

Water Hyacinth-Derived Biopolymers as Reinforcements for Sustainable Fiber-Reinforced Polymer Composites

Renu Chaudhary¹, Vijay Kumar², Akhilesh Kumar³, Sanjay Gupta⁴, Vivek Kumar^{5,*}

Abstract

Composting has gained significant attention for sustainable waste management and nutrient recycling. This study investigated the efficacy of water hyacinth (*Eichhornia crassipes*) as a composting material to produce nutrient-rich organic fertilizer. Water hyacinth compost inoculated with nitrogen-fixing (*Azotobacter chroococcum*) and phosphate-solubilizing bacteria (*Pseudomonas putida*) exhibited increased nitrogen and phosphorus content compared to uninoculated compost or cattle dung compost. Wheat grown with biofertilizer-enriched water hyacinth compost displayed significantly improved grain yield, straw yield, plant height, and nutrient uptake compared to control treatments. Economic analysis revealed that biofertilizer-enhanced water hyacinth compost resulted in greater net returns compared to other treatments. This study highlights the potential of water hyacinth as a sustainable resource for organic fertilizer production, promoting agricultural productivity and economic benefits.

Keywords: Polymer, water hyacinth, cattle dung, Chemical composites, Nanocellulose. Fiber-Reinforced Polymer Composite.

INTRODUCTION

The composting process has received much attention in recent years because of pollution concern and the search for environmentally sound and novel methods of treating different composting materials.

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Water hyacinth (*Eichhornia crassipes*) is an aquatic plant that floats freely in fresh water or can be anchored in mud. It poses practical challenges for shipping, hydropower fisheries and irrigation schemes. It is now considered a major disadvantage to biodiversity. Several efforts have been put to control it, but one novel method is to use this aquatic weed as a composting material. Water hyacinth is rich in nitrogen, phosphorus and trace elements [1].

Compost prepared by conventional technology (cattle) contains very low nutrient content [2]. and it is possible to increase the main content (nitrogen and phosphorus) of the compost by inoculating and fixing nitrogen (*Azotobacter chroococcum*) and phosphate solution (*Pseudomonas putida*) bacteria [3]. In addition to Nitrogen (N) fixation, nitrogen-fixing bacteria solubilize Phosphorous (P) through the production of organic acids and enzymes [4]. The current study was designed to determine

whether the inoculation of N-modifying and P-solubilizing bacteria can affect changes in compost N and P content and wheat growth parameters in particular. The cost effectiveness of the experiment was also calculated, and it was found that compost prepared from water treatment was cheaper compared to cow dung.

MATERIALS AND METHODS

Leaves and Stems of water hyacinth (*Eichhornia crassipes*) were collected from a village pond and cuts into 5-10 cm pieces, dried up to 30 % and placed in pits of 1 M W x 1 M D x 4 M L for 25 d. Likewise cattle dung was partially disintegrated. These partially disintegrated materials were then separately put in pits of 1 M W x 1 M D x 4 M L. The composting of water hyacinth and cattle dung was treated with the following treatments.

- T_1 – 90 % Water hyacinth manure (WHM) + 10 % cattle dung
- T_2 – 90 % WHM + 10 % cattle dung with *A. chroococcum* + *P. putida*
- T_3 – 100 % Cattle dung (CD)
- T_4 – 100 % CD with *A. chroococcum* + *P. putida*

Charcoal based bacterial cultures (10^9 cells g^{-1}) were inoculated into T_2 and T_4 treatments and mixed thoroughly. The composting material was overturned thoroughly after every 15 d to allow proliferation of aerobic inoculated and native micro flora. In water hyacinth compost 10 % cattle dung was mixed as a binding agent. The process of composting was completed in 90 d. For chemical analysis, samples were dried in an oven (45°C) and passed through a 0.05 mm sieve. Organic carbon (C) was determined by Jackson [5], total nitrogen by Subian and Asija [6] and phosphorus by John [7].

Field Experiment

The field experiment was tested on wheat (*Triticum aestivum* L.) variety DBW 296 was sown in sandy loam alluvial soil (farmer's field, Meerut, Uttar Pradesh, India, latitude- 28°51'54.43"N, longitude - 77°56'12.27"E) having pH 7.9, organic carbon 0.38 %, total nitrogen 0.037 % and phosphorous 4.9 ppm are available. Both the composts were applied @ of 5 t ha^{-1} , besides a control plot. Observations on wheat, straw, plant height and N P uptake of wheat plants were recorded at harvest (135 d after planting). The experiment was conducted in a completely randomized block design with three replications. Data were analyzed at a 5% significance level [8].

RESULTS

The nutrient contents of the manures (without inoculation) prepared from water hyacinth had 1.02% and 0.81% (N & P) while the cattle dung had 0.75% and 0.68% N & P respectively. Both the manures treated with bacterial strains exhibited increased nutrients value and it was found to be 1.40% and 1.02% (N & P) in water hyacinth, while in cattle dung the N and P contents were 1.13% and 0.85%, respectively mentioned in Table 1 and Figure 1.

Table 1. Carbon and Nitrogen Ratio During Composting of Water Hyacinth and Cattle Dung Inoculated with *A. Chroococcum* and *P. Putida*.

	Days											
	0			30			60			90		
Treatments	C (%)	N (%)	Ratio	C (%)	N (%)	Ratio	C (%)	N (%)	Ratio	C (%)	N (%)	Ratio
T_1	55.0	0.72	76.3	37.3	0.86	43.3	27.7	0.97	28.5	22.3	1.02	19.9
T_2	55.0	0.72	76.3	40.1	0.89	45.0	28.3	1.13	25.0	19.8	1.40	14.1
T_3	50.0	0.65	76.9	33.2	0.70	47.7	29.4	0.72	40.2	23.2	0.75	30.9
T_4	50.0	0.65	76.9	30.6	0.80	38.2	28.9	0.97	29.7	21.4	1.13	18.9
SEm $\pm$	1.78	1.02		2.59	1.01		1.42	0.09		1.27	0.06	
C D at 5 %	3.21	2.98		7.14	2.96		4.78	0.25		3.77	0.15	

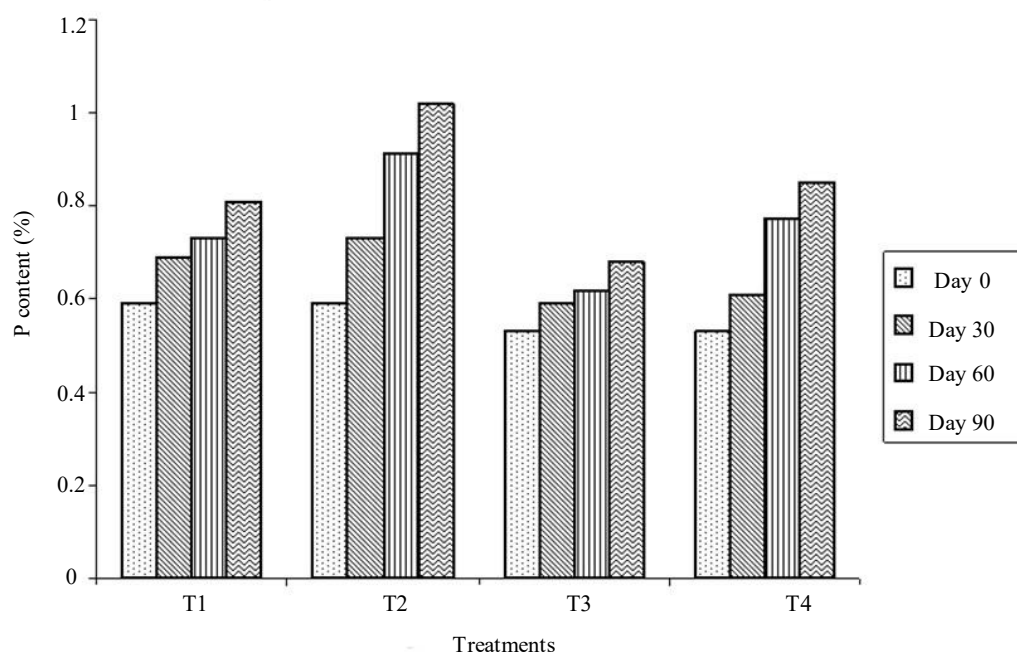


Figure 1. Total P content (%) during composting of water hyacinth and cattle dung inoculated with *A. chroococcum* and *P. putida*.

The data error in Table 2 shows this treatment T₂ performed better as compared to other treatments. In grain yield, treatment T₂ was 33.1 % higher over T₀ (control), 7.19 % over T₄. The second-best treatment was T₄ which exhibited 24.2 % higher grain yield over control. The straw yield was also influenced by different manures. Treatment T₂ was 80.6 % higher over control (T₀) and 4.89 % over T₄. Nitrogen uptake in grain was 147 % more than control by treatment T₂ and 22 % over treatment T₄, and T₄ was 102.5 % higher over treatment T₀. Nitrogen uptake in straw T₂ was 165.2 % and 14.3 % higher over control and treatment T₄ which is shown in Figure 2. The P uptake in grain was 143.2 % and 5.8 % higher over T₀ and T₄ and in straw it was 175 % and 29.1 % over T₀ and T₄ depicted in Figure 3.

The economic analysis Table 3 shows that the fixed cost for all the treatments were reported Rs. 3725, whereas, the variable cost was ranging between Rs. 10611 to Rs. 11011. The lowest cost was observed in treatment T₂ i.e. Rs. 10361 followed by treatment T₄ i.e. Rs. 10461 ha⁻¹. The overall total costs for treatments T₀ (Control), T₁, T₂, T₃ and T₄ was calculated Rs. 11011, 10611, 10361, 11011 and Rs. 10461 respectively. Similarly, the cost of production per qt(quintal) of wheat was less in treatment T₂ (Rs. 626) followed by treatment T₄ (Rs. 677). The added and reduced cost was observed in treatment T₂, where farmer spends comparatively less Rs. 250 over treatment T₁. As explicit from Table 4, net return of Rs. was highest in treatment T₂ (Rs. 19761), which was 12.7 % (Rs. 17533), 10.1 % (Rs. 17934) and 126.7 % (Rs. 8715) higher than treatments T₁, T₄ and T₀. The data revealed that the T₂ treatment was cost effective in comparison to all other treatments followed by T₄.

Table 2. Yield Parameters of Wheat as Influenced by Different Treatments of Manures.

Treatments	Grain Yield (Kg ha ⁻¹)	Straw Yield (Kg ha ⁻¹)	Plant Height (cm)
T ₀ (Control)	1242	2279	66.17
T ₁	1525	3902	68.27
T ₂	1654	4117	72.39
T ₃	1480	3863	68.80
T ₄	1543	3925	70.89
SEm ±	76	81	1.62
C D at 5 %	211	238	4.79

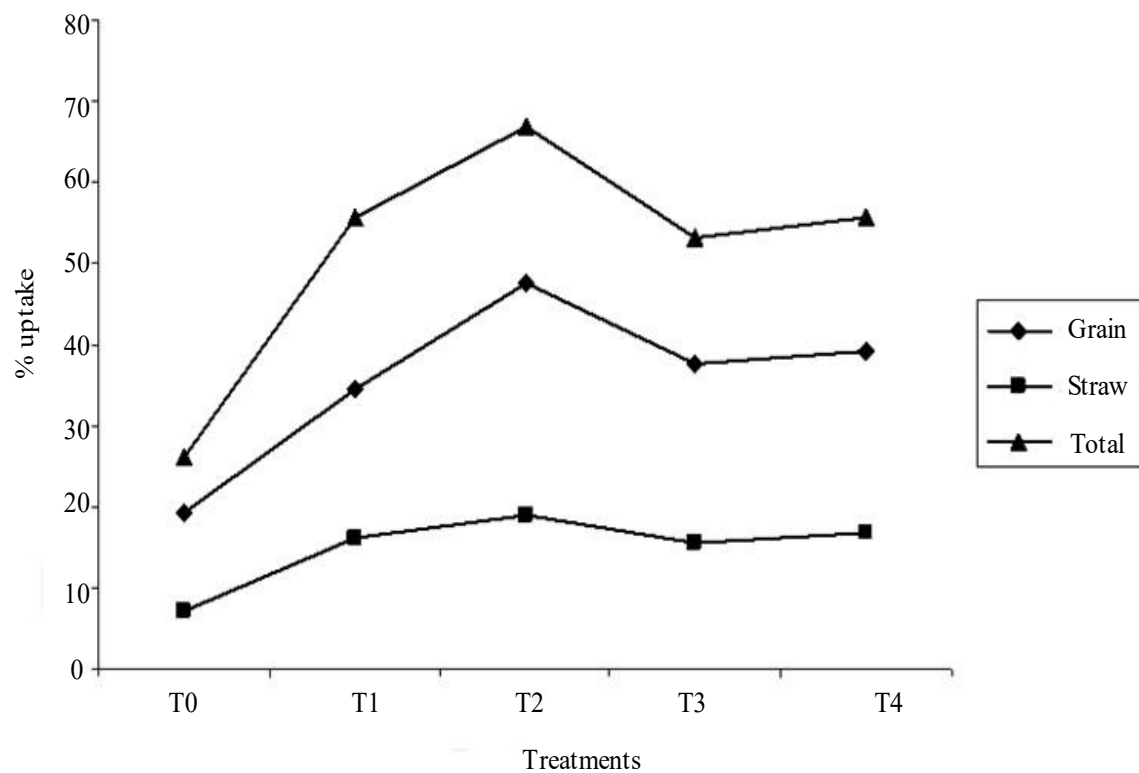


Figure 2. Nitrogen uptake (%) in wheat as influenced by compost treatments.

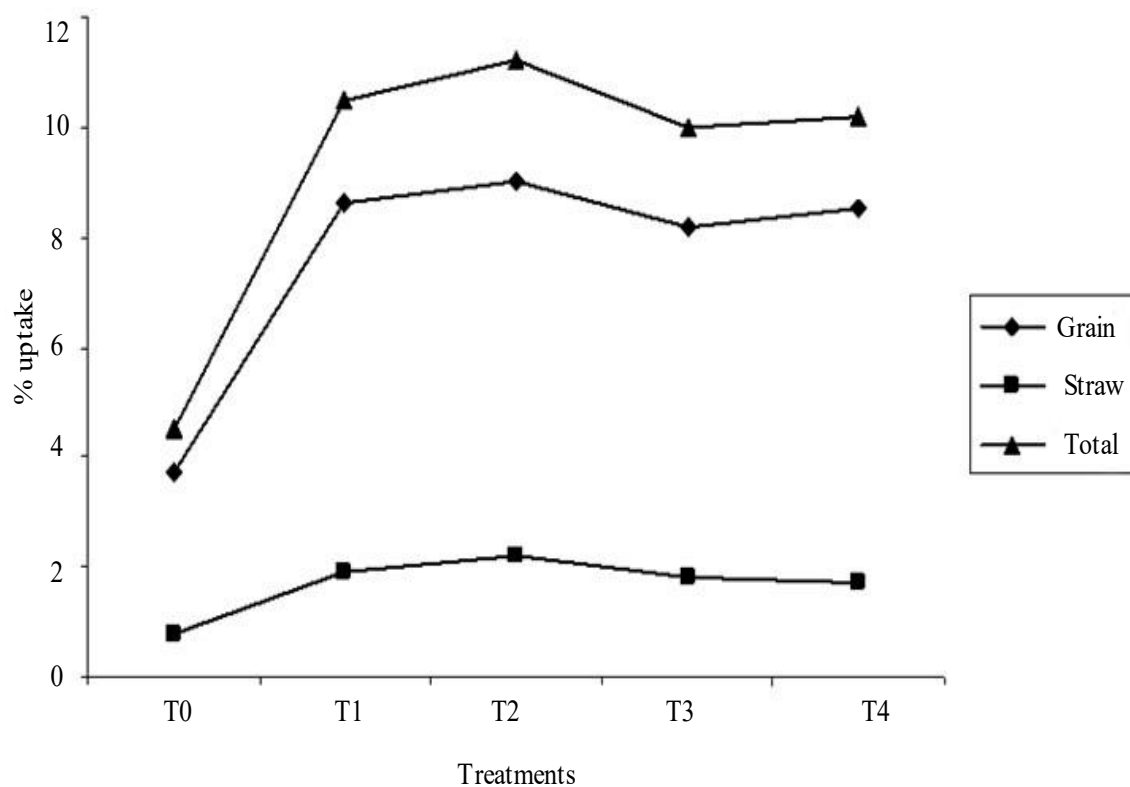


Figure 3. Phosphorous uptake (%) in wheat as influenced by compost treatments.

Table 3. Total Cost Structure for Wheat var. DBW 296 Productions.

S.N.	Particulars	Treatments				
		T_0	T_1	T_2	T_3	T_4
A	Fixed Costs					
1.	Land revenue	176	176	176	176	176
2.	Building and equipment depreciation and repairs	789	789	789	789	789
3.	Interest on average capital invested	1260	1260	1260	1260	1260
4.	Other fixed cost	1500	1500	1500	1500	1500
5.	Total fixed cost	3725	3725	3725	3725	3725
B	Variable cost					
1.	Labor charges	1126	1126	1126	1126	1126
2.	Seed	980	980	980	980	980
3.	Fertilizers	-	600	600	1000	1000
4.	Cost on work	1750	750	500	750	200
5.	Water, electricity charges	1450	1450	1450	1450	1450
6.	Pesticides	1240	1240	1240	1240	1240
7.	Insecticides	240	240	240	240	240
8.	Miscellaneous	500	500	500	500	500
	Total variable cost	7286	6886	6636	7286	6736
C.	Total cost/Cost of cultivation	11011	10611	10361	11011	10461
D.	Cost of production	886	695	626	743	677
E.	Added/Reduced cost		-400	-250	+650	-550

All figures are in Indian Rs. All the values can be converted into UD \$ dividing by 82.74.

Table 4. Gross and Net Returns from Wheat Production with Different Treatments.

S.N.	Treatments	Wheat production (qt)	Wheat selling price / qt	Return from wheat total	Straw production (qt)	Selling price / qt	Total return from wheat straw	Gross return (Rs)	Total cost (Rs)	Net return (Rs)
1.	T_0	12.42	950	11750	22.79	350	7976	19722	11011	8715
2.	T_1	15.25	950	14487	39.02	350	13657	28144	10611	17533
3.	T_2	16.54	950	15713	41.17	350	14409	30122	10361	19761
4.	T_3	14.80	950	14060	38.63	350	13520	27580	11011	16569
5.	T_4	15.43	950	14658	39.25	350	13737	28395	10461	17934

All figures are in Indian Rs. qt = quintal

DISCUSSION

The response of wheat plants to inorganic fertilizers is well understood, but the application of organic fertilizers has shown variable results. The present study indicates that the use of nutritionally rich organic manure can produce significantly good results for grain, straw, and plant height and nutrients uptake by the wheat crop. All the growth parameters of wheat crop were more with the treatment T_2 followed by T_4 . The composting materials of T_2 treatment have more N and P as compared to T_1 and T_3 . The treatments T_1 and T_3 were not inoculated with N fixing bacteria, therefore less nitrogen fixation and more C:N ratio, thus, the composting material was poor from available nitrogen content. Inoculation of *P. putida* leads to solubilization of unavailable phosphate in the composting materials of T_2 and T_4 by production of organic acids, chelating agents, sugar alcohols and combination of all these factors [9,10], as evident from Fig. 1, the P content was more in treatments T_2 and T_4 . Singh et al. [4] reported the production of phytohormones by the inoculated bacteria in the compost; therefore, in this study inoculated bacteria might have produced indole acetic acid (IAA) and made the organic manure richer.

Water hyacinth naturally has more N and P as compared to cattle dung and inoculation of *A. chroococcum* and *P. putida* has enriched it further 1.40 % from 1.02 % i.e 37.2 % more nitrogen than uninoculated treatment T₁. Treatment T₂ has 86.6 % and 23.8 % more available N than T₃ and T₄, similarly the available P was 25.9 % and 20.0 % more than treatment T₁ and T₄. Therefore, all the growth parameters of wheat were more influenced by treatment T₄, which also substantiates from the data of N and P uptake in treatment T₄ depicted in Figure 2 and 3.

The economic analysis of the experiment also revealed the maximum return (Rs.) from the treatment T₂ followed by T₄, which shows inoculation of bacteria into organic manure has improved it with nutrients, thus the biofertilizer inoculation has contributed to economy of wheat production as compared to without biofertilizer organic manure. Kumar et al. also calculated the efficiency of *A. chroococcus* in aridisols compared to tall wheat and moths and obtained a return of 12-38 ha⁻¹ with an investment of 1 rupee ha⁻¹ using bacteria. Therefore, dewatered compost can be used as an economic benefit to increase crop production with high nutrient availability through nitrogen fixation and phosphate solubilizing microorganisms [11].

CONCLUSION

The utilization of manures prepared from water hyacinth and cattle dung, enhanced with microbial inoculants like *A. chroococcum* and *P. putida*, demonstrates promising efficacy and economic viability. This approach presents a sustainable solution by efficiently converting waste biomass into nutrient-rich nano-organic fertilizers. All things considered, adding beneficial microbial strains and composites to organic manures together with water hyacinth and cattle dung provides a sustainable and financially feasible way to enhance soil health, boost agricultural output, and support environmental sustainability. Additional investigation and field testing are required to completely clarify the potential of this strategy in various agroecological settings.

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