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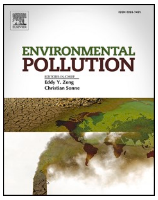

Effects of agro based organic amendments on growth and cadmium uptake in wheat and rice crops irrigated with raw city effluents: Three years field study☆

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ABSTRACT

Cadmium (Cd) accumulates in the vegetative tissues of rice and wheat crops, posing a serious threat in the food chain. A long-term field experiment was conducted to investigate the effects of rice husk biochar (RHB), farm manure (FM), press mud (PrM), and poultry manure (PM) on the growth, yield, and economics of wheat and rice crops grown with sewage water. The results showed that RHB increased wheat plant height (27%, 66%, 70%), spike-length (33%, 99%, 56%), straw yield (21%, 51%, 49%), and grain yield (42%, 63%, 65%) in year-1, year-2, and year-3, than respective controls. For rice crop, RHB showed the maximum increase in plant height (64%, 92%, 96%), spike length (55%, 95%, 90%), straw yield (34%, 53%, 55%), and grain yield (46%, 66%, 69%) each year (2019–2021), compared to their respective controls. The Cd immobilization was increased by the application of RHB while other treatments followed FM > PrM > PM > control in each year of wheat and rice crops. For year-1, benefit-cost ratio remained maximum with the application of FM while for the 2nd and 3rd years in sequence, RHB proved more economical than other treatments and consistently produced wheat and rice with lower Cd concentration than FM, PrM, and PM in grains. This long-term experiment suggested that the application of organic amendments consistently increased biomass of rice and wheat and decreased the Cd concentration in tissues. The RHB remained more effective compared with FM, PrM, and PM in terms of yield, low Cd accumulation and economics of rice and wheat crops.

Abbreviations: Cd, Cadmium; RHB, Rice husk biochar; FM, Farm manure; PrM, Press mud; PM, Poultry manure; BC, Biochar; pH_s, pH of soil saturated paste; EC_e, Electrical conductivity of soil extract; EC, Electrical conductivity; AB-DTPA, Ammonium bicarbonate-diethylene triamine penta-acetic acid; RSC, Residual sodium carbonate; SAR, Sodium adsorption ratio; HCl, Hydrochloric acid; AAS, Atomic absorption spectrometer; DAP, Diammonium phosphate; SOP, Sulphate of potash; SPAD, Soil plant analysis development; IRGA, Infra-red gas analyzer; BAF, Bioaccumulation; TF, Translocation factor; TI, Translocation index; HI, harvest index; II, Immobilization index; DICd, Daily intake of Cd; HRI, Health risk index; CdG, Cd in grains; BW, Body weight; Rf, Reference dose; TVC, Total variable cost; TFC, Total fixed cost; TC, Total cost; TR, Total revenue; p, Price per mound; y, Total output; BCR, Benefit cost ratio; ANOVA, Analysis of variance.

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1. Introduction

Cadmium (Cd) is a non-essential heavy metal that poses a significant threat to the environment and human health (El Rasafi et al., 2020; Rehman et al., 2023). It is widely distributed in the environment due to various anthropogenic activities such as mining, industrial processes, and agricultural practices (Liu et al., 2012; Ali et al., 2019; Okrikata and Nwosu, 2023; Patil et al., 2023). The Cd accumulation in different environmental compartments, particularly in plants, presents a major risk to human health through dietary intake (Rizwan et al., 2016; Zulfiqar et al., 2022). The toxic effects of Cd on plants are well-documented (Azhar et al., 2019; Rehman et al., 2021). The Cd toxicity in plants can reduce the uptake and translocation of nutrients and water, increases oxidative damage (Ronzan et al., 2019), disrupts plant metabolism (Dutta et al., 2021), and inhibits plant morphology and physiology (Haider et al., 2021; Zulfiqar et al., 2022; Zhu et al., 2023). These effects ultimately result in cell death and pose a serious threat to agricultural productivity and food safety (El Rasafi et al., 2020; Yildirim et al., 2023). The impact of Cd on plants is a matter of great concern due to its potential threat to human health primarily through dietary intake via the food chain (L. Ma et al., 2021; Ghasemi-Soloklui et al., 2023). Therefore, it is essential to explore and implement effective remediation strategies to mitigate Cd contamination and its adverse effects on the environment and human health (Ahmad et al., 2023; Xing et al., 2023).

There are various ways to remediate metal contamination from soil like soil washing, phytoremediation, electrokinetic, and chemical amendments that immobilized metals in soil (Keller et al., 2015; Moon et al., 2023). The application of agricultural waste such as crop residues, farm manure (FM), and press mud (PrM) is a promising approach in both ways like the management of agricultural waste and remediation of Cd contaminated soil for the cultivation of field crops (Bai et al., 2023; Yang et al., 2023). Agricultural waste offers cost-effective availability and aids in reducing landfill waste, supporting sustainable waste management for Cd remediation. Moreover, agricultural waste is produced in substantial quantity and that volume of waste can be a challenging especially for those countries with intensive agriculture and densely populated areas (Rani et al., 2023). The agricultural waste contains a significant amount of plant essential nutrients, improper management practices can lead to these nutrients loss and may cause environmental pollution (Waqas et al., 2023). Agricultural waste used for Cd remediation not only tackles contamination but also enhances soil fertility. This approach is crucial in areas where chemical fertilizers are not widely available to the farmers for various economic and/or environmental reasons. The application of FM and PrM reduce the bioavailability of Cd to cereal crops as irrigated with industrial raw effluents (Haider et al., 2023). The PrM can immobilize Cd in the soil, reducing its availability to plants and thus minimizing the uptake of Cd by crop. The presence of organic matter in PrM can help buffer soil pH, making it more suitable for nutrient uptake by plants. Additionally, the decomposition of organic matter in PrM can release nutrients into the soil, promoting plant growth. The FM, rich in nutrients, enhances soil fertility, increases plant growth, and mitigates adverse effects of Cd by improving soil quality and nutrient absorption. Moreover, utilizing biochar (BC) derived from agricultural waste presents a sustainable strategy for both waste management and Cd remediation in fields irrigated with untreated city effluents (Kalengyo et al., 2023). Rice husk BC (RHB), rich in silicone and functional groups like carbonyl group, and hydroxyl group, which can effectively immobilize Cd in soil, diminishing its uptake by plants (Zhang et al., 2023). The presence of silicone in RHB also offers advantageous effects for plants grown in Cd-contaminated soil (Sohail et al., 2020). Studies highlight the crucial role of agricultural waste and its BC in remediating Cd-contaminated soil (Hamid et al., 2020). Although prior research has focused on these organic amendments, their long-term effects remain unstudied. In this experiment, we evaluated the impact of RHB and agricultural waste amendments on agricultural crops across three consecutive years of experimentation.

Rice (*Oryza sativa* L.) is the most important food crop in Pakistan, surpassed only by wheat (*Triticum aestivum* L.). It contributes significantly to the national food supply, with more than 2 million tons produced annually (Muthayya et al., 2014). It serves as a staple food grain crop and plays a crucial role in ensuring food security for the population. Rice is a major cash crop in Pakistan and has a significant impact on the national economy. It accounts for 2.7% of the value added in agriculture and 0.6% of gross domestic product (Azam and Shafique, 2017). Pakistan is the world's 10th largest producer of rice, and its exports make up more than 8% of the world's total rice trade (Irshad et al., 2018). The country produces an average of 6 million tons of rice each year, contributing to foreign exchange earnings (Dawe, 2002). On the other hand, wheat contributes around 37% of the total food energy intake in Pakistan (Javed et al., 2016). It dominates all crops in terms of acreage and production, accounting for 37.1% of the crop area and 65% of the food grain production. The impact of climate change has presented a myriad of challenges for both of these crops, including the reduction of reliable irrigation sources, decreased rainfall, and elevated temperatures. Consequently, there is an imminent requirement to enhance the growth of rice and wheat crops through the implementation of organic amendments. It was hypothesized that the utilization of organic amendments could potentially mitigate the toxic effects of Cd, leading to prolonged positive outcomes and improved yields of cereal crops. The main objectives of this experiment is to evaluated the effect of RHB, FM and PrM on the growth and yield of crops in wheat rice cropping system, as cultivated in waste water irrigated fields; to assess the effectiveness of applied amendments on the immobilization of Cd and phytoavailability of Cd in soil as continuously irrigated with untreated raw city effluents; to calculate the cost-benefit ratio of the selected amendments applied in Cd-contaminated fields over the three-year experimentation period.

2. Materials and methods

2.1. Experimental location and climatic conditions

The experiment was conducted in a sewage irrigated field located in the subtropical arid climatic zone. During the experimentation summer season was extremely hot and dry, with temperatures often reaching well above 100 °F (37.8 °C) during the peak months. Winter season was mild and short, with temperatures averaging around 50–70 °F (10–21 °C). The region received low rainfall, averaging around 5–8 inches annually, and the humidity levels was relatively high, especially in the hotter months. Sandstorms and dusty winds remained common during the dry spells. Historically, the experimental field had been continuously irrigated with untreated sewage for the last 30 years.

2.2. Material characterization and experimentation

Before the experiment, soil samples were collected from the experimental field (0–20 cm depth), and raw city effluent samples were also collected and were brought to the Soil and Water Chemistry Laboratory for characterization. The soil samples were prepared by air-drying, grinding with a wooden pestle and mortar, sieving through a 2 mm mesh size sieve, and stored in zipper bags. The physical properties of the soil, such as saturation percentage and soil texture, were determined using the gravimetric method and hydrometric method, respectively, following Bouyoucos (1962). The soil saturated paste was prepared for the determination of soil pH (pH_s), and the extract of soil saturated paste was extracted by a vacuum extraction machine. The extracted soil sample was used for the determination of electrical conductivity (EC_e), and soluble cations and anions were determined in the soil extract. The ammonium bicarbonate-diethylene triamine penta-acetic acid (AB-DTPA) solution was used for the determination of the bioavailable fraction of Cd in the soil (Salinity Laboratory Staff, 1954; Page et al., 1982)), and the data of the experimental field's soil are given in Table 1.

Table 1

Pre-experimentation analysis of soil and organic amendments.

Parameters	Unit	Soil	Organic amendments			
			RHB	FM	PM	PrM
Clay	%	17.45	–	–	–	–
Silt	%	38.05	–	–	–	–
Sand	%	44.50	–	–	–	–
Texture		Loam	–	–	–	–
S.P	%	30.25	–	–	–	–
pH		7.23	9.85	7.66	7.34	7.28
EC	dS/m	3.56	5.65	4.55	4.78	5.01
K	%	0.88	0.98	0.91	0.93	0.90
P	%	0.12	0.67	0.77	0.56	0.66
N	%	0.01	0.10	0.05	0.04	0.04
AB-DTPA Cd	mg/kg	0.14	ND	ND	ND	ND

The raw city effluent samples were collected and analyzed prior to the commencement of the experiment. The chemical properties of the water, such as pH and electrical conductivity (EC), were determined using a pH meter and an EC meter, respectively. The values of residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) of the water were also calculated. To quantify the concentration of Cd in the raw city effluents, 1% hydrochloric acid (HCl) solution was added to the water samples. The samples were filtered through Whatman 42 filter paper and collected in plastic bottles. The filtered samples were analyzed using an atomic absorption spectrometer (AAS) (model was Thermo electron S series), and the results are given in Table 1.

The RHB was prepared in a gas-operated furnace at the local level. The FM, poultry manure (PM) and PrMd were obtained from the local farms and a sugar mill respectively. All amendments were air-dried (stored under shade for one month), ground using a Willy mill equipped with stainless steel blades, and stored in plastic bags until used in the experiment. The EC and pH of the organic amendments were determined by creating a suspension of organic amendments and distilled water in a 1:1 ratio. The nutritional content of the organic amendments was assessed by digesting organic amendments in acids (HNO_3 and $HClO_4$). Additionally, the soluble silicon content in the amendments was evaluated, as indicated in Table 1. For the experimental setup, the field was divided into blocks measuring 9 m in length and 9 m in width for each treatment. The treatments, including RHB, FM, PM, and PrM, were applied at a rate of 10 Mg/ha in four replicates. The experimental design employed was a randomized complete block design.

2.3. Cultivation of crops and agronomic practices

Before the cultivation of wheat and rice crops, the field was prepared, and a basal dose of fertilizers, especially phosphorus, was applied before the sowing or transplanting of seeds/seedlings in the field, using diammonium phosphate (DAP). The designed dose of amendments was applied before the broadcasting of wheat seeds and thoroughly mixed in the upper layer of the soil. The seeds of the wheat crop (variety Galaxy-2013) were broadcast at a rate of 125 kg/ha in the field. The recommended dose of fertilizers, such as nitrogen: phosphorus: potassium (120:90:60 kg/ha), was applied using urea, DAP, and sulphate of potash (SOP). The complete dose of DAP and half dose of urea was applied before the broadcasting of seeds, and the remaining dose of urea was applied just before the reproductive stage. A total of five irrigations were done until the harvesting of the wheat crop. To control the weeds, insects, and diseases, suitable pesticides were applied. The same practices were carried out in the consecutive three years of experiments, but amendments were not applied every year. Rice seedlings (Variety Super Basmati-515) were transplanted (two seedlings per hole) in puddling conditions of the field. The recommended dose of fertilizers, such as nitrogen: phosphorus: potassium (150:60:40 kg/ha), was applied using DAP, urea, and SOP. The complete dose of DAP and half dose of urea was applied after the transplanting of rice seedlings. To control the weeds, insects, and diseases, suitable pesticides were applied. Standing water (22 cm) was maintained to reduce the growth of weeds in rice fields. The same practices were carried out in the consecutive three years of experiments, but amendments were not applied in every year of the experiment.

2.4. Chlorophyll values and photosynthetic parameters

The chlorophyll estimation (soil plant analysis development; SPAD) was done using a SPAD meter (SPAD-502), and the data were recorded after 50 days of sowing for both wheat and rice crops. The physiological parameters were determined using an infra-red gas analyzer (IRGA) (Analytical Development Company, Hoddesdon, England) between 10:00 a.m. and 12:00 p.m. after 50 days of sowing for both wheat and rice crops, and the data were recorded (Yong et al., 2010).

2.5. Plant sampling and analysis

After the completion of the reproductive growth stage (wheat plants were 112 days and rice plants were 120 days) of both crops, plant height and spike length were measured using a stainless-steel meter rod, and the data were recorded. The plants were harvested manually, packed in zipper bags, and brought to the lab, where they were separated into straw and grains. The fresh weight of the straw of both crops was measured using an electrical weighing balance, and the data were recorded. The plant parts were oven-dried at 65 ± 5 °C until constant weight and dry weight of the plants was obtained. The straw and grain/paddy were ground in a Willy mill fitted with stainless steel blades. The ground plant samples were digested using a mixture of diacids (HNO_3: $HClO_4$) and heated on a hot plate until a clear solution appeared. The digested plant samples were diluted with distilled water, filtered through Whatman 42 filter papers, and analyzed using an AAS for Cd determination (Ryan et al., 2001). The same procedures were repeated for the second and third years of the experiment.

2.6. Soil sampling and analysis

The soil samples were collected at a depth of 0–20 cm using an auger and placed in zipper bags. The bioavailable concentration of Cd was determined by extracting the soil samples with an AB-DTPA solution. In this method, 10 g of soil was placed in a conical flask, and 20 mL of AB-DTPA solution was added. The flask was then shaken for 5 min using a mechanical shaker. The soil and AB-DTPA suspension was then centrifuged at 1000 rpm, and the resulting supernatant solution was filtered through Whatman 42 filter paper. The filtrate was then analyzed using an AAS for Cd determination, and the data were recorded. This procedure was repeated for the second and third years of the experiment.

2.7. Secondary parameters calculation

The uptake of Cd by wheat and rice plants was calculated by multiplying the dry weight of plant tissues (shoot or grains/paddy) with respective Cd concentration (shoot or grains/paddy). The bioaccumulation (BAF) of Cd was calculated by dividing the Cd concentration in plant tissues (straw and grains) with Cd concentration of soil. The translocation factor (TF) (shoot to grains/paddy) of Cd was calculated by dividing the concentration of Cd in grains/paddy with Cd concentration in straw. The translocation index was calculated by following:

$$\text{Translocation index of Cd (TI)} = \text{grains Cd}/(\text{grains Cd} + \text{shoot Cd concentration}) \times 100$$

The harvest index was calculated as:

$$\text{Cd harvest index (HI)} = (\text{Cd in shoot} + \text{grains})/(\text{Cd in roots} + \text{shoots} + \text{grains}) \times 100$$

The immobilization index was calculated by the following:

Cd Immobilization index (II) = (Cd in control − Cd in treated)/Cd in control × 100

The daily intake of Cd (DICd) was calculated by:

DICd = (CdG × A × B)/BW

Health risk index (HRI) = DICd/Rf

In equations, Cd in grains (CdG), factor A, B, Body weight (BW), and reference dose (Rf) is 0.085, 0.45, 75 kg, and 0.01.

2.8. Economic analysis

The methodology introduced by Chaudhry et al. (1992) was adopted for the evaluation and subsequent allocation of expenses and economic gains associated with various inputs. Total variable cost (TVC) per plot for production such as cost of amendments, insecticides and herbicides. Total fixed cost (TFC) encompassed land rental, land preparation, seeds, and fertilizer application.

Total cost (TC) = TVC + TFC

Total revenue (TR) per acre generated from straw and grains/paddy sales was determined by multiplying the price per mound received by the farmers (p) with the total output (y) (in mounds) for the season.

TR = p × y

Gross profit was calculated by deducting the total variable cost from the total revenue.

Gross profit = TR − TVC

Net profit earned per acre by the farmers was estimated by subtracting the total cost from the total revenue.

Net profit = TR − TC

The benefit cost ratio (BCR) was determined by dividing the total revenue by the total cost (Ali et al., 2021).

BCR = TR ÷ TC

2.9. Statistical analysis

After collecting the experimental data Year-1, Year-2, and Year-3, the results of current experiment were analyzed by applying analysis

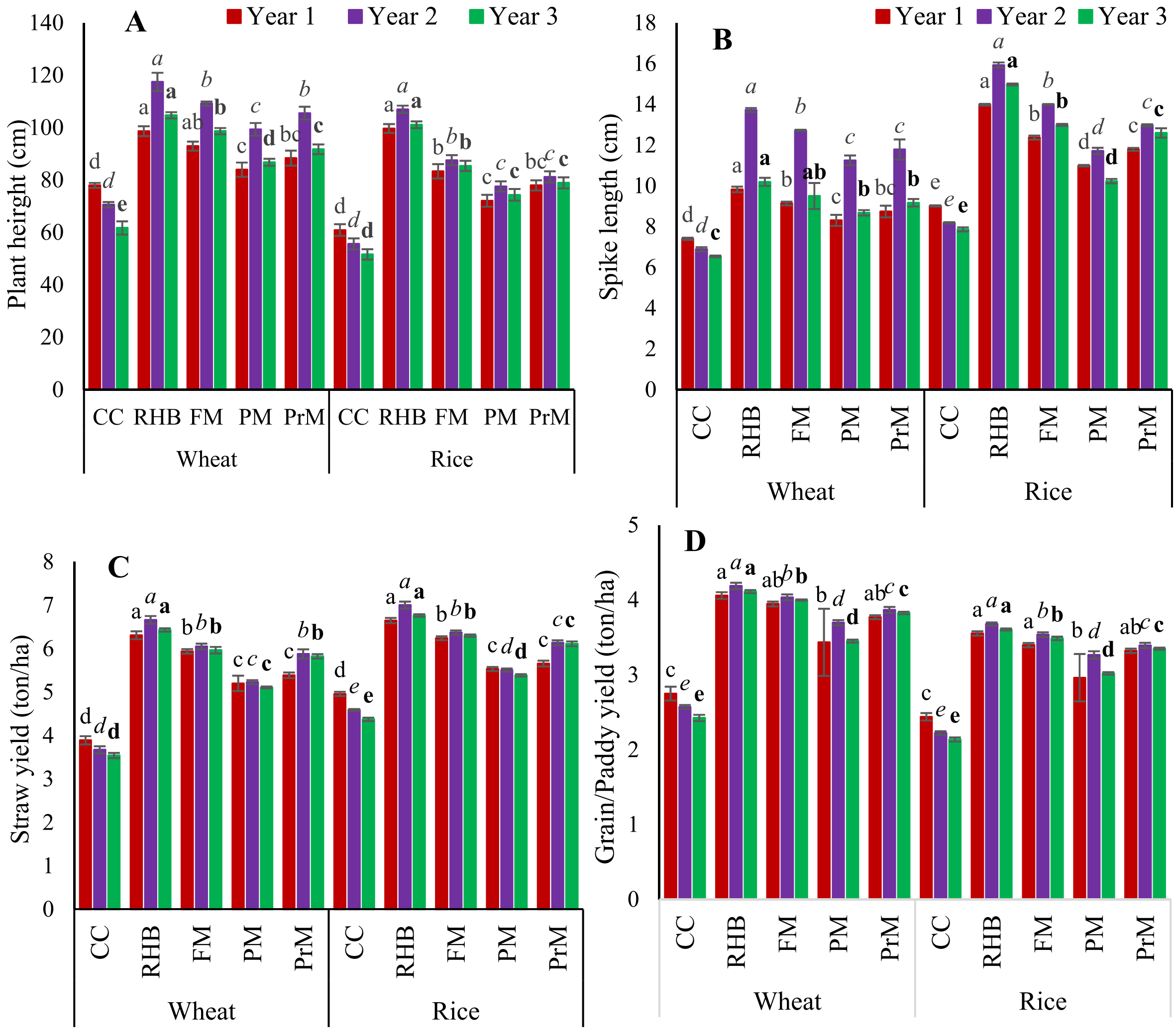

Fig. 1. Effects of agricultural waste materials and biochar on the plant height (A), spike length (B), straw yield (C), grain/paddy yield (D) of wheat and rice plants as cultivated in raw city effluents irrigated fields in consecutive three years. On X-axis CC: contaminated control, RHB: rice husk biochar, FM: farmyard manure, PM: poultry manure, PrM: press mud. Bars indicating the mean values, error bars showing standard deviation, and different lettering (normal for year-1, italic for year-2, and bold for year-3) highlighting the significant ($P < 0.05$) difference (Tukey test) among the applied treatments.

of variance (ANOVA) under randomized complete block design. The statistical software (SPSS 22.0) was used for windows and Tukey test was applied for the multiple comparison of among the applied treatments at 5% level of significance (Steel et al., 1997). Basic statistics like mean, and standard deviation were calculated in Excel-2019. Figures and tables were developed in Excel −2019.

3. Results

3.1. Enhancement of growth and yield of wheat and rice crops in Cd-contaminated soil through organic amendments

The growth and development of wheat plants gradually declined over three years of experimentation due to Cd contamination (Fig. 1). Interestingly, the application of agricultural waste and BC reversed this trend by increasing plant height, spike length, straw yield, and grain yield. In 2019 (Year-1), RHB increased plant height, spike length, straw yield, and grain yield by 27%, 33%, 21%, and 42%, respectively, compared to the control. The application of FM, PM, and PrM treatments increased plant height by 19%, 8%, and 13%, and spike length by 23%, 12%, and 18%, respectively. The FM showed a 14% increase in straw yield, PrM improved by 4%, while PM had a minimal effect. Grain yields also increased significantly by the application of FM, PM, and PrM, improved by 38%, 20%, and 32%, respectively, compared to the control. In the subsequent year (2020), treatments had significant impacts on plant height; RHB led with a 66% increase, FM followed with 55%, and PrM and PM yielded 50% and 41% increases, respectively. For spike length, RHB showed the most notable improvement (99%), FM had 85%, PrM had 71%, and PM had 63%. Applied treatments like RHB, FM, PrM, and PM increased straw yield by 51%, 37%, 33%, and 18%, and grain yield by 63%, 57%, 50%, and 44%, respectively, compared to the control. In the third year of the experiment (2021), the applied treatments continued to show an increasing trend for plant height; RHB (70%) > FM (60%) > PrM (49%) > PM (41%), as compared to the control. A similar pattern was observed in spike length for wheat plants, with respective increments of 56%, 45%, 40%, and 33% for RHB, FM, PrM, and PM. Furthermore, the application of RHB, FM, PrM, and PM treatments yielded increases of 49%, 38%, 35%, and 18% in straw yield, and 65%, 60%, 53%, and 38% in wheat grain yield, respectively, relative to the control.

Over a three-year period, the cultivation of rice at an experimental site showed a consistent trend (Fig. 1). The application of RHB led to substantial enhancements in various growth parameters. In the first year, the RHB treatment resulted in a significant increase of 64% in rice plant height, 55% in spike length, 34% in straw yield, and 46% in paddy yield compared to the control treatment. In the second year, the growth-promoting effects of RHB became even more pronounced, with improvements of 92%, 95%, 53%, and 66% in plant height, spike length, straw yield, and paddy yield, respectively. Notably, the third year showed a continued positive response to RHB, with increments of 96%, 90%, 55%, and 69% in the aforementioned parameters when compared to the control. Other treatments like FM, PrM, and PM also exhibited notable effects on rice growth. In the first year, FM led to a 37% increase in plant height, 37% in spike length, 26% in straw yield, and 39% in paddy yield compared to the control. PrM showed increases of 28%, 31%, 14%, and 36% in plant height, spike length, straw yield, and paddy yield, respectively. PM resulted in an 18% increase in plant height, 22% in spike length, 12% in straw yield, and 21% in paddy yield relative to the control treatment. In the second year, the FM treatment yielded a remarkable increase of 57% in plant height, 71% in spike length, 39% in straw yield, and 59% in paddy yield compared to the control. Similarly, PrM led to enhancements of 46%, 59%, 34%, and 53% in plant height, spike length, straw yield, and paddy yield, respectively. PM exhibited increases of 39%, 43%, 20%, and 47% in plant height, spike length, straw yield, and paddy yield, respectively, relative to the control treatment. In the third year (2021), the FM treatment resulted in a growth response characterized by a 65% increase in plant height, 65% in spike length, 44% in straw yield, and 63% in paddy yield compared to the control. Similarly, PrM demonstrated increases of 53%, 60%, 40%, and 57% in plant height, spike length, straw yield, and paddy yield, respectively. The PM treatment led to increments of 44%, 30%, 23%, and 41% in plant height, spike length, straw yield, and paddy yield, respectively, relative to the control treatment.

3.2. Enhancement of physiological attributes of wheat and rice crops in Cd-contaminated soil through organic amendments

The application of organic amendments, including RHB, FM, PrM, and PM, significantly enhanced the chlorophyll contents and physiological attributes in wheat and rice crops over three consecutive years of experimentation (Fig. 2). For wheat plants, the SPAD value was increased by RHB, FM, PrM, and PM by 32%, 21%, 19%, and 10% in Year-1, 47%, 38%, 37%, and 27% in Year-2, and 51%, 39%, 39%, and 30% in Year-3, as shown in Fig. 2A. The trend of applied treatments remained as RHB (40%) > FM (30%) > PrM (25%) > PM (18%) for photosynthetic rate in Year-1, RHB (60%) > FM (48%) > PrM (37%) > PM (31%) in the second year, and in the third year, the trend remained as RHB (58%) > FM (47%) > PrM (42%) > PM (34%), as shown in Fig. 2B. The trend of applied treatments also remained consistent for transpiration rate and stomatal conductance across the three years. The application of RHB, FM, PrM, and PM treatments consistently yielded positive results, with RHB consistently showing the highest impact across the three years. For stomatal conductance, the trend of applied treatments with respect to control, was remained as RHB (65%) > FM (48%) > PrM (42%) > PM (29%) in Year-1, RHB (98%) > FM (66%) > PrM (59%) > PM (52%) in second year, and in third year that trend remained as RHB (96%) > FM (75%) > PrM (67%) > PM (51%) as shown in Fig. 2D. For the Sub-stomatal CO2 intake was increased by RHB, FM, PrM, and PM that was 48, 44, 37, and 18% in Year-1, 73, 67, 60, and 53% in Year-2, while in Year-3 the response was 70, 66, 58, and 43% as shown in Fig. 2E.

In rice crop cultivation, organic amendments such as RHB, FM, PrM, and PM significantly enhanced chlorophyll contents and physiological attributes over three consecutive years of experimentation (Fig. 2). For rice plants, the SPAD value increased by 30%, 19%, 17%, and 8% in Year-1, 42%, 33%, 32%, and 22% in Year-2, and 53%, 41%, 41%, and 32% in Year-3 (Fig. 2A). The trend of applied treatments remained as RHB (39%) > FM (29%) > PrM (24%) > PM (17%) for photosynthetic rate in Year-1, RHB (59%) > FM (48%) > PrM (37%) > PM (31%) in the second year, and in the third year, the trend remained as RHB (59%) > FM (48%) > PrM (43%) > PM (35%) (Fig. 2B). The trend of applied treatments also remained consistent for transpiration rate and stomatal conductance across the three years. The application of RHB, FM, PrM, and PM treatments consistently yielded positive results, with RHB consistently showing the highest impact across the three years. For stomatal conductance, the trend of applied treatments with respect to control, was remained as RHB (63%) > FM (47%) > PrM (36%) > PM (29%) in Year-1, RHB (103%) > FM (69%) > PrM (62%) > PM (55%) in second year, and in third year that trend remained as RHB (97%) > FM (74%) > PrM (69%) > PM (55%) as shown in Fig. 2D. For the Sub-stomatal CO_2 intake was increased by RHB, FM, PrM, and PM that was 50, 45, 38, and 18% in Year-1, 63, 55, 53, and 47% in Year-2, while in Year-3 the response was 72, 66, 59, and 43% as shown in Fig. 2E.

3.3. Reduction of Cd concentration and uptake by wheat and rice crops in Cd-contaminated soil through organic amendments

The concentration of Cd in wheat and rice straw and grain/paddy was maximum in field irrigated with raw city effluents and not receiving any organic amendment (Fig. 3). The concentration (mg/kg) of Cd was significantly reduced by the application of RHB in both straw and grains of wheat plant, which was 0.76 and 0.011 in Year-1; 0.72 and 0.009 in

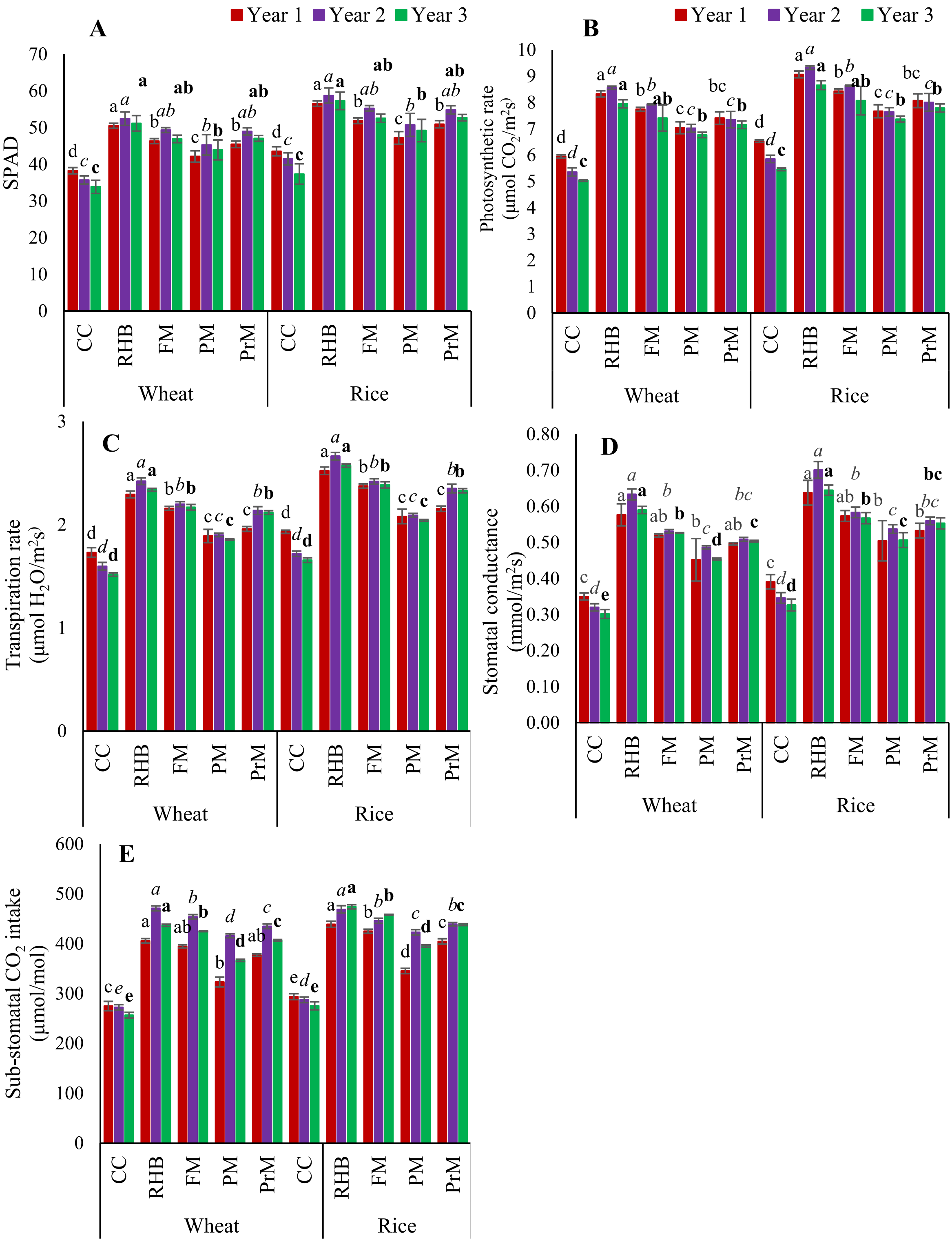

Fig. 2. Effects of agricultural waste materials and biochar on the chlorophyll contents (A), photosynthetic rate (B), transpiration rate (C), stomatal conductance (D), and sub-stomatal conductance CO$_2$ intake (E) in leaves of wheat and rice plants as cultivated in raw city effluents irrigated fields in consecutive three years. On X-axis CC: contaminated control, RHB: rice husk biochar, FM: farmyard manure, PM: poultry manure, PrM: press mud. Bars indicating the mean values, error bars showing standard deviation, and different lettering (normal for year-1, italic for year-2, and bold for year-3) highlighting the significant ($P < 0.05$) difference (Tukey test) among the applied treatments.

Year-2; 0.85 and 0.010 in Year-3 respectively. The Cd concentration in wheat straw was reduced by FM, PrM, and PM which showed 65, 54, and 40% reduction in Year-1; 76, 73, and 67% reduction in Year-2, 81, 79, and 75% reduction in Year-3 as shown in Fig. 3A. The Cd in grains was reduced by 86, 80, and 76% in Year-1; 94, 91, and 87% in Year-2; 94, 92, and 90% in Year-3 by the application of FM, PrM, and PM by comparing with control treatment (Fig. 3B). The uptake of Cd in wheat straw and grains was reduced by the application of organic amendments as grown

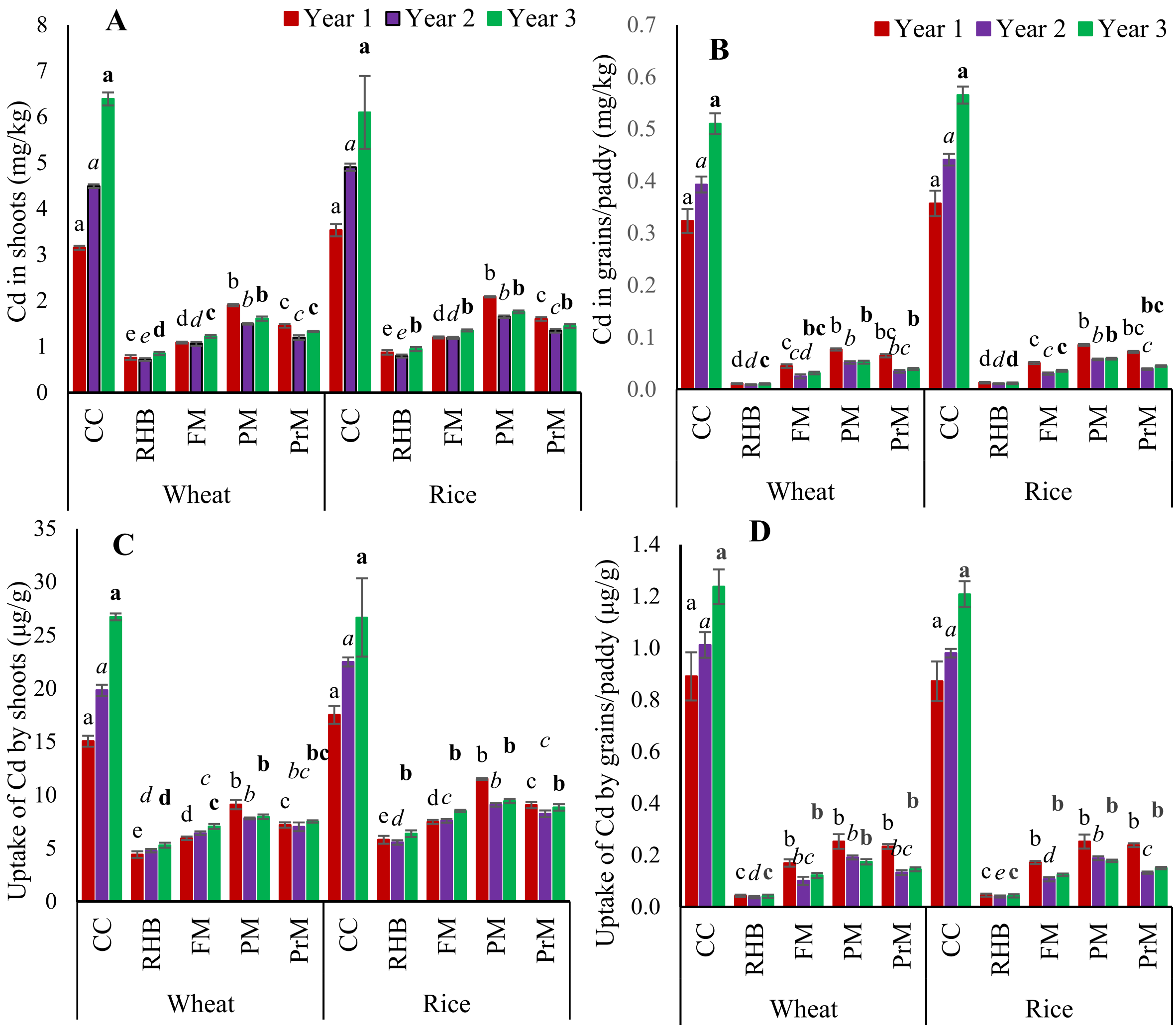

Fig. 3. Effects of agricultural waste materials and biochar on the cadmium concentration in shoots (A), cadmium concentration in grains (B), cadmium uptake by shoots (C), and cadmium uptake by grains (D) wheat and rice plants as cultivated in raw city effluents irrigated fields in consecutive three years. On X-axis CC: contaminated control, RHB: rice husk biochar, FM: farmyard manure, PM: poultry manure, PrM: press mud. Bars indicating the mean values, error bars showing standard deviation, and different lettering (normal for year-1, italic for year-2, and bold for year-3) highlighting the significant ($P < 0.05$) difference (Tukey test) among the applied treatments.

in Cd-contaminated soils. The trend of applied treatments remained as RHB (−71%) < FM (−61%) < PrM (−52%) < PM (−40%) in Year-1; RHB (−76%) < FM (−68%) < PrM (−65%) < PM (−61%) in Year-2; RHB (−80%) < FM (−74%) < PrM (−72%) < PM (−70%) in Year-3 for the uptake of Cd in wheat straw as compared to their respective control treatments (Fig. 3C). The uptake of Cd in grains was reduced and the trend of applied treatments was remained as RHB (−95%) < FM (−81%) < PrM (−74%) < PM (−72%) in Year-1; RHB (−96%) < FM (−90%) < PrM (−87%) < PM (−81%) in Year-2; RHB (−97%) < FM (−90%) < PrM (−88%) < PM (−86%) in Year-3 as compared to their respective control treatments (Fig. 3D).

The concentration (mg/kg) of Cd was significantly reduced by the application of RHB in both straw and paddy of rice plant, which was 0.87 and 0.013 in Year-1; 0.79 and 0.011 in Year-2; 0.94 and 0.012 in Year-3 respectively. The Cd concentration in rice straw was reduced by FM, PrM, and PM which showed 66, 55, and 41% reduction in Year-1; 76, 73, and 66% reduction in Year-2, 78, 71, and 76% reduction in Year-3 as shown in Fig. 3A. The Cd in paddy was reduced by 86, 80, and 76% in Year-1; 93, 91, and 87% in Year-2; 94, 92, and 90% in Year-3 by the application of FM, PrM, and PM by comparing with control treatment (Fig. 3B). The uptake of Cd in rice straw and paddy was reduced by the application of organic amendments as grown in Cd-contaminated soils. The trend of applied treatments remained as RHB (−67%) < FM (−57%) < PrM (−48%) < PM (−34%) in Year-1; RHB (−75%) < FM (−66%) < PrM (−63%) < PM (−60%) in Year-2; RHB (−76%) < FM (−68%) < PrM (−67%) < PM (−65%) in Year-3 for the uptake of Cd in rice straw as compared to their respective control treatments (Fig. 3C). The uptake of Cd in rice paddy was reduced and the trend of applied treatments was remained as RHB (−95%) < FM (−80%) < PrM (−73%) < PM (−71%) in Year-1; RHB (−96%) < FM (−89%) < PrM (−86%) < PM (−81%) in Year-2; RHB (−97%) < FM (−90%) < PrM (−88%) < PM (−85%) in Year-3 as compared to their respective control treatments (Fig. 3D).

3.4. BAF, TF, TI, and HI of Cd in wheat and rice crops in Cd-contaminated soil

The utilization of organic amendments, specifically RHB, FM, PrM, and PM, has yielded a noteworthy outcome in diminishing the bioaccumulation, translocation, and harvest index of Cd within wheat and rice cultivations, as graphically represented in Fig. 4. Within the context of wheat plants, the BAF of Cd within grains exhibited a consistent reduction attributed to RHB, with recorded values of 0.23, 0.22, and 0.22 for Year-1, Year-2, and Year-3, respectively. Throughout the three-

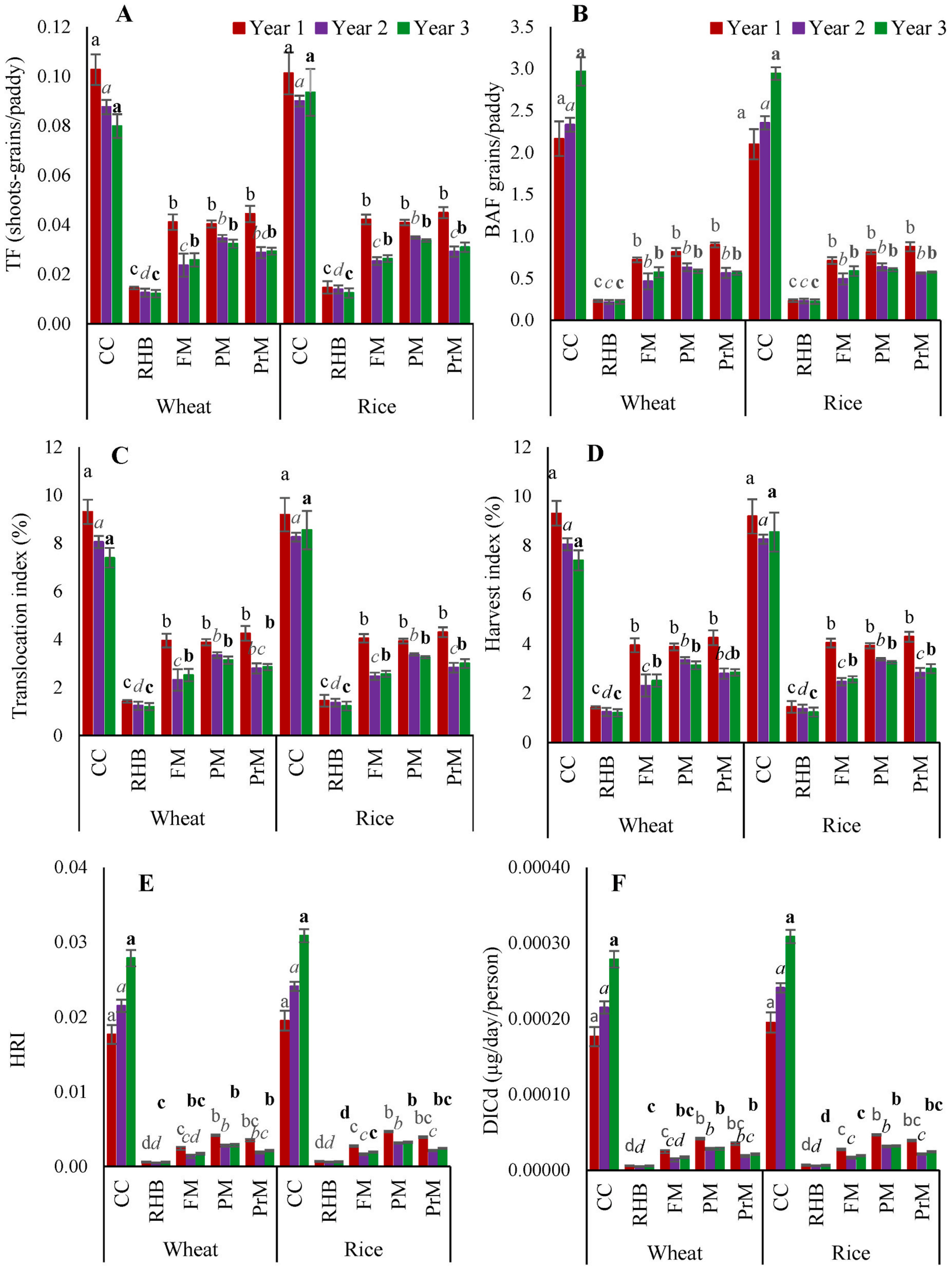

Fig. 4. Effects of agricultural waste materials and biochar on the translocation factor (shoot-grain) (A), bioaccumulation factor for grains (B), translocation index (C), health risk index (D), and daily intake of Cd (E) in wheat and rice plants as cultivated in raw city effluents irrigated fields in consecutive three years. On X-axis CC: contaminated control, RHB: rice husk biochar, FM: farmyard manure, PM: poultry manure, PrM: press mud. Bars indicating the mean values, error bars showing standard deviation, and different lettering (normal for year-1, italic for year-2, and bold for year-3) highlighting the significant ($P < 0.05$) difference (Tukey test) among the applied treatments.

year temporal span, the hierarchical trend of applied treatments persisted, wherein CC > PM > PrM > FM > RHB held true for the BAF of Cd within wheat grains. The TF of Cd from the shoot to the grains of wheat plants, significantly reduced by the application of RHB. The quantified values of BAF for Cd was 0.014, 0.013, and 0.012, recorded for Year-1, Year-2, and Year-3 respectively, are delineated in Fig. 4B. The established a trend of applied treatments, CC > PM > PrM > FM > RHB, maintained its consistency for TF (shoot-grains) within wheat plants throughout the multi-year experimental duration. Furthermore, the TI of Cd within wheat plants demonstrated minimal values upon application of RHB, thereby endorsing the persisting trend of applied treatments: CC > PM > PrM > FM > RHB, an observation sustained over the entire duration of the experimentation. Correspondingly, the harvest index of Cd exhibited a reduction concomitant with RHB application, thereby aligning with the prevalent trends observed for BAF, TF, and TI, as graphically depicted in Fig. 4.

The BAF of Cd for paddy in rice plant was reduced by RHB which was 0.23, 0.23, and 0.22 for Year-1, Year-2, and Year-3 respectively. The trend of applied treatments remained as CC > PM > PrM > FM > RHB for BAF of Cd in paddy of rice plants from first year to third year. The translocation factor of Cd from shoot to grains of wheat plant was reduced by RHB application that was 0.015, 0.014, and 0.012 in Year-1, Year-2, and Year-3 respectively as shown in Fig. 4B. The trend of applied treatments remained as CC > PM > PrM > FM > RHB for TF (shoot-grains) in rice plants from Year-1 to Year-3 of experimentation. The translocation index of Cd in rice plants was minimum in RHB and trend of applied treatments as CC > PM > PrM > FM > RHB during whole of duration experimentation. The harvest index of Cd was reduced by the application of RHB and followed the same trend as BAF, TF, and TI as shown in Fig. 4A–D.

3.5. Health risk assessment and estimation of economic returns of wheat and rice crops cultivated in Cd-contaminated soil

The application of amendments had varying effects on health risk parameters, such as the daily intake of Cd and the health risk index of Cd, as illustrated in Fig. 4E and F. The DICd (μg/day/person) reached its lowest value in the RHB-applied treatment in comparison to the contaminated control treatment throughout the entire duration of the experiment, encompassing both wheat and rice crops. Specifically, for the wheat crop, the minimum DICd was recorded as 0.0000060 μg/day/person in soils amended with RHB during the first year, followed by 0.0000049 μg/day/person in the second year and 0.0000056 μg/day/person in the third year. Conversely, the unamended control exhibited the highest DICd. In the case of rice cultivation (as depicted in Fig. 4), the minimum DICd was observed as 0.0000070 μg/day/person in RHB-amended soil during the first year, followed by 0.0000060 μg/day/person in the second year and 0.0000064 μg/day/person in the third year, with the unamended control showing the maximum DICd. Furthermore, the application of RHB led to a reduction in the health risk index. This reduction manifested as values of 0.00060 for wheat and 0.00070 for rice paddy in Year-1, 0.00049 for wheat and 0.00060 for rice in the second year of the experiment, and 0.00056 for wheat and 0.00064 for rice in the third year, as depicted in Fig. 4.

Based on the findings of the current experiment, the gross profit for the first year was highest with the RHB treatment, reaching 123.5 USD per plot. The order of gross profit for the other treatments remained as FM > PrM > PM > CC throughout the growth of the wheat crop, as depicted in Table 2. In the second season, the RHB application again resulted in the highest gross profit of 189.4 USD per plot, while the order for the other treatments remained consistent: FM > PrM > PM > CC for wheat crops. Similarly, in the third season, the RHB application led to the maximum gross profit of 179.7 USD per plot for the wheat crop, with the same order observed for the other treatments: FM > PrM > PM > CC, as presented in Table 2. The results for the rice crop followed a similar pattern, with the highest gross profit observed in the RHB treatment at 126.5 USD per plot in Year-1, 131.5 USD per plot in Year-2, and 127.9 USD per plot in Year-3. Throughout the entire experiment, the trend of applied treatments remained consistent: FM > PrM > PM > CC.

The application of FM led to an increase in net profit during the cultivation of wheat crops in the first year, resulting in 125.6 USD per plot. The trend of applied treatments for Year-1 remained FM > PM > PrM > RHB > CC. The maximum net profit was achieved through the application of FM, attributed to its lower cost and higher biological yield. However, RHB proved to be more expensive initially during the cultivation of the wheat crop. In the second year of the experiment, the RHB treatment yielded the highest net profit at 148.93 USD per plot, with the order of other treatments being RHB > FM > PrM > PM > CC. The residual effect of RHB in the second year surpassed that of other organic amendments, resulting in a greater biological yield, as indicated in Table 2. In the third year, the net profit during the cultivation of wheat crops was higher than Year-1 but lower than Year-2. The application of RHB resulted in the maximum net profit of 139.29 USD per plot, while the trend of applied treatments remained RHB > FM > PrM > PM > CC, as shown in Table 2. For the cultivation of rice crops, the RHB treatment consistently produced the highest net profit in Year-1, Year-2, and Year-3, at 81.82 USD per plot, 86.85 USD per plot, and 83.29 USD per plot, respectively. The trend of applied treatments for net profit in rice cultivation remained consistent: RHB > FM > PrM > PM > CC throughout the experiment duration.

The BCR was significantly influenced by the application of organic amendments during the cultivation of wheat crops. In Year-1, the highest BCR was achieved with FM at 3.98, while the lowest was with RHB at 2.09, attributed to the production cost of BC. RHB exhibited the highest BCR in Year-2 (4.68) and Year-3 (4.45) during wheat cultivation, as presented in Table 2. In the cultivation of rice crops, the highest BCR was achieved with the application of RHB in Year-1 (2.83), Year-2 (2.95), and Year-3 (2.87), while the other treatments yielded lower

Table 2
Economic analysis of study during each year.

Treatments	Wheat								
	Gross Profit ($)			Net Profit ($)			BCR		
	Year-1	Year-2	Year-3	Year-1	Year-2	Year-3	Year-1	Year-2	Year-3
CT	76.77	118.36	111.73	86.52	77.93	71.30	3.14	2.93	2.76
RHB	123.53	189.36	179.72	90.75	148.93	139.29	2.09	4.68	4.45
FM	117.58	180.12	173.02	125.63	139.69	132.59	3.98	4.46	4.28
PM	96.02	163.01	149.03	103.21	122.58	108.60	3.40	4.03	3.69
PrM	108.43	173.14	166.26	114.78	132.71	125.83	3.62	4.28	4.11
	Rice								
CT	88.52	80.94	80.14	43.89	36.31	35.51	1.98	1.81	1.80
RHB	126.45	131.48	127.92	81.82	86.85	83.29	2.83	2.95	2.87
FM	120.42	124.85	122.91	75.78	80.21	78.28	2.70	2.80	2.75
PM	105.38	113.66	106.98	60.75	69.03	62.35	2.36	2.55	2.40
PrM	115.84	119.84	116.60	71.21	75.21	71.97	2.60	2.69	2.61

BCR values, as shown in Table 2.

3.6. Bioavailable concentration and immobilization of Cd in Cd-contaminated soil during wheat and rice crop cultivation

The bioavailable concentration of Cd (AB-DTPA extractable Cd) reached its peak in the control treatment (sole irrigation with untreated urban effluents), measuring 0.150 mg/kg in Year-1, 0.169 mg/kg in Year-2, and 0.172 mg/kg in Year-3, as illustrated in Fig. 5A, during the wheat crop cultivation. The application of RHB led to a reduction in Cd concentration, measuring 0.047 mg/kg in Year-1, 0.042 mg/kg in Year-2, and 0.047 mg/kg in Year-3 for wheat crop cultivation. Demonstrated in Fig. 5B, the immobilization index of Cd was highest with RHB, registering 68% in Year-1, 75% in Year-2, and 72% in Year-3. Throughout the entire wheat cultivation experiment, the trend of applied treatments for the immobilization index remained consistent: RHB > FM > PrM > PM.

In rice crop cultivation, the maximum AB-DTPA Cd concentration was observed in the control treatment, measuring 0.170 mg/kg in Year-1, 0.187 mg/kg in Year-2, and 0.192 mg/kg in Year-3 (Fig. 5A). The lowest Cd concentration was observed in the RHB-applied treatment, measuring 0.055 mg/kg, 0.048 mg/kg, and 0.053 mg/kg in Year-1, Year-2, and Year-3, respectively. The immobilization index of Cd in rice crop cultivation was highest with RHB, recording 68% in Year-1, 74% in Year-2, and 73% in Year-3, as depicted in Fig. 5B. Throughout the entire duration of the rice cultivation experiment, the trend of applied treatments for the immobilization index remained consistent: RHB > FM > PrM > PM.

4. Discussion

The current experimental findings revealed that raw city effluents contain substantial concentrations of heavy metals, such as Cd, which elevate the bioavailable Cd content in the soil (Table 1). Over a span of three consecutive years, the experiment demonstrated that these raw city effluents resulted in an increase Cd concentration in the shoots and grains of both wheat and rice crops, as depicted in Fig. 3. The significant Cd content present in the raw city effluents contributed to a heavy metal load in the soil (Hamid et al., 2020). These sources also led to increased Cd mobility within the soil, ultimately leading to its accumulation in plants, posing a significant ecological threat (Zhang et al., 2023). The movement and accessibility of Cd in the soil are contingent upon its varying distribution and chemical forms (Ondrasek et al., 2020). In the soil environment, Cd exists not only in its ionic form but also as part of organic and inorganic complexes formed by interactions with organic matter, organic ligands, metal ions, as well as oxides of iron and manganese (Hamid et al., 2020; Yuan et al., 2021). In plants, the primary avenue for Cd entry is through porewater contact (Imoto and Yasutaka, 2020). Furthermore, the chemical attributes of the soil, including factors pH, cation exchange capacity, and the presence of organic and inorganic complexes, exert considerable influence on the availability and uptake of Cd by plants (Bali et al., 2020; Yuan et al., 2021). The elevated Cd uptake by plants results in a reduced uptake of essential plant nutrients, such as Ca Mg, K, Zn, Fe (Waqas et al., 2023). The deficiency in essential elements like Ca, Mg, and Fe leads to reduction of photosynthetic pigments, like chlorophyll, ultimately affecting photosynthetic activity (Bai et al., 2023; Yang et al., 2023). Indeed, parallels can be drawn with the present experiment where an increase in the bioavailable Cd concentration in the soil (Fig. 5) coincided with a decrease in the SPAD values of chlorophyll contents (Fig. 2) in both crops. The decline in foliar chlorophyll content restricted photosynthetic rates and caused growth reduction. Similar conclusions have been drawn by Azhar et al. (2019) and Rehman et al. (2023), where Cd-induced reductions in wheat and rice plant height were attributed to the potential denaturation of protein bonds, specifically H–S protein bonds, resulting in hindered plant growth (Lin et al., 2007). Furthermore, it has been observed that Cd negatively impacts the dry biomass of roots, shoots, and grain yield (Fig. 1), primarily through physiological changes (Fig. 2) and the limited uptake of essential nutrients.

Utilizing agricultural waste and BC to remediate Cd pollution holds significant promise for mitigating Cd contamination in both soil and water systems (Bai et al., 2023; Yang et al., 2023). In this study, the application of organic amendments like RHB, FM, PrM, and PM exhibited the ability to enhance plant growth even in the presence of Cd-induced stress. Notably, among these organic amendments, RHB emerged as the most efficacious in terms of Cd remediation, as highlighted in Fig. 5. It's worth mentioning that RHB has been reported to contain a substantial amount of silicon and possesses a high stability index for degradation, contributing to its remarkable Cd remediation properties (Usman et al., 2023; Kalengyo et al., 2023). The BC, a well-established agent for alleviating soil contaminants including Cd (Yuvaraj et al., 2021), functions by binding Cd ions through mechanisms such as ionic exchange, precipitation, and ion complexation, as reported by He et al. (2019). Numerous studies reported its capacity to diminish

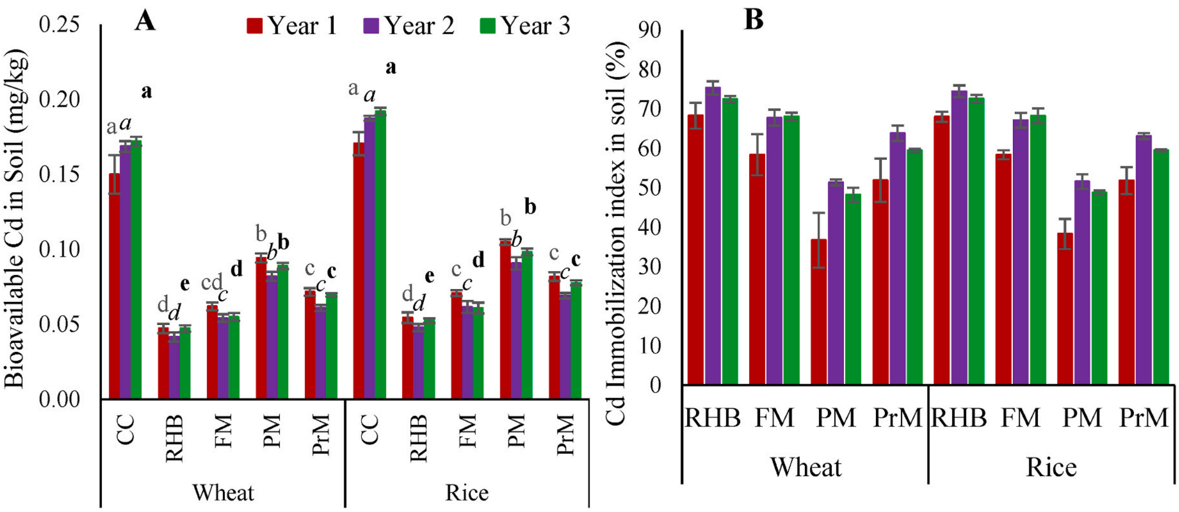

Fig. 5. Effects of agricultural waste materials and biochar on the cadmium concentration in soil (AB-DTPA) (A), and immobilization index of cadmium in soil (B) of wheat and rice plants as cultivated in raw city effluents irrigated fields in consecutive three years. On X-axis CC: contaminated control, RHB: rice husk biochar, FM: farmyard manure, PM: poultry manure, PrM: press mud. Bars indicating the mean values, error bars showing standard deviation, and different lettering (normal for year-1, italic for year-2, and bold for year-3) highlighting the significant ($P < 0.05$) difference (Tukey test) among the applied treatments.

the bioavailability, uptake, and movement of Cd within plants (Hussain et al., 2023; Zhou et al., 2023). Specifically, investigations have indicated that the application of BC derived from rice straw and bamboo effectively immobilizes Cd in soil, with rice straw BC demonstrating greater efficiency compared to bamboo BC (Lu et al., 2017). Correspondingly, Yousaf et al. (2016) highlighted the ability of BC to curtail the availability and absorption of Cd in wheat plants, outperforming PrM, FM, and compost. In the current experiment, RHB emerges as the most potent organic amendment, surpassing FM, PrM, and PM, as evidenced by the consistent augmentation in plant growth, physiological attributes, and the yield of both wheat and rice crops across three successive years (Figs. 1–4).

The absorption, movement, and accumulation of Cd within plants are influenced by the AB-DTPA extractable Cd in soil. Notably, the highest levels of AB-DTPA extractable Cd were found in the control treatment compared to other treatments, as illustrated in Fig. 5. Consequently, this led to the greatest Cd accumulation in both plant shoots and grains/paddy, as depicted in Fig. 4. The substantial Cd accumulation within different plant parts underscores its remarkable mobility within the plant's anatomy. As Cd is absorbed by plant roots, it is subsequently transported from the roots to the aerial parts, eventually concentrating in the consumable portions of the plants. In the present experiment, various secondary parameters including BAF, TF (shoots to grains/paddy), TI, HI, and immobilization index (II) exhibited the highest values in the control treatment, which did not receive any form of organic amendment, as shown in Fig. 4. This phenomenon can be attributed to the gradual buildup of Cd in the soil over successive years. Additionally, Figs. 4 and 5 demonstrate a progressive increase in Cd concentration and associated secondary parameters over time. Specifically, the highest Cd concentration was observed in year-3 when compared to year-1 and year-2. In the context of this study, the application of organic amendments (such as RHB, FM, PrM, and PM) resulted in a significant reduction of the secondary parameters. These organic amendments possess active sites and functional groups that immobilize Cd on their surfaces. Particularly noteworthy is the observation that RHB exhibited the most effective immobilization of Cd in year-1, year-2, and year-3 in comparison to FM, PrM, and PM. This outcome can be attributed to the unique properties of RHB, which promote the fixation of Cd and its reduced movement within the plant-soil system.

The accumulation of Cd within the consumable portions of wheat and rice crops poses a significant threat to human health (Rehman et al., 2023). As evidenced by this experiment, cultivating agricultural crops in fields irrigated with untreated urban effluents entails a potential risk to humans (Sohail et al., 2020). As illustrated in Fig. 4, the data indicated that the daily intake of Cd reached its highest level in the control treatment, which gradually increased over time. The DICd exhibited its peak value in year-3, relative to the initial years (year-1 and year-2). This pattern aligned with the health risk assessment associated with Cd, as seen in the HRI for Cd, which was at its highest during the third year of the experiment. These observations collectively underscore a vital concern: cultivating field crops within areas irrigated by untreated urban effluents presents a significant potential threat to food safety (Chen et al., 2018; Li et al., 2021; Ma et al., 2021). The findings provided a clear indication that comprehensive measures must be taken to safeguard both the nutritional integrity of agricultural produce and the overall health of human populations (Sohail et al., 2020). As indicated by this experiment, application of RHB significantly reduced the DICd and HRI of Cd in both crops during the whole experiment. Because RHB more immobile (Rehman et al., 2021) the Cd as mentioned in Fig. 5 and finally decreased the uptake, translocation and accumulation of Cd in grains/paddy of crops in consecutive three years of experiment. While the application of other organic amendments like FM, PrM, and PM showed minimum DICd and HRI than control and maximum RHB in year-2 > year-3 > year-1. In the second and third years of the study, the RHB exhibited the most favorable outcomes in terms of BCR, net profit, and gross profit when compared to the first year and the alternatives FM, PrM, and PM. Notably, during the first year, FM displayed greater economic efficiency in comparison to other organic amendments. However, it was necessary to acknowledge that this economic advantage comes with a drawback: the DICd and the Human Health Risk Index are higher than that of RHB (Rehman et al., 2020; Sohail et al., 2020). This discrepancy can be attributed to the more resource-intensive processing of BC, which, while expensive, provides a safety guarantee for food production at the farmer level. A multitude of researchers have concurred that BC boasts exceptional stability and enduring impact. It is worth noting that the control treatment yielded relatively lower net profit, gross profit, and BCR compared to other organic amendments. Furthermore, the produce from this treatment poses a hazard to both human health and animals due to Cd levels surpassing permissible limits, as highlighted by numerous studies.

5. Conclusions

This long-term study examined the effects of different organic amendments on the growth, yield, and economic benefits of wheat and rice crops for three years. The results revealed that maximum increase in yield attributes of rice and wheat were recorded with the application of RHB. Overall, all organic amendments decreased Cd concentrations in soils and plants. Grain Cd concentration was recorded well below the permissible limit in both rice and wheat crops with the application of organic amendments. Maximum benefit-cost ratio was calculated for RHB, which concluded that RHB is the most economical amendment among the organic materials tested and remained available in soil to immobilize Cd in soil and restricting its translocation in the plant tissues. The future research should be focused on increasing the efficacy of these organic matter with decreased application rates.

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CRediT authorship contribution statement

Hiba Shaghaleh: Writing – original draft, Software, Conceptualization. **Muhammad Azhar:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Muhammad Zia-ur-Rehman:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Yousef Alhaj Hamoud:** Writing – review & editing, Visualization, Methodology, Data curation. **Ammar Ali Adam Hamad:** Writing – review & editing, Validation, Software, Resources. **Muhammad Usman:** Investigation, Formal analysis, Data curation. **Muhammad Rizwan:** Writing – review & editing, Software, Formal analysis, Conceptualization. **Jean Wan Hong Yong:** Writing – review & editing, Visualization, Validation, Methodology, Funding acquisition, Formal analysis. **Hesham F. Alharby:** Writing – review & editing, Software, Project administration, Funding acquisition, Formal analysis. **Abdullah G. Al-Ghamdi:** Writing – review & editing, Visualization, Validation, Software. **Basmah M. Alharbi:** Writing – review & editing, Visualization, Resources, Methodology, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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