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INTEGRATED EFFECTS OF VERMICOMPOST, NPK FERTILIZERS, CADMIUM AND LEAD ON THE GROWTH, YIELD AND MINERAL NUTRIENT ACCUMULATION IN SPINACH (*Spinacia oleracea* L.)

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Abstract

An integrated fertilizer experiment was conducted on the spinach plant at the net house of Soil, Water and Environment department under University of Dhaka during the rabi season using pot culture. The intention of the study was to evaluate the integrated effect of vermicompost, NPK fertilizers, Cd and Pb on soil properties, spinach growth, yield and concentration of nutrients. The trial was carried out in a Completely Randomized Design (CRD) followed by two replications, having twelve treatments, including control. The maximum growth and yield contributing characteristics of spinach plant *viz.* plant height (23.10 cm), leaf area (61.13 cm^2 $plant^{-1}$), length of leaf (10.85 cm $plant^{-1}$), no. of leaf (10 $plant^{-1}$), yield of fresh (10.92g $plant^{-1}$) and dry materials (1.05g $plant^{-1}$) found in T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}). All the growth and yield parameters observed lowest with the sole Cd application and the performance of sole Pb also showed reducing trends compared to other integrated treatments. The highest achievements of macro elements N (0.0798%), P (0.0027%), K (0.0068%) and S (0.0084%) of post-harvest soil with the treated pot in T_{12} over the control. Mineral nutrients of leaves (N-2.29%, P-1.30% and K-8.24%) were found highest in the same T_{12}. It may be concluded that the maximum production of spinach, sustain the soil productivity and achieve the high nutritional value of the leaf in the treatment T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) recommended for its cultivation.

Keywords: Vermicompost; NPK fertilizers; Cd and Pb; Nutrient accumulation; Growth and yield; Spinach.

INTRODUCTION

Spinach (*Spinacia oleracea* L.), known as ‘Palong Shak’ or ‘Bengal Spinach’ in Bangladesh, is a notable nutrient-rich leafy vegetable crop belonging to the family Chenopodiaceae (George 2009). It is an annual plant with a short growing cycle. Spinach is thought to be native to Southwest Asia, where the Persians first cultivated it. It is now grown worldwide, except for the tropics (USDA 2005). According to the leaf texture, spinach is broadly classified into three types: i) smooth leaf, ii) savoy, and iii) semi-savoy. Smooth-leaf spinach is the preferred leaf type for processing and salads, whereas savoy and semi-savoy are used for cooking (Rubatzky and Yamaguchi 1997). It contains high amounts of K, Fe, Mg, vitamins (A, B_6, C, E, K), antioxidants, and chlorophylls (Maeda *et al*. 2010) and it is rich in fiber and low in calories. The growing interest in low-calorie diets and increased understanding of spinach’s nutritional and health benefits have increased its demand over the past few decades and are expected to continue to increase in the coming years.

Globally, in 2020, spinach was grown on approximately 921000 ha with an annual production of approximately 30 million tons (FAO 2020). A high intake of spinach has positive effects on human health, say improving eye health and decreasing the risk of most degenerative diseases of aging, such as cardiovascular disease, Alzheimer's disease (Commenges *et al*. 2000), cataracts (Brown *et al*. 1999) and several forms of cancer (Gandini *et al.* 2000). Spinach extract also can be used as a natural antibiotic and preservative in food industries and pharmaceuticals (Issazadeh *et al*. 2017). In recent years, spinach cultivation is increasing brightly in Bangladesh due to consumer demand (BBS 2007).

Over the past few decades, intensive agriculture has negatively affected the soil environment (e.g., loss of soil organic matter, soil erosion, and water pollution) (Zhao *et al*. 2009). Maintaining and improving soil quality, thus, is the utmost to sustaining agricultural productivity and environmental quality for future generations (Reeves 1997). The use of manure and mulching are two of the basic cultivation techniques of organic agriculture (Efthimiadou *et al.* 2009). Moreover, emerging evidence indicates that to overcome soil fertility constraints, integrated soil fertility management involving the judicious use of combinations of organic and inorganic resources is quite a feasible approach (Abedi *et al.* 2010). Combined NPK and farmyard manure increased soil organic matter, total N, Olsen P, and ammonium acetate exchangeable K by 47%, 31%, 13%, and 73%, respectively, compared to the application of NPK through inorganic fertilizers (Bhattacharyya *et al.* 2008). Tiwari *et al.* (2002) have reported that the inclusion of manure in the fertilization schedule improved the organic carbon status and available N, P, K, and S in soil, sustaining soil health.

Studies have found evidence of the soils contaminated with several heavy metals brought into the environment by natural (weathering and erosion of parent rock material or ore deposits) or artificial (wastewater irrigation, mining activities) sources (Yang *et al*. 2009). Of the heavy metals in question, cadmium (Cd) is non-essential and accumulates quickly in plants (Toppi and Gabbrielli 1999). Over and above, Cd induces changes in plants' physical, biochemical and genetic levels, which are accountable for plant growth reduction (Nouariri *et al.* 2006), leaf chlorosis, leaf or root necrosis (Baryla *et al.* 2001) and eventually causing death of plants (Toppi and Gabbrielli 1999). Likewise, Pb is also phytotoxic. It affects plant photosynthesis by reducing chlorophyll content. Pb reduces the uptake of chlorophyll-essential elements, such as Fe and Mg, affecting chloroplast, changing essential enzymatic processes for photosynthesis, and disturbing the closing of stomata (Sharma and Dubey 2005). Lead has significant impacts on dry seedling mass, shoot and root length, and weight (Farooqi *et al*. 2009) and it adversely affects the respiration and metabolism of plants (Paolacci *et al.* 1997).

Vermicompost is often applied to treat heavy metal, pesticide, and oil-contaminated soils (Yuvaraj *et al*. 2020). The availability of heavy metals decreases under the vermicompost amendment on account of forming complexes with heavy metals (Zhang *et al.* 2019), thus decreasing the accumulation of heavy metals in plants (Paltseva *et al.* 2018). Considering the above facts this investigation was undertaken. The aim of the investigation was to assess the combined effect of vermicompost, NPK fertilizers, and heavy metals on different physico-chemical parameters of soil and plant. It was intended to evaluate the effectiveness of vermicompost amendment to immobilize Cd and Pb in spinach plants growing in soil added with cadmium and lead.

MATERIAL AND METHODS

Collection and analysis of soil samples and vermicompost

The soil sample was collected from Ati-Bazar, a vegetable growing area in Savar, Dhaka, Bangladesh, 23°43'53" N 90°18'02" E to a surface soil depth of 0-15 cm and vermicompost from a local market. The soil sample was air-dried, grounded using a wooden hammer, sieved through a 2mm stainless steel sieve, and stored in polythene bags for physico-chemical analysis. The soil was silt loam in texture deduced from the USDA soil texture triangle using the proportion percentages (Bouyoucos

1962). Some physico-chemical properties of the initial soil and vermicompost were determined with the standard method as described by Jackson (1958) presented in Table 1.

Pot experiment

The experiment was carried out during the rabi season at the net house of the department of Soil, Water and Environment under University of Dhaka, Bangladesh. Seven kilograms of air-dried soil were taken in a 10 kg capacity plastic pot (diameter 25 cm and height 23 cm). Vermicompost and three types of inorganic fertilizers were collected from a local market, and heavy metals, i.e., cadmium and lead as $CdCl_2$ and $PbNO_3$ from the departmental laboratory. The experimental pots were laid out in a Completely Randomized Design (CRD) having twelve treatments with two replications.

Table 1. Analysis of physico-chemical parameters of initial soil and vermicompost.

Soil properties	Values	Soil properties	Values (%)	Vermicompost properties	Values (%)
pH	8.31	Available S	0.0284	Organic carbon	14.40
EC (µS/cm)	330	Total N	0.08	Total N	0.08
CEC (cmol/kg)	18.11	Total P	0.04	Total P	0.77
OC (%)	0.27	Total K	0.28	Total K	0.89
OM (%)	0.75	Total S	0.04	Total S	0.39
C: N ratio	25:1	Iron (Fe)	2.99	Iron (Fe)	0.83
Available N (%)	0.0106	Zinc(Zn)	0.01	Zinc (Zn)	0.04
Available P (%)	0.0002	Lead (Pb)	0.0008	Lead (Pb)	0.0005
Available K	0.0048	Cadmium (Cd)	0.0002	Cadmium (Cd)	0.0006

The sources of fertilizers were used in the experiment as indigenous vermicompost at the rate of 5 ton ha^{-1}, N_{25} as 50 kg ha^{-1} urea, P_8 as 16 kg ha^{-1} di-ammonium phosphate (DAP), K_{10} as 20 kg ha^{-1} muriate of potash (MoP), Cd_4 as 6.5 kg ha^{-1} $CdCl_2$ and Pb_4 as 6.4 kg ha^{-1} $PbNO_3$ were applied. Treatments were T_1: Control (-VC, -NPK, -Cd and -Pb), T_2: vermicompost 5 ton ha^{-1}, T_3: Standard dose $N_{25}P_8K_{10}$ kg ha^{-1}, T_4: $N_{25}P_8K_{10}$ kg ha^{-1} + vermicompost 5 ton ha^{-1}, T_5: Cd_4 kg ha^{-1}, T_6: vermicompost 5 ton ha^{-1} + Cd_4 kg ha^{-1}, T_7: $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}, T_8: vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}, T_9: Pb_4 kg ha^{-1}, T_{10}: vermicompost 5 ton ha^{-1} + Pb_4 kg ha^{-1}, T_{11}: $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1} T_{12}: vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}.

Fig. 1. Better growth of *Spinacia oleracea* observed in the T_{12} treatment.

Seeds of Prime Seed Company were collected from a local market. The germination rate of the seeds was 80% and 98% physical purity. Growth parameters were measured at seven-day intervals up to 56 days and watered the plants in due course. The spinach plants were allowed to grow in the pot for fifty-six days (8 weeks).

Harvesting

After 8 weeks the spinach plants were harvested. The whole plant was uprooted and then the leaves, stem, and roots were separated. The plant samples were transferred to poly bags and then carried to the laboratory. The leaves, stems, and especially roots were washed up using tap water, then with distilled water and wrapped with soft tissue paper. Fresh weights were recorded immediately. The samples were then air-dried on the rooftop and, finally, oven-dried at 80ºC (Isaac and Jones 1972) overnight in the laboratory. The dry weights of the samples were recorded, and the samples were grounded by a mechanical grinder and stored in plastic pots for further analysis.

Chemical analysis

The harvested spinach plants and post-harvest soil of each treatment were applied vermicompost, NPK fertilizers, and Cd and Pb as treatment were further chemically analyzed for their available and total nutrient content. For available soil nitrogen (NH_4 + NO_3), 10g of air-dried soil was taken for distillation and to determine the total N of plant leaves, soil, and vermicompost, 0.2g of leaves, 0.5g of soil, and 0.5g of vermicompost were digested in a Kjeldahl digestion flask (Nagornyy 2013). Available soil P, K, and S were determined as described by Jackson (1958). The total P, K and S, 0.2g of leaf, 1g of soil, and 0.5g of vermicompost were digested with nitric-perchloric acid (HNO_3:$HClO_4$ = 2:1) to determine these by the method of Huq and Alam (2005). The phosphorous present in the digest was determined by the vanadomolybdophosphoric yellow color method at 430nm and the sulphur by the turbidimetric method at 420nm (Bardsley and Lancaster 1965) using a spectrophotometer (model UV 1800) (Jackson 1958) the potassium by using a JENWAY flame photometer (model PFP 7) (Pratt 1965). The cadmium and lead present in the digest were measured using a VARIAN Atomic Absorption Spectrometer (model AA240).

Statistical analysis

Analysis of Variance (ANOVA), and Fisher's Least Significant Difference (LSD) test were made using IBM SPSS Statistics 26 at 5% level of probability and for the tabular evaluation of the result, Microsoft Excel 2016 was used.

RESULTS AND DISCUSSION

Plant height

The spinach plants' height varied significantly ($p \leq 0.05$) for different combinations of vermicompost, NPK fertilizers, Cd, and Pb for seven consecutive days up to 56 days (Table 2). On the 56th day of harvesting, the tallest plant (23.10 cm) was recorded from T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1}+ Pb_4 kg ha^{-1}) compared to T_5 (4.10 cm). Others showed intermediate effects. The shortest plant was found with the sole application of Cd_4 kg ha^{-1} (T_5) and the Pb_4 kg ha^{-1} resulted similar to Cd. The vermicompost alone or integrated incorporation showed a higher rate of plant length. Hossain *et al.* (2022) reported that the overall best growth, yield and nutrient accumulation in the height of chili were achieved in 4 ton Trichocompost ha^{-1} + $N_{23}P_{10}K_{25}$ kg ha^{-1} treatment.

Table 2. Effects of vermicompost, NPK, Cd, and Pb on the height (cm) of spinach plants on different days after sowing (DAS).

Treatments	**Plant height (cm) at different DAS**							
	7^d	**14^d**	**21^d**	**28^d**	**35^d**	**42^d**	**49^d**	**56^d**
T_1: Control (-VC, -NPK, -Cd & -Pb)	1.50	3.73	5.55	6.20	6.70	7.80	8.30	8.75
T_2: VC 5 ton ha^{-1}	2.15	5.23	5.70	8.75	9.35	12.40	14.95	17.25
T_3: $N_{25}P_8K_{10}$ kg ha^{-1}	1.25	5.36	5.75	6.20	7.20	9.20	11.75	13.50
T_4: $N_{25}P_8K_{10}$ kg ha^{-1} + VC 5 ton ha^{-1}	1.95	3.61	4.75	08.30	11.85	15.00	18.35	20.50
T_5: Cd_4 kg ha^{-1}	1.10	3.00	3.10	3.30	3.40	3.75	3.90	4.10
T_6: VC 5 ton ha^{-1} + Cd_4 kg ha^{-1}	2.00	7.31	7.95	10.80	10.85	12.65	14.15	17.10
T_7: $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	1.85	5.75	6.00	7.75	8.25	10.15	11.95	12.95
T_8: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	1.80	5.50	7.55	10.15	10.85	12.80	16.10	19.70
T_9: Pb_4 kg ha^{-1}	2.20	5.87	7.15	8.40	9.35	11.75	14.05	16.65
T_{10}: VC 5 ton ha^{-1} + Pb_4 kg ha^{-1}	2.50	6.77	7.55	10.55	10.70	14.80	18.15	19.50
T_{11}: $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	1.55	3.98	4.40	5.60	8.65	12.35	14.55	17.65
T_{12}: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	2.10	5.40	6.45	8.80	12.35	16.45	19.90	23.10
LSD at 5%	**NS**	**NS**	**1.29**	**2.33**	**2.08**	**1.75**	**2.84**	**4.23**

Leaf area

Among the different treatments, the area of leaves per plant at different stages of growth showed significant variation ($p \leq 0.05$) (Table 3). On the 56th day of harvesting, the highest area (61.13 cm^2) of the leaf was recorded in T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) compared to T_5 (3.05 cm^2). Other treatments showed intermediate effects.

Table 3. Effects of organic-inorganic fertilizers and cadmium-lead on the leaf area of spinach plants' leaf area (cm^2) on different days after sowing (DAS).

Treatments	**Leaf area (cm^2) at different DAS**							
	7^d	**14^d**	**21^d**	**28^d**	**35^d**	**42^d**	**49^d**	**56^d**
T_1: Control (-VC, -NPK, -Cd & -Pb)	0.06	0.79	1.52	2.17	3.73	4.27	11.17	14.13
T_2: VC 5 ton ha^{-1}	0.13	1.25	1.41	2.99	4.09	4.44	16.18	26.38
T_3: $N_{25}P_8K_{10}$ kg ha^{-1}	0.16	1.85	4.19	10.60	11.89	15.38	19.83	29.00
T_4: $N_{25}P_8K_{10}$ kg ha^{-1} + VC 5 ton ha^{-1}	0.12	0.64	3.96	8.54	20.12	22.18	44.07	49.55
T_5: Cd_4 kg ha^{-1}	0.05	0.48	0.75	1.31	1.63	2.13	2.28	3.05
T_6: VC 5 ton ha^{-1} + Cd_4 kg ha^{-1}	0.04	1.36	3.93	3.69	5.52	7.75	15.92	23.00
T_7: $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	0.03	1.25	1.75	2.67	3.17	3.28	3.88	6.80
T_8: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	0.18	1.25	4.75	12.56	20.40	26.28	34.07	45.63
T_9: Pb_4 kg ha^{-1}	0.23	2.46	4.11	17.08	18.45	23.33	28.58	30.40
T_{10}: VC 5 ton ha^{-1} + Pb_4 kg ha^{-1}	0.16	0.54	2.21	5.99	11.02	13.56	28.19	37.50
T_{11}: $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	0.27	2.57	4.20	10.19	18.18	20.96	24.67	34.25
T_{12}: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	0.28	1.82	3.75	12.33	20.58	26.63	46.77	61.13
LSD at 5%	**NS**	**NS**	**1.91**	**5.45**	**6.12**	**9.44**	**4.93**	**12.72**

Number of leaves

The number of leaves per plant among the treatments at different stages of growth showed significant variation ($p \leq 0.05$) (Table 4). On the days of 56th and 49th of harvesting, the maximum number (10 $plant^{-1}$) of leaves was recorded in T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) and T_4 ($N_{25}P_8K_{10}$ kg ha^{-1} + VC 5 ton ha^{-1}) and lowest in T_5 (4 plant^{-1}). Other treatments showed intermediate effects.

Table 4. Effects of vermicompost, NPK, Cd, and Pb on no. of leaves of spinach plants on different days after sowing (DAS).

Treatments	Number of leaves at different DAS							
	7^d	**14^d**	**21^d**	**28^d**	**35^d**	**42^d**	**49^d**	**56^d**
T_1: Control (-VC, -NPK, -Cd & -Pb)	2	2	3	4	5	5	5	5
T_2: VC 5 ton ha^{-1}	2	2	3	5	5	6	7	7
T_3: $N_{25}P_8K_{10}$ kg ha^{-1}	2	3	4	5	6	7	8	8
T_4: $N_{25}P_8K_{10}$ kg ha^{-1} + VC 5 ton ha^{-1}	2	4	5	6	6	7	10	10
T_5: Cd_4 kg ha^{-1}	2	2	3	5	5	5	4	4
T_6: VC 5 ton ha^{-1} + Cd_4 kg ha^{-1}	2	2	4	4	6	5	6	6
T_7: $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	1	2	4	4	5	5	6	6
T_8: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	2	2	4	5	5	5	7	7
T_9: Pb_4 kg ha^{-1}	2	4	5	6	7	**7**	7	7
T_{10}: VC 5 ton ha^{-1} + Pb_4 kg ha^{-1}	2	4	4	6	7	6	8	8
T_{11}: $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	2	4	4	6	6	6	7	9
T_{12}: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	2	4	5	7	6	6	10	10
LSD at 5%	**NS**	**0.73**	**1.03**	**0.73**	**1.03**	**1.26**	**1.78**	**1.03**

Longest leaf

The longest leaf per plant at different stages of growth varied significantly ($p \leq 0.05$) among different treatments (Table 5). On the 56th day of harvesting, the longest leaf (10.85 cm) was recorded in T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) compared to T_5 (1.85 plant^{-1}). Other treatments showed intermediate effects. The Cd produced the lowest length of leaf in T_5. The independent application of Cd and Pb decreased the length of the leaf in all the days' interval.

Table 5. Effects of vermicompost, NPK, Cd, and Pb on the longest leaf (cm) of spinach plants on different days after sowing (DAS).

Treatments	Longest leaf (cm) at different DAS							
	7^d	**14^d**	**21^d**	**28^d**	**35^d**	**42^d**	**49^d**	**56^d**
T_1: Control (-VC, -NPK, -Cd & -Pb)	0.75	2.20	3.05	3.85	4.00	4.55	4.85	5.15
T_2: VC 5 ton ha^{-1}	1.05	3.25	3.60	5.35	6.15	6.50	6.80	7.25
T_3: $N_{25}P_8K_{10}$ kg ha^{-1}	1.15	3.50	3.95	5.20	5.50	5.85	6.10	6.60
T_4: $N_{25}P_8K_{10}$ kg ha^{-1} + VC 5 ton ha^{-1}	1.20	2.95	4.60	4.90	6.75	9.15	9.45	10.00
T_5: Cd_4 kg ha^{-1}	0.60	1.50	1.55	1.60	1.65	1.70	1.80	1.85
T_6: VC 5 ton ha^{-1} + Cd_4 kg ha^{-1}	0.70	3.10	4.50	4.55	5.60	6.90	7.15	7.65
T_7: $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	0.60	2.70	3.35	3.50	4.35	5.95	6.20	6.95
T_8: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	0.75	1.95	2.35	3.65	5.50	8.75	9.00	9.50
T_9: Pb_4 kg ha^{-1}	1.50	3.90	4.00	4.30	5.50	6.65	7.00	7.40
T_{10}: VC 5 ton ha^{-1} + Pb_4 kg ha^{-1}	1.20	2.05	3.00	4.75	6.65	8.35	8.60	9.25
T_{11}: $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	1.45	3.95	4.30	4.60	6.20	7.25	7.50	7.75
T_{12}: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	1.50	3.45	4.75	5.80	7.85	9.75	10.05	10.85
LSD at 5%	**NS**	**NS**	**1.38**	**2.05**	**1.70**	**2.17**	**2.15**	**2.35**

Fresh and dry weight of plants

The fresh and dry weight of roots, shoots, and leaves per plant varied significantly ($p \leq 0.05$) among the different treatments (Table 6). The highest fresh weight of the plant (10.92 g) was observed in T_{12}, and the lowest in T_5 (0.75 g) and control T_1 (0.81 g), respectively. Others show intermediate effects. The highest dry weight of the plant (1.05 g) was also observed in T_{12} and the lowest in treatment T_5 (0.07 g) and control T_1 (0.09 g), respectively. Results revealed that spinach's overall growth and yield performance were better in T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}). The study also showed highest fresh material of spinach was with T_{12} which yielded maximum dry matter.

Table 6. Effects of vermicompost, NPK, Cd, and Pb on the fresh and dry weight of spinach plants.

Treatments	Fresh weight and dry weight (g) per plant							
	Fresh weight				Dry weight			
	Leaf	**Shoot**	**Root**	**Total**	**Leaf**	**Shoot**	**Root**	**Total**
T_1: Control (-VC, -NPK, -Cd & -Pb)	0.56	0.11	0.14	0.81	0.07	0.01	0.01	0.09
T_2: VC 5 ton ha^{-1}	0.69	0.15	0.19	1.03	0.06	0.02	0.03	0.11
T_3: $N_{25}P_8K_{10}$ kg ha^{-1}	1.52	0.17	0.25	1.94	0.07	0.02	0.02	0.11
T_4: $N_{25}P_8K_{10}$ kg ha^{-1} + VC 5 ton ha^{-1}	8.90	0.30	0.67	9.87	0.61	0.13	0.18	0.92
T_5: Cd_4 kg ha^{-1}	0.54	0.09	0.12	0.75	0.03	0.03	0.01	0.07
T_6: VC 5 ton ha^{-1} + Cd_4 kg ha^{-1}	5.19	0.21	0.52	5.92	0.45	0.09	0.05	0.59
T_7: $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	3.02	0.18	0.28	3.48	0.20	0.06	0.03	0.29
T_8: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}	7.69	0.22	0.50	8.41	0.44	0.05	0.13	0.62
T_9: Pb_4 kg ha^{-1}	3.45	0.17	0.28	3.90	0.09	0.08	0.03	0.20
T_{10}: VC 5 ton ha^{-1} + Pb_4 kg ha^{-1}	7.74	0.19	0.42	8.35	0.49	0.08	0.15	0.72
T_{11}: $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	4.84	0.20	0.34	5.38	0.39	0.03	0.05	0.47
T_{12}: VC 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}	9.82	0.33	0.77	10.92	0.68	0.18	0.19	1.05
LSD at 5%	**0.64**	**0.06**	**0.14**	**0.69**	**0.11**	**0.06**	**0.06**	**0.10**

Nutrient content in the post-harvest soil (macro elements)

The concentration of available macronutrients N, P, K, and S in the soil of the spinach plant cultivated pots are presented in Table 7. The variation among N, P, and K values were significant ($p \leq 0.05$). The maximum amounts of available nitrogen (0.0798%), phosphorus (0.0027%), and potassium (0.0068%) in the soil were observed in the treatment T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) followed by the treatment T_4 (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1}) and remaining treatments.

Table 7. Concentrations (%) of available nitrogen, phosphorous, potassium, sulphur, organic carbon, organic matter, and cation exchange capacity (cmol/kg) in the soil of spinach plants experiment.

Treatments	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Sulphur (S)	Organic Carbon (OC)	Organic Matter (OM)	Cation Exchange Capacity (CEC)
T_1	0.0078	0.0005	0.0054	0.0057	0.43	0.74	16.00
T_2	0.0279	0.0029	0.0062	0.0014	0.81	1.39	17.26
T_3	0.0120	0.0006	0.0055	0.0020	0.60	1.03	16.00
T_4	0.0572	0.0026	0.0068	0.0073	0.86	1.48	18.11
T_5	0.0173	0.0004	0.0048	0.0052	0.62	1.07	9.68
T_6	0.0199	0.0016	0.0061	0.0042	0.75	1.29	27.58
T_7	0.0160	0.0015	0.0052	0.0053	0.83	1.43	26.95
T_8	0.0372	0.0020	0.0062	0.0041	0.69	1.19	24.42
T_9	0.0160	0.0003	0.0052	0.0059	0.81	1.39	10.53
T_{10}	0.0240	0.0014	0.0061	0.0014	0.71	1.22	27.16
T_{11}	0.0226	0.0007	0.0051	0.0024	0.59	1.01	20.63
T_{12}	0.0798	0.0027	0.0068	0.0084	0.82	1.41	34.95
LSD at 5%	**1.20**	**0.80**	**0.0006**	**NS**	**NS**	**NS**	**6.44**

The maximum amount of total nitrogen (0.30%), phosphorous (0.05%), and potassium (0.34%) in the soil were observed in T_{12}, followed by T_4 and the remaining treated pots except T_5 displayed minimum macro elements (Table 8). Impressively, the soil's residue of Cd (24.40 ppm) and Pb (33.00 ppm) was higher under the presence of vermicompost as it immobilizes cadmium and lead to plants by forming an organic-metallic complex.

Table 8. Concentrations (%) of total nitrogen, phosphorous, potassium, sulphur, iron, zinc, cadmium (ppm), lead (ppm) in the soil of spinach plants.

Treatments	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Sulphur (S)	Iron (Fe)	Zinc (Zn)	Cadmium (Cd)	Lead (Pb)
T_1	0.11	0.04	0.28	0.01	2.99	0.01	1.90	4.50
T_2	0.16	0.05	0.32	0.01	3.04	0.01	2.70	6.00
T_3	0.12	0.04	0.30	0.01	2.96	0.01	1.00	5.00
T_4	0.23	0.05	0.34	0.01	3.69	0.01	2.20	12.00
T_5	0.05	0.04	0.28	0.01	3.21	0.01	24.40	14.00
T_6	0.08	0.05	0.30	0.01	2.97	0.01	3.95	6.50
T_7	0.07	0.05	0.30	0.05	2.79	0.01	12.50	17.00
T_8	0.13	0.04	0.33	0.01	2.62	0.01	10.55	6.50
T_9	0.05	0.01	0.29	0.01	2.98	0.01	1.90	20.50
T_{10}	0.08	0.04	0.31	0.01	1.23	0.01	3.75	29.50
T_{11}	0.06	0.04	0.30	0.01	3.43	0.01	3.40	16.00
T_{12}	0.30	0.05	0.34	0.01	3.02	0.01	3.45	33.00
LSD at 5%	**1.00**	**0.84**	**0.02**	**0.01**	**0.70**	**0.90**	**0.45**	**8.51**

Mineral nutrient content in the leaf

The concentration of total nutrients N, P, K, and S in the leaf of spinach plants are presented in Table 9. There is a significant variation among N, P, and K values ($p \leq 0.05$). The maximum amounts of total nitrogen (2.29%), phosphorus (1.30%), and potassium (8.24%) in the leaf were observed in the treatment T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) followed by the T_4 (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1}) and remaining treatments.

Table 9. Concentrations (%) of total nitrogen, phosphorous, potassium, sulphur, iron, zinc, cadmium (ppm), lead (ppm) in the leaf of spinach plants.

Treatments	Nitrogen (N)	Phosphorous (P)	Potassium (K)	Sulphur (S)	Iron (Fe)	Zinc (Zn)	Cadmium (Cd)	Lead (Pb)
T_1	0.93	0.09	0.89	0.16	0.06	0.01	3.75	31.25
T_2	1.54	0.33	3.97	0.37	0.20	0.01	4.50	32.50
T_3	1.48	0.08	3.69	0.51	0.15	0.01	1.88	25.00
T_4	2.16	0.79	6.01	0.57	0.35	0.01	4.75	37.50
T_5	1.30	0.39	3.83	0.31	0.19	0.01	15.75	30.00
T_6	1.93	0.68	4.63	0.35	0.15	0.01	5.38	37.75
T_7	1.43	0.37	4.52	0.36	0.20	0.01	14.88	33.75
T_8	2.07	0.54	5.31	0.42	0.13	0.01	8.75	35.00
T_9	1.88	0.26	3.13	0.67	0.09	0.01	3.00	72.50
T_{10}	2.04	0.80	4.42	0.79	0.21	0.01	4.63	26.25
T_{11}	1.91	0.11	3.48	0.75	0.12	0.01	4.38	67.50
T_{12}	2.29	1.30	8.24	0.92	0.21	0.01	5.38	48.75
LSD at 5%	**0.42**	**0.83**	**0.02**	**0.02**	**0.02**	**0.44**	**0.45**	**0.80**

The findings revealed that the addition of vermicompost amendment in the soil resulted the lower cadmium content in T_6 (vermicompost 5 ton ha^{-1} + Cd_4 kg ha^{-1}) and T_8 (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Cd_4 kg ha^{-1}) which were 5.38 ppm and 14.88 ppm, respectively. The highest Cd concentration was found 15.75 ppm in leaves with T_5 (Cd_4 kg ha^{-1}). The study also showed that vermicompost-included treatments reduced the Cd content in leaves. It might be the chemistry of vermicompost protect the Cd content in plants. Results created a piece of evidence that vermicompost restricted the toxic element in plants.

The presence of vermicompost resulted in a comparatively higher concentration of lead (Pb) in the leaf than cadmium in T_{10} (vermicompost 5 ton ha^{-1} + Pb_4 kg ha^{-1}) and T_{12} (vermicompost 5 ton ha^{-1} + $N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) which were 26.25 ppm and 48.75 ppm. The absence of vermicompost in T_9 (Pb_4 kg ha^{-1}) and T_{11} ($N_{25}P_8K_{10}$ kg ha^{-1} + Pb_4 kg ha^{-1}) which were rapidly increased by 72.50 ppm and 48.75 ppm, respectively. Although Fe as a treatment was not employed, iron uptake still reduced to some extent in the presence of Pb content in the treatment T_9 (Pb_4 kg ha^{-1}). Naz *et al.* (2015) showed the evidence that Pb stress inhibits chlorophyll synthesis by causing impaired uptake of essential elements such as iron and magnesium. The sulphur content in the leaf was also reduced slightly and it is worth mentioning that Bashir *et al.* (2015) reported that exposure of plants to excessive toxic metals like Cd might affect the uptake of S and negatively impact the plant's yield.

Vermicompost application, thus, significantly caused a decrease in cadmium and lead uptake into the spinach plant under cadmium and lead-contaminated condition. Bioaccumulation of heavy metals in plant tissue and their absorption are dependent on organic material, pH, temperature, and availability of nutrient elements. Vermicompost applied in soil diminishes the bioavailability of heavy metals thereby altering them to less soluble forms. The findings were in the agreement of Najar *et al.* (2015), who reported vermicomposting may also bring a greater decrease in heavy metals.

Table 10. Nutritional value of spinach (USDA 2020).

Phytochemicals	Value/100 g (unit)	Phytochemicals	Value/100 g (unit)
Energy	22 kcal	Iodine	6.1 µg
Carbohydrates	2.64 g	Zinc	0.42 mg
Dietary fiber	1.6 g	Nitrogen	0.46 g
Fat	0.6 g	Vitamin A	306 µg
Protein	2.91 g	β-Carotene	3670 µg
Water	92.4 g	Lutein/zeaxanthin	7920 µg
Calcium	67 mg	Thiamine	0.076 mg
Iron	1.05 mg	Riboflavin	0.192 mg
Magnesium	93 mg	Niacin	0.51 mg
Manganese	0.426 mg	Vitamin B_6	0.214 mg
Phosphorous	41 mg	Folate	113 µg
Potassium	460 mg	Vitamin C	30.3 mg
Sodium	107 mg	Biotin	4 µg

Recent studies also evidenced that spinach plants are enriched with nutrients and vitamins (Table 10). Results showed that the mineral nutrients of leaves (N-2.29%, P-1.30% and K-8.24%) were found highest in treatment T_{12}. USDA (2020) showed that spinach was rich in vit. C (30.30 mg/100 g), betacarotene (3670 µg), vit. B_6 (0.21 mg), biotin (4 µg/100 g), Na (107 mg/100 g), vit. A (306 µg/100 g), water (92.40 g), protein (2.91 g/100 g). Spinach might be a medicinal plant and useful for humans as it has high nutritional value. Miano (2016) reported similar findings that a considerable amount of vitamins are present in spinach.

The application of vermicompost with NPK fertilizers favors the increase of mineral nutrient content accumulation in the leaves of spinach plants, ultimately helping in plant growth and development. This study confirmed that the application of vermicompost reduces Cd and Pb uptake in spinach, presumably by forming organic-bound complexes. The application of vermicompost would be a cost-effective method of decreasing the elevated Cd and Pb concentration in spinach and thus could be recommended for plant production and food security. Admittedly, vermicompost is of great interest for phytoremediation. Evaluation of their potential, however, requires further study of the effect of vermicompost amendments on a broader range of crops and agro-ecological sustainability.

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