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Full Length Article

Use of Poultry Mortality Compost for Biofortification of Trace Elements in Food Crops

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Abstract

Micronutrient malnutrition is a global issue, although more severe in resource poor countries. Organic fertilizers, naturally enriched with micronutrients, may be an economical and sustainable strategy to improve human nutrition through biofortification of staple crops and vegetables. Two consecutive field experiments were conducted to investigate the effects of poultry-mortality (PM) compost on the yield and quality of okra, and its residual effect on maize. PM compost used in this study was prepared by composting dead poultry-birds with poultry litter in aerated bins under natural microbial populations. Okra was fertilized with three levels of PM compost (control, 1250 kg ha^{-1} and 1850 kg ha^{-1}) while maize was grown subsequently in the same plots without any further addition of PM compost. Results showed that okra yield was increased significantly with PM compost application at the rate of 1850 kg ha^{-1}, due to improvement in soil organic matter, soil aggregate stability and high concentration of plant-available zinc (Zn), iron (Fe) and manganese (Mn) in PM compost. Furthermore, Zn and Fe concentration in okra fruit was also enhanced. Maize grain-yield and grain-micronutrients concentration was also higher due to residual effect of PM compost applied to okra grown just before maize. In conclusion, use of PM compost as an organic fertilizer may be an excellent, cost-effective and workable option to combat micronutrients (Zn and Fe) malnutrition in developing countries through enhancing soil health. © 2020 Friends Science Publishers

Keywords: Compost; Okra; Biofortification; *Zea mays*; Soil health

Introduction

Human population is ever growing at startling rate and it is a big challenge for scientists and policy makers to meet the future food requirements (Tilman *et al.*, 2011). According to FAO (Food and Agriculture Organization) estimates, about 70-100% increase in agricultural production is required to fulfil food demands for over 9 billion people by 2050 (FAO, 2011). Most of this will have to come from current agricultural systems which are already facing severe issue of productivity decline and unable to fulfil nutritional requirements for existing populations. According to an estimatae, more than two billion people in the world are facing micronutrient malnutrition (FAO, 2011). Soil degradation is considered as one of the major causes of decline in productivity and quality of agricultural crops in tropical and sub-tropical regions (ECA, 2001). There are several causes of soil degradation including continuous cropping, imbalanced use of fertilizers, soil salinization, erosion, compaction, nutrient depletion and soil pollution (Lal, 1997).

Continuous cropping in tropics and subtropics lowers the soil nutrients status and soil microbial functioning (ECA, 2001) leading to decreased crop productivity (FAO, 2006). Nitrogen (N), phosphorus (P) and potassium (K) are the most demanded required essential elements for plants, and inorganic fertilizers are used to fulfil the crop requirements for these elements. Studies have shown that sole application of synthetic fertilizers to get high productivity especially in tropical and sub-tropical regions is not a sustainable approach (Akande *et al.*, 2010; Rehim *et al*., 2016). Excessive consumption of synthetic fertilizers not only increased the environmental concerns but also deteriorate the soil health (Shiyam and Binang, 2011). Therefore, a regular application of organic amendments is generally recommended in these regions to maintain soil health and productivity. Soil carbon improved by using the organic and chemical fertilizers improves the soil fertility and ultimately increase the crop yield (Rautaray *et al.*, 2003). As organic fertilizers cannot fulfill the nutritional demand over the large area due to limited accessibility, low nutrient conformation and high labor requirement;

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Photograph: Impact of poultry-mortality compost on okra yield, micronutrient biofortification and its residual effect on maize. Three levels of compost: 0, 1250 kg compost ha^{-1} and 1850 kg compost ha^{-1}. (photo by M. Umair Mubarak)

Therefore, mixture of inorganic and natural manures may be a viable option to achieve sustainable results (Akande *et al.*, 2010). Composted organic manures not only provide a significant quantity of plant-available macronutrients, but also provide substantial amount of micronutrients thereby improve physical and chemical characteristics of soils (Hopkins *et al.*, 2017).

Biofortification is a process of improving nutritional quality of food crops through use of biotechnology, conventional plant breeding or agronomic practices. It is a cost effective and sustainable way to alleviate mineral malnutrition and is directly related to the wellbeing of population masses (Janila *et al.*, 2015; Idrees *et al.*, 2018; Ishfaq *et al.*, 2018). Being a rich source of micronutrients, poultry-mortality (PM) compost can be a potential soil amendment to biofortify the food crops to mitigate the wide-spread micronutrient malnutrition in developing countries (Dekissa *et al.*, 2008). Several studies have reported positive impacts of poultry farm litter compost on soil health and crop yields (Adekiya *et al.*, 2016; Agbede *et al.*, 2017; Adekiya *et al.*, 2019), however, very few have included dead poultry birds in compost. In addition, information about the impact of such compost on micro mineral contents in food crops is very sketchy. It is hypothesized that addition of PM compost would be an economical source for micronutrient biofortification of food crops.

The specific objectives of this study were, a) to check the effect of PM compost on okra (*Abelmoschus esculentus* L.) yield and fruit mineral contents considering its biofortification potential, b) to observe the residual effect of PM compost application on maize (*Zea mays* L.) yield, grain minerals concentration and soil health.

Material and Methods

Two consecutive field experiments were conducted at research farm of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad Pakistan. Experimental site falls in semi-arid climate with cool dry winters and hot summers. Soil of the experimental site was sandy clay loam, with pH 7.7, EC_e 2.57 dS m^{-1} and saturation percentage 30%. First field experiment was conducted to investigate the effect of different levels of poultry compost on the yield and quality of okra in 2017 at research farm of University of Agriculture, Faisalabad Pakistan. Experimental site is in the middle of latitude (31°26’19.60” N 73°4’12.0” E) and falls in semi-arid climate with dry cool winters and hot summers. In second experiment, maize crop was grown on the same field after harvesting of okra to investigate the residual effect of applied compost levels on maize yield, grain minerals concentration and soil health.

The poultry-mortality (PM) compost was prepared at University of Veterinary and Animal Sciences (UVAS), Patoki campus, Pakistan. The birds were not euthanized, but the naturally dead birds collected from various poultry farms were used. The PM compost was analyzed for mineral concentrations being shown in Table 1.

Experimental Layout and Crops Husbandry

Experiment was conducted under randomized complete block design (RCBD) with four replications with plot size of 9 m × 12 m for each treatment. Compost was applied at the rate of 0 (control), 1250 (PMC1) and 1850 (PMC2) kg ha^{-1} to okra crop at the time of seed bed preparation. Recommended dose of chemical fertilizers i.e. urea, triple superphosphate and sulphate of potash at the rate of 150: 100: 60 kg NPK ha^{-1} was applied in control. However, amount of NPK present in compost was subtracted from the recommended dose in treatments containing compost. Seeds of okra cultivar “Sabzpari” were obtained from Institute of Horticulture, University of Agriculture Faisalabad. After harvesting the okra, maize cultivar “Malka” was cultivated in the same field with same experimental design to investigate residual effects of different rates of PM compost on the yield and quality of maize. Recommended dose of chemical fertilizers i.e., urea, diammonium phosphate and sulphate of potash i.e. 198: 114: 90 kg NPK ha^{-1} was applied in maize.

Collection of Plant Samples and Analysis

Different growth and yield related parameters were taken for both crops. Okra crop was harvested at three stages (40, 50 and 60 days after sowing), and all data were combined for calculating actual yield. Maize crop was harvested at maturity and grain yield was determined following Mehboob *et al*. (2018).

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Table 1: Physicochemical properties of compost used in experiments

Minerals	Concentrations	Minerals	Concentrations
Nitrogen (%)	3.35	Copper (mg kg^{-1})	41.2
Phosphorus (%)	2.67	Iron (mg kg^{-1})	630.75
Potassium (%)	3.5	Magnesium (mg kg^{-1})	419.02
Aluminium (mg kg^{-1})	20.31	Managense (mg kg^{-1})	226.0
Arsenic (mg kg^{-1})	0.55	Nickel (mg kg^{-1})	2.2
Boron (mg kg^{-1})	11.61	Lead (mg kg^{-1})	1.1
Barium (mg kg^{-1})	8.71	Silicon (mg kg^{-1})	17.07
Cadium (mg kg^{-1})	0.10	Zinc (mg kg^{-1})	459

Table 2: Effect of poultry-mortality compost on agronomic parameters of okra and maize, and soil quality indicators

Treatments		Plant height (cm)	Fruit fresh weight (g)	Fruit dry weight (g)	Fruit length (cm)	Number of fruits per plant	Chlorophyll contents (SPAD value)	Organic matter (%)	Aggregate stability (%)
Okra	Control	101.7 c	475.0 b	50.6 b	14.0 b	20.2 b	45.8 b	0.67 b	25.62 b
	1250 kg compost ha^{-1}	111.5 b	503.9 ab	55.4 a	14.7 b	22.5 ab	52.6 ab	0.82 a	19.54 ab
	1850 kg compost ha^{-1}	122.5 a	555.4 a	57.9 a	15.7 a	25.0 a	53.3 a	0.85 a	32.71 a
		Plant height (cm)	Number of cobs (m^{-2})	Cob length (cm)	Cobs weight (kg m^{-2})	Number grains per cob	Chlorophyll contents (SPAD value)	Organic matter (%)	Aggregate stability (%)
Maize	Control	215.7 b	9.5 b	15.6 b	1.8 b	420.0 b	76 b	0.68 b	14.42 c
	1250 kg compost ha^{-1}	232.5 a	11.5 a	18.1 a	2.1 a	492.5 a	77.5 b	0.72 b	25.87 b
	1850 kg compost ha^{-1}	238.7 a	13.7 a	18.7 a	2.6 a	501.5 a	83.8 a	0.84 a	32.42 a

Means sharing the similar letter (s) do not differ significantly at $P \leq 0.05$ according to LSD test

Samples of shoots, roots, okra fruits and maize grains were oven dried at 80˚C for minerals analysis. Phosphorus, K, Zn, Mn and Fe in shoots, roots, fruits and grains were determined using spectrophotometer (Model No CE 7400), flame photometer (Model No JENWAY PFP 7) and atomic absorption spectrophotometer (Model No Agilent 200 series AA) after wet digestion with mixture of nitric and perchloric acids at the ratio 2:1 (Chapman and Pratt, 1961). Chlorophyll contents were determined with chlorophyll meter (SPAD 502 P) at vegetative growth stages of both crops.

Post-harvest soil analysis was carried out for organic matter (Nelson and Sommers, 1996) and aggregate stability (a measure of the extent to which soil aggregates resist in falling apart when wetted and hit by rain drops). Water stable aggregation was measured from disturbed samples using artificial rainfall simulator (Van *et al.*, 2006).

Statistical Analysis

Collected data were analyzed statistically by using statistical software (Statistic 8.1). Least significance difference (LSD) test at 5% probability level was applied to compare treatments means (Steel *et al.*, 1997).

Economic Analysis

The economic analysis was done considering fruit yield of okra and grain yield of maize. Gross income was calculated according to prices (at the time of harvest) of okra and maize at Faisalabad market, and was converted to US dollar at given exchange rate at the time of harvest. Total permanent cost includes cost of land rent, seed bed preparation, fertilizers, compost, pesticides, herbicides and harvesting costs (Table 3).

Results

Plant Growth, Yield and Chlorophyll Content

Application of PM compost increased the plant height of okra at both levels and its residual effect also increased the plant height of maize crop. Highest level of compost i.e. 1850 kg ha^{-1} (PMC2) resulted the maximum plant height in okra (122.5 cm) and in maize (238.7 cm) compared to 1250 kg compost ha^{-1} (PMC1) and control (Table 2).

PM compost played a significant role to enhance the chlorophyll content in both experiments and PMC2 significantly enhanced the chlorophyll contents in okra (53.3 SPAD value) as well as maize (83.8 SPAD value) and it was about 16 and 10% higher in okra and maize respectively, than control (Table 2).

The highest total okra biomass and yield were recorded at PMC2 and similar results for maize cultivated after okra without further addition of PM compost were observed. The highest maize yield (5.93 tons ha^{-1}) was obtained at PMC2. However, PMC1 did not increase the okra yield significantly compared to control, while maize yield was significantly increased in these plots showing residual effect of PMC1. As the total biomass production is concerned, it was significantly increased in okra as well as in maize at both compost levels i.e. PMC1 and PMC2 (Fig. 1).

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Table 3: Economic analysis of poultry-mortality compost application on okra and maize

	Treatments	Fruit/grain yield (t ha^{-1})	Fruit/grain value (\$ ha^{-1})	Gross income (\$ ha^{-1})	Permanent cost (\$ ha^{-1})	Variable cost (\$ ha^{-1})	Total cost (\$ ha^{-1})	Net benefits (\$ ha^{-1})	Benefit-cost ratio
	Control	10.89	6585	6585	750	396.4	1146.4	5439	5.74
Okra	1250 kg compost ha^{-1}	11.81	7141	7141	750	493.7	1243.6	5898	5.74
	1850 kg compost ha^{-1}	13.44	8127	8127	750	548.4	1298.4	6829	6.25
	Control	4.42	1765.5	1765.5	750	419.3	1169.3	596.2	1.50
Maize	1250 kg compost ha^{-1}	5.73	2035	2035	750	419.3	1169.3	865.7	1.74
	1850 kg compost ha^{-1}	5.93	2101	2101	750	419.3	1169.3	931.7	1.79

Okra :24 $ per 40 kg, maize: 6.9 $ per 40 kg Compost: 7 $ per 40 kg
Permanent cost=Land rent & ploughing &labor

Minerals Concentration in Shoots, Roots and Grains

The analysis of PM compost has shown that it is a rich source of various plant nutrients including P, K, Fe, Zn, Mn etc. At PMC2 the highest concentration of P and K in root, shoot, and fruit of okra and grains of maize has been observed (Fig. 2). At PMC1, P and K concentrations was significantly higher in root, shoot and fruit of okra but not in shoot and grain of maize.

More importantly, PM compost application increased the concentration of micronutrients (Zn, Fe and Mn) in both okra and maize crops. Zn in okra shoots, roots and fruits were 78.41, 49.32 and 100.38 mg kg^{-1}, respectively, and maize shoots, roots and grains contained 118.75, 138.06 and 185.03 mg Zn kg^{-1} at PMC2. Application of PM compost at the highest rate increased 15-25% Zn concentration in okra and 17-40% in maize compared to control (Fig. 3). Likewise, Fe in okra shoots, roots and fruits were 249.29, 227.29 and 245.07 mg Fe kg^{-1}, respectively, and maize shoots, roots and grains contained 681, 630 and 446.5 mg kg^{-1} at PMC2 and the increase was 20-25% for Fe in okra and 20-40% in maize compared to control (Fig. 3). Mn in okra shoots, roots and fruits were 67.69, 62.85 and 106.6 mg kg^{-1}, respectively, and maize shoots, roots and grains contain 158.26, 213.06 and 64.03 mg Mn kg^{-1} at the highest rate of application of PM compost. In okra fruit, increase in Mn concentration was 15-30%, while 16-20% Mn increase was observed in maize grain (Fig. 3). At PMC1, the concentration of Zn, Fe and Mn increased, however this increase was not significant in all cases. Okra fruits and maize grain showed significant increase at PMC2 compost level for Zn and Fe respectively.

Soil Organic Matter and Aggregate Stability

Post-harvest soil analysis of both crops okra and maize had revealed a significant increase in soil organic matter (SOM) at PMC2 with reference to control (Table 2). However, PMC1 level did not show the significant increase in both SOM. The SOM after okra and maize was 0.85 and 0.84%, respectively at PMC2 compared to that in control *i.e.,* 0.67 and 0.68% (Table 2). Soil aggregate stability was also enhanced in both experiments at PMC2.

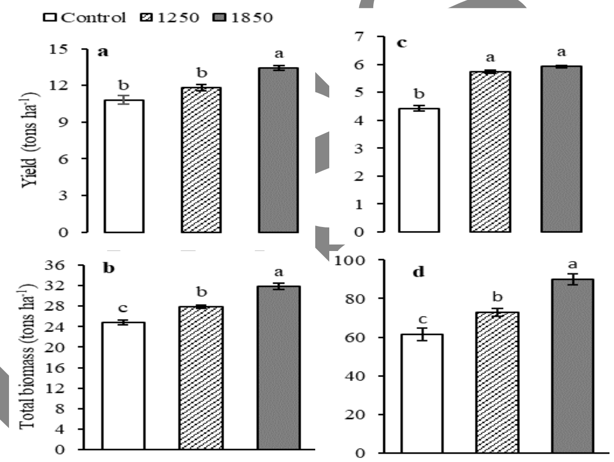

Fig. 1: Effect of poultry-mortality compost on grain yield and total biomass of okra and maize. Grains yield of okra (a), Total biomass of okra (b), Grains yield of maize (c) and total biomass of maize (d). Compost levels were 0 (Control), 1250 kg compost ha^{-1} (PMC1) and 1850 kg compost ha^{-1}(PMC2). Column shows means of four replications while bars show standard error. Means sharing the similar letter (s) do not differ significantly at $P \leq 0.05$ according to LSD test

Discussion

Application of PM compost improved the growth and yield of both crops due to notable improvement in soil health including soil structure, moisture holding capacity, aggregate stability and water infiltration in the soil (Table 2; Dekissa *et al.,* 2008). Besides increased nutrients concentration, better soil health also enhanced nutrient uptake efficiency of plants either because of better root architectural characteristics or more organic acid release in root rhizosphere (Silva *et al.,* 2006). Residual effect of PMC enhanced the growth and yield because of slow release of nutrients compared to that in inorganic fertilizers. Compost is a cocktail of many macro and micronutrients (Ewulo, 2005; Turan, 2009) which enhanced the chlorophyll contents (Table 2) leading to more biomass production due to elevated photosynthesis process (Sevik *et al.,* 2012). Organic composts enhance micronutrients concentrations in plants and increased the crop productivity (Rautaray *et al.,* 2003; Mottaghian *et al.,* 2008).

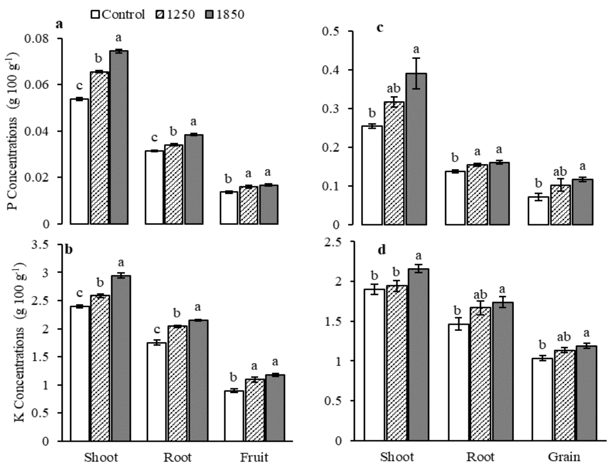

Fig. 2: Effect of poultry-mortality compost on P and K concentrations in shoots, roots and fruits/grains of okra and maize. P concentrations in okra shoot, root and fruit (a), K concentrations in shoot, root and fruit of okra (b), P concentrations in okra shoot, root and grain of maize (c), K concentrations in shoot, root and grain of maize (d). Compost levels were 0 (Control), 1250 kg compost ha^{-1} (PMC1) and 1850 kg compost ha^{-1}(PMC2). Column shows means of four replications while bars show standard error. Means sharing the similar letter (s) do not differ significantly at $P \leq 0.05$ according to LSD test

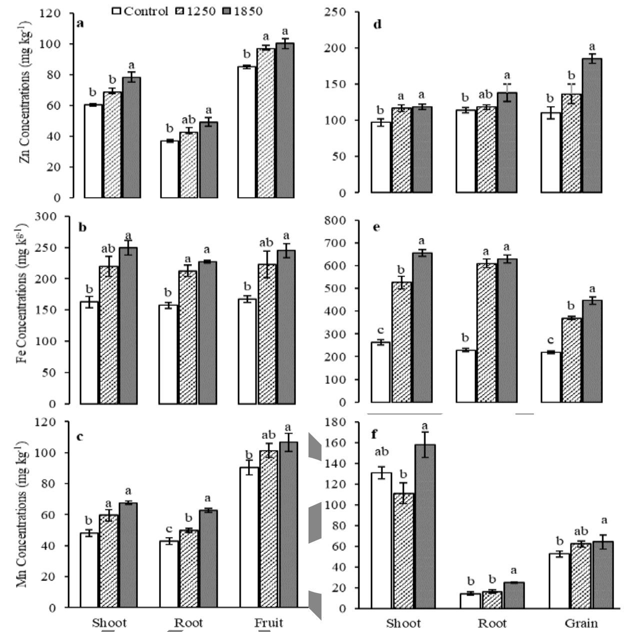

Fig. 3: Effect of poultry-mortality compost on Zn, Fe and Mn concentrations in shoots, roots and fruits of okra and grains of maize. Zn concentrations in okra shoot, root and fruit (a), Fe concentrations in shoot, root and fruit of okra (b), Mn concentrations in okra shoot, root and fruit (c), Zn concentrations in shoot, root and grain of maize (d), Fe concentrations in shoot, root and grain of maize (e), Mn concentrations in shoot, root and grain of maize (f). Compost levels 0 (Control), 1250 kg compost ha^{-1} (PMC1) and 1850 kg compost ha^{-1}(PMC2). Column shows means of four replications while bars show standard error. Means sharing the similar letter (s) do not differ significantly at $P \leq 0.05$ according to LSD test

The increase in okra yield can be attributed to increased individual fruit weight, increased fruit numbers per plant and also increased fruit length, whereas augmented maize grain yield was owing to increased number of cobs per unit area, more number of grains per cob and increased cob length, and weight (Table 2). Addition to increase in growth and yield of crops, poultry compost improved the physical condition of soil and enhanced the delivery and availability of nutrient to the crop roots (Akande *et al.*, 2010; Lin *et al.*, 2018). Increased concentration of P and K in plants revealed the plant availability of these minerals present in compost and/or enhanced nutrient uptake due to better soil health. It was further notable that application of PM compost improved the soil conditions and owing to expansion of plant roots, nutrient uptake efficiency was enhanced (data not given). Earlier reports have shown that application of poultry manure and organic matter enhances the N, P and K uptake by plants (Ewulo, 2005; Nathiya and Sanjivkumar, 2014).

High concentration of micronutrients such as Fe and Zn in the compost has great significance as these minerals have been reported deficient in 40 to 50% of world soils and their deficiency in soil lead to deficiency in humans. More alarmingly, these micronutrients are rarely fertilized by most of the resource-poor farmers of developing countries.

Higher concentrations of micronutrients Fe, Zn and Mn in soils due to PM compost impact directly to plant health as these are essential elements playing significant role in growth and development of crops (Thomas *et al.*, 2012; Latifah *et al.*, 2015; Haider *et al*., 2019). The uptake and accumulation of these minerals in edible plant parts is an indicator of improved nutritional values of crop commodities to combat Zn and Fe deficiencies in humans and animals as well. Agronomic biofortification of Zn has been well adopted in many parts of the world and a great success story has been emerged in Turkey (Cakmak and Kutman, 2018).

Although a significant impact of PM compost has been observed on growth and yield in this study and in earlier reports as well, we would more emphasize on its biofortification potential. According to best of our knowledge, it is the first report to highlight the biofortification of potential compost. Presence of high concentration of these micronutrients are due to composted dead birds and these higher concentrations of micronutrients are not present in other sources of organic amendments such as animal manure compost or crop residue composts in such high amounts that residual effect also shows a significant increase in maize grain (Fig. 3). Therefore, the specialty of the PM compost is its biofortification potential for Zn and Fe.

The economic analysis, one of key factors to adapt any new product, of PM compost is very positive and shows economic returns, if we only include its N, P and K nutrients value (Table 2). The value addition impact due to trace elements biofortification in okra fruits is extra benefit. The increased yield and grain quality (biofortification with trace elements) of subsequent maize crop is a further economic plus. Improved soil OM content and aggregate stability also indicate additional benefits in changing climate to sustain and improve soil quality.

Conclusion

In conclusion, application of PM compost proved promising for increase in mineral content in okra fruit and yield. Enrichment of okra fruits with trace elements (Zn, Fe and Mn) is a most needed aspect to eliminate the malnutrition in developing countries. Furthermore, yield enhancement of maize due to improved soil health considering increased soil OM and improved aggregate stability is direly required for sustainable agriculture. High trace element concentration in PM compost indicated a long-term biofortifying impact on subsequent crops. Application of micronutrients enriched PM compost is a sustainable and economical technology to biofortify the staple food without further burdening the farmers.

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