days) on soil microbiological properties

Factors	Source of variations/ <i>F</i> value						
	<i>T</i> (df = 3)	<i>SD</i> (df = 1)	<i>D</i> (df = 6)	Interactions			
				<i>T</i> $\times$ <i>SD</i> (df = 3)	<i>T</i> $\times$ <i>D</i> (df = 18)	<i>SD</i> $\times$ <i>D</i> (df = 6)	<i>T</i> $\times$ <i>SD</i> $\times$ <i>D</i> (df = 18)
MBC	330030.49*	371040.26*	97431.82*	73434.39*	10369.34*	4539.47*	3090.66*
MBN	2586.38*	6727.76*	4035.79*	325.21*	74.25*	73.45*	39.78*
MBP	1557.10*	5940.47*	2225.97*	63.70*	33.63*	105.32*	17.45*
Fungal population	5091.62*	6811.12*	312.71*	45.86*	16.37*	22.84*	8.30*
Bacterial population	84498.62*	15974.11*	1143.10*	386.50*	92.16*	41.56*	10.41*
Soil respiration	148422.90*	50440.61*	97795.60*	3819.49*	3203.45*	3249.21*	907.69*
MBC/SOC	4021.28*	0.01 ^{ns}	614.34*	814.00*	208.56*	224.68*	52.82*
MBN/TKN	1515.77*	106.16*	435.52*	168.70*	63.42*	32.63*	20.02*
MBP/AP	223.51*	36.97*	156.10*	72.43*	72.21*	9.24*	42.94*
MBC/MBN	3981.14*	367.73*	323.84*	1297.86*	89.91*	48.64*	102.83*
MBC/MBP	582.75*	25.08*	112.44*	398.10*	50.16*	19.80*	15.06*
MBN/MBP	254.26*	196.58*	22.75*	102.24*	40.69*	19.35*	14.40*

T treatments, *SD* soil depth (cm), *D* days, *MBC* microbial biomass carbon, *MBN* microbial biomass nitrogen, *MBP* microbial biomass phosphorus, *SOC* soil organic carbon, *TKN* total Kjeldhal N, *AP* available phosphorus, *ns* not significant, *df* degree of freedom

* Significant at $p < 0.05$

from its lowest value ($15.31 \mu\text{g g}^{-1}$) in compost mulched plots to the highest ($79.09 \mu\text{g g}^{-1}$) in vermicompost (WHVcM) mulched plots (Fig. 2). Three-way factorial ANOVA (Table 1) also revealed that microbial P (MBP) significantly differed with treatments ($F = 1557.10$), soil depth ($F = 5940.47$) and days ($F = 2225.97$). Further, it was found that ratio of soil microbial C to microbial N (MBC/MBN), microbial P (MBC/MBP), and the ratio of microbial N to microbial P (MBN/MBP) was also significantly ($p < 0.05$) different between treatments, soil depth and days.

Contribution of Microbial C, N and P to soil C, N and P

Contribution of microbial C, N and P to soil organic C, total N and available P, respectively were significantly ($p < 0.05$) different amongst mulching treatments, soil depths (except for MBC to SOC) and days (Table 2). Greater contribution (6.41 %) of microbial C (MBC) to SOC was recorded for vermicompost (WHVcM) mulched plots and lowest (1.59 %) was recorded in green mulched plots (Table 2). The contribution of microbial N (MBN) to soil total N (TN) ranged 3.16–4.71 % in control plot, 1.73–3.55 % in green (WHGM) mulched soil, 2.35–5.11 % in compost (WHCM) mulched plot and 1.76–4.38 % in vermicompost (WHVcM) mulched plots (Table 2). The percentage contribution of microbial biomass phosphorus (MBP) to soil available phosphorus (P) ranged from 9.88 to 18.96 % in control plot, from 7.32 to 21.18 % in green

(WHGM) mulched soil, from 7.88 to 19.58 % in compost (WHCM) mulched plot and from 8.66 to 12.15 % in vermicompost (WHVcM) mulched plots (Table 2).

Microbial Populations and Soil Respiration

Interactions among treatments, depths and days significantly ($p < 0.05$) influenced the fungal and bacterial populations (Table 2). Bacterial population ranged $20.11\text{--}74.31 \text{ CFU} \times 10^4$ and fungi varied from $10.04 \text{ CFU} \times 10^3$ to $31.09 \text{ CFU} \times 10^3$ irrespective of treatments, depths and days (Fig. 3). In general, microbial populations (fungi and bacteria) increased gradually till 77–98 days after mulching and decreased during harvest (112 day) in all the treatments (Fig. 3). Among treatments, microbial populations were highest in vermicompost mulched plots followed by compost and green mulched plots. Spatially, microbial populations were maximum in the surface-soil (0–15 cm) layer and minimum in the sub-surface-soil (15–30 cm) layer in all the treatments. Over all, microbial populations were significantly ($p < 0.05$) greater in mulched plots than in the control plot (Fig. 3; Table 2).

In both the soil depth, soil respiration significantly ($p < 0.05$) increased in all the mulched plots over control (Table 2). Soil respiration was minimum in control plot ($19.20 \mu\text{g CO}_2\text{-C g}^{-1}$ of soil d^{-1}) at sub-surface soil layer (15–30 cm), and maximum respiration rate was recorded in vermicompost mulched plots ($89.21 \mu\text{g CO}_2\text{-C g}^{-1}$ of soil d^{-1}) at 0–15 cm soil layers irrespective of sampling days (Fig. 3).

Table 2 Spatio-temporal variations in percentage contribution of microbial biomass C, N and P to respective parent nutrient pool (C, N and P) under various forms of water hyacinth mulch treatments

Treatments	Soil depth (cm)	Days after mulching/% contribution							CD (<i>p</i> < 0.05)
		7	14	35	56	77	98	112	
MBC/SOC									
Control	0–15	3.89 ± 0.35	2.75 ± 0.11	2.94 ± 0.28	2.44 ± 0.24	2.15 ± 0.21	2.31 ± 0.16	1.75 ± 0.24	NS
	15–30	2.15 ± 0.89	1.59 ± 0.15	2.98 ± 0.23	2.81 ± 0.39	1.85 ± 0.09	1.86 ± 0.09	1.93 ± 0.56	NS
WHGM	0–15	3.83 ± 0.92	3.18 ± 0.27	4.41 ± 1.14	3.59 ± 1.02	4.07 ± 1.24	4.42 ± 1.04	4.11 ± 1.15	NS
	15–30	1.78 ± 0.22	2.42 ± 0.14	2.18 ± 0.32	2.44 ± 0.87	2.04 ± 0.21	2.14 ± 0.12	2.07 ± 1.27	NS
WHCM	0–15	4.23 ± 0.62	3.99 ± 0.42	2.03 ± 0.27	1.91 ± 0.31	2.57 ± 0.13	2.43 ± 0.25	2.11 ± 0.18	NS
	15–30	4.01 ± 0.88	3.04 ± 0.57	2.34 ± 0.19	2.33 ± 0.55	2.11 ± 0.28	2.33 ± 0.27	2.09 ± 0.12	NS
WHVcM	0–15	5.73 ± 1.46	5.75 ± 0.39	4.99 ± 1.65	5.45 ± 1.37	4.30 ± 1.08	4.22 ± 1.05	4.74 ± 1.59	NS
	15–30	5.22 ± 1.31	6.41 ± 1.62	5.31 ± 1.78	5.21 ± 1.45	3.86 ± 0.67	4.84 ± 1.29	4.65 ± 1.47	NS
MBN/TKN									
Control	0–15	3.08 ± 1.01	2.34 ± 0.25	1.89 ± 0.14	2.66 ± 0.20	2.49 ± 0.19	2.96 ± 0.86	3.37 ± 1.05	2.48
	15–30	3.02 ± 1.14	1.99 ± 0.22	1.79 ± 0.24	2.41 ± 0.18	2.11 ± 0.09	2.18 ± 0.42	2.62 ± 0.89	1.22
WHGM	0–15	2.87 ± 0.93	3.62 ± 0.70	3.48 ± 0.75	3.83 ± 0.19	4.71 ± 1.02	4.13 ± 1.13	4.34 ± 1.21	2.73
	15–30	1.73 ± 0.27	3.64 ± 0.47	3.42 ± 0.53	3.21 ± 0.15	4.05 ± 0.94	4.55 ± 1.47	4.37 ± 1.19	1.94
WHCM	0–15	4.27 ± 1.25	3.21 ± 0.29	3.25 ± 0.97	3.41 ± 0.42	3.52 ± 0.31	4.25 ± 1.25	5.11 ± 1.57	4.03
	15–30	2.88 ± 0.81	2.63 ± 0.34	2.66 ± 0.46	3.29 ± 0.27	3.55 ± 0.56	3.22 ± 0.31	4.17 ± 1.15	2.19
WHVcM	0–15	3.44 ± 1.56	3.22 ± 0.41	2.97 ± 0.88	2.82 ± 0.13	2.65 ± 0.21	3.48 ± 0.55	4.38 ± 1.23	3.21
	15–30	1.76 ± 0.54	2.11 ± 0.53	1.85 ± 0.22	2.44 ± 0.16	2.35 ± 0.07	2.61 ± 0.42	3.97 ± 1.02	2.05
MBP/AP									
Control	0–15	8.03 ± 2.31	7.57 ± 1.11	8.96 ± 2.23	10.08 ± 3.24	8.88 ± 2.11	8.61 ± 2.94	8.32 ± 2.56	6.12
	15–30	5.99 ± 1.97	6.32 ± 1.68	8.14 ± 1.06	8.49 ± 2.97	6.87 ± 1.04	7.31 ± 2.08	6.39 ± 1.35	5.41
WHGM	0–15	16.54 ± 2.31	16.21 ± 2.37	10.01 ± 2.78	11.13 ± 1.85	9.52 ± 1.09	9.75 ± 2.14	8.78 ± 1.29	9.29
	15–30	11.18 ± 1.44	12.12 ± 2.05	9.50 ± 1.53	9.24 ± 1.08	8.84 ± 1.25	9.11 ± 2.01	7.32 ± 1.08	7.56
WHCM	0–15	13.77 ± 1.73	12.44 ± 1.95	11.34 ± 2.04	13.01 ± 1.78	11.39 ± 2.46	10.26 ± 1.37	10.26 ± 1.56	8.13
	15–30	11.16 ± 1.09	11.53 ± 1.71	9.34 ± 1.33	9.58 ± 1.14	9.46 ± 1.51	7.88 ± 1.15	8.62 ± 1.25	7.09
WHVcM	0–15	12.26 ± 2.02	10.37 ± 1.44	11.74 ± 1.08	10.37 ± 1.29	10.13 ± 1.45	10.94 ± 1.79	10.87 ± 1.34	9.05
	15–30	11.15 ± 1.27	9.72 ± 1.03	11.65 ± 1.27	8.66 ± 1.34	9.97 ± 1.83	10.57 ± 1.66	9.25 ± 1.78	6.47

SOC soil organic carbon, TKN total Kjeldhal N, AP available phosphorus, MBC microbial biomass carbon, MBN microbial biomass nitrogen, MBP microbial biomass phosphorus, NS not significant, $\pm$ SD, $n = 20$

Relationships Amongst Soil Microbial and Physico-Chemical Properties

Soil microbial C (MBC), N (MBN) and P (MBP) showed significant ($p < 0.05$) positive correlations with their respective parent soil nutrient pool viz., soil organic C ($r = 0.363$), total N ($r = 0.546$) available P ($r = 0.874$) (Fig. 4). Correlation amongst microbial nutrients (C, N and P) was also positive and statistically significant ($p < 0.05$) (Fig. 4). Soil pH was negatively correlated with both soil nutrient pool (C: $r = -0.478$; N: $r = -0.824$; P: $r = -0.737$) and microbial biomass C ($r = -0.620$), N ($r = -0.705$) and P ($r = -0.658$). Soil organic C recorded a significant ($p < 0.05$) positive correlation with total N ($r = 0.637$) and available P ($r = 0.834$). Soil C/N ratio did not influence the microbial nutrients which was evident from

the insignificant correlation coefficients (Table 3). Contribution of microbial nutrients to soil organic C, total N and available P were also affected by their respective microbial counterpart. Microbial populations (fungi and bacteria) and soil respiration registered significant ($p < 0.05$) positive correlations with moisture content, SOC, total N and available P, while, they established a significant ($p < 0.05$) negative correlation with soil pH (Table 4). Further, microbial populations and soil respiration showed significant positive correlations with microbial nutrients.

Discussion

Soil organic matter is of great importance because of its influence on soil physical, chemical and biological

Fig. 3 Soil microbial populations and respiration under different forms of water hyacinth mulches. *d* Days, *CON* control, *WHGM* green mulch, *WHCM* compost mulch, *WHVcM* vermicompost mulch. Vertical error bars represents standard error ($\pm$, $n = 20$)

properties and on creating a favourable medium for biological reactions and life support in the soil environment [14]. Earlier, Körschens et al. [23] did report that both inert and decomposable fractions of SOM have special importance in sustainable productivity of soils. The present research results

confirms with aforesaid findings that the large proportion of soil organic matter significantly increased in the water hyacinth mulched plots (Fig. 1). This further suggests that water hyacinth compost can be a potential N supplier for the lowland rice farming system in humid tropics. The

Fig. 4 Relationship between soil organic C, total N and available P with microbial biomass C, N and P, and amongst soil microbial biomass nutrients (C, N, P) under different forms of water hyacinth mulches

Table 3 Correlations (r values; $n = 200$) amongst soil chemical and microbiological properties under different forms of mulching treatments

	SMC	pH	SOM	C/N	MBC/MBN	MBC/MBP	MBN/MBP	MBC/SOC	MBN/TKN	MBP/AP
MBC	0.405*	-0.620*	0.693*	-0.021 ^{ns}	0.480*	0.335*	-0.318*	0.382*	0.026 ^{ns}	-0.511*
MBN	0.174*	-0.705*	0.766*	0.101 ^{ns}	-0.304*	-0.304*	-0.007 ^{ns}	-0.087 ^{ns}	0.544*	-0.479*
MBP	0.345*	-0.658*	0.836*	0.165*	-0.013 ^{ns}	-0.295*	-0.392*	-0.047 ^{ns}	0.319*	-0.402*

SMC soil moisture content, SOC soil organic carbon, TKN total Kjeldhal N, AP available phosphorus, MBC microbial biomass carbon, MBN microbial biomass nitrogen, MBP microbial biomass phosphorus, ^{ns} not significant

* Significant at $p < 0.05$

vermicompost mulched plots had greater microbial biomass P than the compost and green mulched plots, suggesting that vermicompost prepared from the water hyacinth have greater

P assimilation potential. Nonetheless, greater microbial biomass could also be attributed to differences in the quantity and quality of the substrate and also soil nutrient status [17].

Table 4 Correlations (r values; $n = 200$) amongst soil chemical, microbial nutrients, microbial populations and soil respiration under different forms of mulching treatments

	MC	pH	SOC	TKN	AP	C/N	MBC	MBN	MBP
Fungal Population (CFU $\times 10^3$)	0.296*	-0.228*	0.436*	0.773*	0.699*	-0.134*	0.635*	0.614*	0.726*
Bacterial population (CFU $\times 10^4$)	0.312*	-0.361*	0.213*	0.716*	0.600*	-0.314*	0.493*	0.601*	0.625*
Soil respiration ($\mu\text{g CO}_2\text{-C g}^{-1}$ of soil d^{-1})	0.214*	-0.308*	0.754*	0.812*	0.897*	-0.110 ^{ns}	0.873*	0.763*	0.859*

MC moisture content, SOC soil organic carbon, TKN total Kjeldhal N, AP available phosphorus, MBC microbial biomass carbon, MBN microbial biomass nitrogen, MBP microbial biomass phosphorus, *ns* not significant

* Significant at $p < 0.05$

Table 5 Percentage increase in microbial population and paddy yield attributes as influenced by residue loading over control treatment

Variables	Soil depth (cm)	Population (variation in %)		Treatments	Yield attributes	
		Bacteria	Fungi		Biomass (g dw m^{-2})	Yield (q ha^{-1})
Control to WHGM	0–15	35.42	33.85	Control	883.49 $\pm$ 114.57	26.63 $\pm$ 7.87
	15–30	39.01	56.73			
Control to WHCM	0–15	125.09	57.30	WHGM	1308.31 $\pm$ 76.03 (48.08)	41.08 $\pm$ 10.92 (54.26)
	15–30	133.82	74.78			
Control to WHVcM	0–15	154.19	66.48	WHCM	1115.32 $\pm$ 149.97 (26.24)	37.25 $\pm$ 9.24 (39.88)
	15–30	170.27	106.28	WHVcM	1442.68 $\pm$ 205.22 (63.29)	45.34 $\pm$ 11.24 (70.26)

Values in parentheses are the percentage increase over control; $n = 5$, $\pm$ SE

Microbial carbon (MBC), nitrogen (MBN) and phosphorus (MBP) registered a significant positive correlation ($p < 0.05$) with the respective parent nutrient reserve such as organic C, total N and available P, respectively (Fig. 4). Until now, no report is available on the effect of water hyacinth mulching on microbial biomass nutrients (C, N and P). Nevertheless, there are plenty of reports available on different types of mulching material such as crop residues, industrial wastes, organic wastes and plastic reveal that an increased microbial biomass and activity in response to applying agricultural soils [5]. However, microbial nutrients in water hyacinth (green, compost and vermicompost) mulched plots was higher than the values reported for different mulch material such as crop residues [16, 34], tree parts [2], weeds [30], yard wastes [32] and plastic [24] from different parts of the world. Nonetheless, mulch can strongly influence soil microbial activity provided the nutrient contents of the mulching materials are favourable. In the present context, different forms of water hyacinth had higher C, N and P which could have facilitated the microbial growth faster.

In the present investigation, percentage contribution of microbial carbon (MBC) to soil organic C (SOC) ranged from 1.59 to 10.22 %, contribution of microbial N (MBN) to soil total N (TN) ranged from 1.73 to 5.11 % and that contribution of microbial P (MBP) to soil available P(P) ranged from 7.32 to 21.18 % (Table 2). The aforesaid ranges of values were remarkably higher than the earlier reported values for different land use systems (forest,

agriculture and *jhum*) in north-eastern India [7, 8]. Greater contribution of microbial C, N and P to soil C, N and P, respectively in the water hyacinth mulched plots as compared to control plots indicates rapid microbial utilisation and high input nutrient turnover rate due to microbial activity.

The C/N ratio of the microbial biomass could be an indicator of the relative proportion of fungi to bacteria [13]. Consequently, the organic amendments with wider C/N ratio, such as the cereals and mustard would probably lead to the colonisation of fungal populations, which was evident from wider $C_{\text{mic}}/N_{\text{mic}}$ ratio. Pulses having a narrow C/N ratio lead to higher bacterial activity, indicated by a narrow $C_{\text{mic}}/N_{\text{mic}}$ ratio [37]. Contrast to this, in the present study green mulched plots had wider $C_{\text{mic}}/N_{\text{mic}}$ ratio (6.49–20.34) and compost mulched (3.61–5.98) and vermicompost mulched (7.11–12.60) plots had narrow $C_{\text{mic}}/N_{\text{mic}}$ ratio, revealing that bacterial populations were greater than the fungal populations. This is evident from also the greater percentage increase in bacterial population as compare to that of fungus (Table 5) at least in the compost/vermicompost treated soils. Further, decreasing fungal population may be due to the production of phenolic compounds and antifungal acids during the decomposition of crop residues [27]. Earlier, Arunachalam et al. [9] and Pennanen [28] have reported such a relationship between microbial population and soil pH during organic matter decomposition in sacred grove and boreal coniferous forest, respectively. Eventually, microbial populations had significant negative correlations

with soil pH (Table 4). Hence, it could be said that combination of bacterial and fungal communities made the differences in the soil nutrient mineralisation of water hyacinth mulched plots over control plots. This community could possibly include ammonifiers, N-fixing bacteria and sugar fungi [21].

From the present study, it is established that soil mulched with different forms of water hyacinth significantly increased the fungal and bacterial populations compared to control plots (Fig. 3). Likewise, soil respiration rate also indicated greater microbial activity in water hyacinth mulched plots than in the control plots. Hassink [18] also reported substrate induced soil respiration in grassland soils. It was obvious that rapidly decomposable organic matter rich water hyacinth mulch induced the growth microbial populations which in turn lead to the higher microbial nutrients (C, N and P) in all the treatments. Nonetheless, both fungal and bacterial populations were significantly declined in sub-surface soils. This could be attributed to the nutrients availability in sub-surface soil to help promote the growth of microbial communities. Further, Tangjang et al. [31] also found that decrease in microbial population with increase in soil depth in agro-forestry systems of north-eastern India.

Over all, the present study has shown that water hyacinth (*E. crassipes*) has a great potential to increase the size of microbial biomass, which in turn plays a significant role in maintaining soil nutrient pool. To this effect, mulching provided healthier environmental conditions for microbial communities to manifest greater biomass C, N and P. Earlier, Tiquia et al. [32] also reported that direct C input in the form of organic mulching improved the soil microbial biomass. It is evident from the present study that increment in SOM and microbial biomass C in water hyacinth mulched plots indicates the improvement in soil fertility when compared to control plots. This was corroborated by the increase in biomass and yield of paddy crop as well (Table 5) Further, utilisation of *E. crassipes* as soil mulch found to answer two ecological problems, firstly, holistic control of this obnoxious aquatic weed that degrades the wetlands and secondly, water hyacinth can be a promising candidate species for preparation of compost and vermicompost, which can be used as alternative to chemical fertilizers to preserve the soil biodiversity and health through increasing microbial nutrient biomass, and ensure the food security in the tropical rainfed agro-ecosystems.

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