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DETERMINATION OF PHYSICOCHEMICAL ATTRIBUTES, AVAILABLE NUTRIENTS AND HEAVY METAL ACCUMULATION ON DIFFERENT AGRICULTURAL TYPES AT SAMBALPUR, ODISHA

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Abstract: Micronutrients are vital for enhancing soil health and fostering plant growth. Soil quality is an essential element of the environment that influences crop productivity. Currently, the majority of heavy metals accumulate in the topsoil, leading to increasing absorption by various plant parts over time, resulting in pollution and toxicity. The current study focused on the determination of physicochemical properties and available nutrients from ten distinct agricultural soil use systems: *Solanum melongena* (Brinjal, Solanaceae), *Solanum lycopersicum* (Tomato, Solanaceae), *Capsicum annuum* (Chilli, Solanaceae), *Zea mays* (Maize, Gramineae), *Vigna unguiculata* (Cowpea, Fabaceae), *Phaseolus vulgaris* (Flat bean, Fabaceae), *Solanum tuberosum* (Potato, Solanaceae), *Allium cepa* (Onion, Liliaceae), *Colocasia esculenta* (Colocasia, Araceae), and *Abelmoschus esculentus* (Okra, Malvaceae). Soil samples were examined for heavy metals: Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Lead (Pb), and Cadmium (Cd). The soil pH was very alkaline for the soil taken from *Solanum lycopersicum*, followed by *Phaseolus vulgaris*. The electrical conductivity (EC) and cation exchange capacity (CEC) were observed to be elevated in *Capsicum annuum* (0.5±0.023 mS/cm) and *Solanum lycopersicum* (9.6±0.028 cmol(+)/kg). The magnesium content was highest in the soil of *Abelmoschus esculentus* (0.896± 0.001 cmol(+)/kg), while the calcium concentration was elevated in *Vigna unguiculata* (3.18± 0.044 cmol(+)/kg). Organic carbon was elevated in *Solanum lycopersicum* (1.64±0.310) %, while available nitrogen was significantly greater in *Phaseolus vulgaris* (302.38±0.058) kg/ha. The available phosphorus and potassium concentrations were higher in *Solanum lycopersicum* (156±0.816) kg/ha and *Vigna unguiculata* (600.1±0.804) kg/ha, respectively. Manganese (Mn) concentration was observed to be elevated in *Solanum melongena* (26.24±0.023 mg/kg) compared to other species within the Solanaceae family. Zinc content was elevated in *Phaseolus vulgaris* (33.38± 0.015 mg/kg). Increased manganese build up facilitates iron transport in plants (*Capsicum annuum* - 43.2± 0.015 mg/kg). The concentration of copper (Cu) was lower in *Allium cepa* at (6.44±0.023) mg/kg and greater in *Zea mays* at (23.38±0.026) mg/kg. Lead and cadmium are present in minimal quantities without impacting soil fertility; the effective concentration of these metals may not influence plant development or metabolic processes.

Keywords: Micronutrients. Physicochemical attributes, Electrical conductivity, Cation exchange capacity.

INTRODUCTION

Plants absorb heavy metals from the soil via their roots and from the atmosphere through their aerial vegetative structures. The majority of heavy metals accumulate in the topsoil, and

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with time, due to enhanced plant uptake and accumulation, their concentrations in the soil increase (Alloway, 2021). Human activities result in the release of heavy metals into the environment. The metals may accumulate in crop plants after leaching into the soil, groundwater, and surface water. While plants do not necessitate heavy metals, they rapidly assimilate them in detrimental forms. Agricultural land contaminated with elevated levels of heavy metals adversely affects plant metabolism and growth, soil biological activity, fertility, biodiversity, and the health of humans and animals. The detrimental impacts of heavy metals on plants demonstrated a multitude of adverse effects, both direct and indirect, across many crop species (Wuana and Okieimen, 2011).

One of the main causes of soil pollution is believed to be heavy metals. Numerous metals, especially Cu, Ni, Cd, Zn, Cr, and Pb, contribute to heavy metal contamination of the soil (Effron *et al.,* 2004; Singh and Kalamdhad, 2011). Lead is among the most common heavy metal pollutants in soil, as noted by Zeng *et al.* (2007) and Mensah *et al.* (2009). Metals may exist in solution, in solid form, as free ions, or adsorbed onto colloidal particles within the soil. The development of soil, agricultural practices, and human activities all contribute to the accumulation of heavy metals in topsoil. Adsorption, precipitation/dissolution, and complexation reactions govern the soluble state of metals (Singh *et al*., 2018).

Vegetables grown in fields polluted with heavy metals or near heavy metal sources may absorb higher concentrations of heavy metals than other vegetable species. Vegetables absorb heavy metals into their tissues when these metals are deposited on their surfaces (Kachenko and Singh, 2005). Heavy metal concentrations are higher in the roots and leaves of herbaceous plants than in the stems and fruits, hence vegetables accumulate more heavy metals than fruits. Vegetables are said to harbour harmful compounds, such as pesticide residues and heavy metals, which may lead to numerous health issues in individuals. Heavy metal intake is linked to anaemia, lung disease, hyperactivity, male infertility, cancer, and, in certain cases, fatality. Even at minimal concentrations, many metals such as lead, copper, cadmium, nickel, cobalt, chromium, and selenium can be harmful to both humans and plants.Based on the above information, this study aims to ascertain nutrient flux and the concentration of heavy metal release in agricultural soil samples obtained from several vegetable crop fields.

MATERIALS AND METHODS

Sampling was conducted using the methodology established by Kujur and Patel (2014) earlier described Parkinson *et al.* (1971). Soil samples were obtained from agricultural fields cultivated with ten distinct crops at the local farmers' land in Sambalpur, Odisha. The crop fields from which samples were collected include *Solanum melongena* (Brinjal, Solanaceae), *Solanum lycopersicum* (Tomato, Solanaceae), *Capsicum annuum* (Chilli, Solanaceae*), Zea mays* (Maize, Gramineae), *Vigna unguiculata* (Cow pea, Fabaceae), *Phaseolus vulgaris* (Flat bean, Fabaceae), *Solanum tuberosum* (Potato, Solanaceae), *Allium cepa* (Onion, Liliaceae), *Colocasia esculenta* (Colocasia, Araceae), and *Abelmoschus esculentus* (Malvaceae). Each site was divided into blocks, and five soil samples were randomly collected from a depth of 0–20 cm using 15 x 15 x 15 cm trenches. Soil, following appropriate sifting, was dispatched to the laboratory in sterile polyethylene bags for further investigation.

Soil organic carbon was quantified using the titration method established by Walkley and Black method (Mylavarapu *et al.,* 2014) as referenced by Mishra (1968). The pH, electrical conductivity (EC), and cation exchange capacity were assessed using the procedures outlined by ISSS (2002). Total soil nitrogen was quantified using the Kjeldahl method (Jackson, 1958). Total nitrogen in a soil sample was transformed to ammonia and subsequently measured. The phosphorus content of the soil was determined using the chlorostannous-reduced molybdophosphoric blue colorimetric method in hydrochloric acid, as described by Olsen and Sommers (1982). The available potassium content was assessed using the ammonium acetate method in conjunction with the flame photometer technique (ISSS 2002).

Total dissolved cadmium, chromium, copper, lead, manganese, iron and zinc were recovered utilizing methodologies established by Akinyele & Shokunbi, (2015).Metals were extracted using acid digestion utilizing a mixture of strong nitric, hydrochloric, and hydrofluoric acids in a 1:3:3 volume ratio (Marcet *et al.,* 1997).The examination of Zn, Fe, Mn, Cu, Pb, and Cd was conducted from ten different agricultural soil samples using atomic absorption spectroscopy (AAS)

Statistical Analysis

Mean values were shown significance or not by performing Duncan multiple range test (DMRT) at $p< 0.05$ using software SPSS 16.0. Analysis of variance was also perform at $p<0.05$ level of significance using software SPSS 16.0.

RESULTS AND DISSCUSSION

The study aimed to determine the physicochemical properties and accessible nutrients in various agricultural soil types. The study also focused on assessing the total concentration of heavy metals in ten distinct soil types. Mean values were significant at $p< 0.05$ level of significance (DMRT) and shown in the form of superscript letters.

Table 1 Mean concentration of pH, Electrical conductivity, Cation exchange capacity, Calcium and Magnesium in ten different agricultural soil types (0-20cm)

	Soil types	pH	EC mS/cm	CEC cmol(+)/kg)	Ca cmol(+)/kg)	Mg cmol(+)/kg)
1	*Solanum melongena*	7.42± 0.38^{bc}	0.4± 0.062^{d}	7.181± 0.063^{c}	0.317± 0.006^{a}	0.219± 0.005^{b}
2	*Zea mays*	7.2± 0.23^{abc}	0.3± 0.023^{c}	5.963± 0.053^{a}	1.208± 0.005^{d}	0.126± 0.015^{a}
3	*Vigna unguiculata*	7.27± 0.047^{abc}	0.1± 0.081^{a}	6.432± 0.241^{b}	3.185± 0.044^{h}	0.518± 0.005^{f}
4	*Solanum lycopersicum*	8.0± 0.077^{d}	0.38± 0.023^{c}	9.6± 0.028^{f}	0.933± 0.019^{c}	0.292± 0.046^{c}
5	*Phaseolus vulgaris*	7.5± 0.32^{c}	0.2± 0.008^{b}	5.624± 0.631^{a}	1.332± 0.008^{e}	0.419± 0.003^{d}
6	*Capsicum annuum*	6.9± 0.045^{a}	0.5± 0.023^{a}	7.63± 0.025^{d}	1.055± 0.003^{b}	0.192± 0.006^{b}
7	*Solanum tuberosum*	7.4± 0.040^{bc}	0.15± 0.081^{a}	8.53± 0.124^{e}	1.182± 0.052^{d}	0.099± 0.004^{a}
8	*Allium cepa*	7.1± 0.008^{ab}	0.18± 0.023^{a}	7.83± 0.234^{d}	0.962± 0.001^{c}	0.046± 0.003^{e}
9	*Colocasia esculenta*	7.3± 0.077^{bc}	0.08± 0.013^{a}	6.32± 0.531^{b}	1.792± 0.015^{f}	0.761± 0.042^{g}
10	*Abelmoschus esculentus*	7.5± 0.049**c**	0.2± 0.017^{b}	5.354± 0.452^{a}	1.921± 0.007^{g}	0.896± 0.001^{h}

Values are mean ± SD, Superscript letters shown significance of mean values; DMRT,P<0.05

The value of p^H was higher in soil grown with *Solanum lycopersicum* (8.0± 0.77) followed by *Phaseolus vulgaris* (7.5± 0.322) and *Abelmoschus esculentus* (7.5 ± 0.049) may be due to accumulation of high organic matter (1.64± 0.310, 1.4± 0.183, 1.52± 0. 0145 % respectively; Table 1). Soil organic matter is act as an important index for long term sustainability of soil health (Swain *et al.,* 2023). Accumulation of high organic matter was shown in *Zea mays* (1.98± 0.058) followed by *Solanum lycopersicum (*1.64± 0.310)% because, plantation increases soil organic carbon from input of litters from organic and inorganic residues comes out of above ground vegetation , that helps to amelioration of organic carbon in soil (Mukopadhyaya and Musto, 2016). Electrical conductivity is the measure of salt concentration in soil and also act as an indicator for nutrient loss or availability and texture. Electrical conductivity was found to be higher in *Capsicum annum* (0.5±0.023) mS/cm. The values shown significance at $p < 0.05$ level of significance observed from analysis of variance (ANOVA) and represented in Table 2. The value of electrical conductivity was found in the crops of Solanceae family as in *Solanum melongena* -0.4±0.062mS/cm; *Solanum lycopersicum*- 0.3± 0.023 mS/cm. The variation in EC may be due to activities of root exudates from above ground vegetation that cause the differential value of EC in soil (Mukopahyaya and Masto, 2016).

Table 2 Analysis of Variance of physicochemical attributes of ten different agricultural soil types (0- 20 cm)

	Sum of Squares	df	Mean Square	F	Sig.
pH	2.183	9	.243	7.002	.000
EC	.576	9	.064	24.908	.000
CEC	51.414	9	5.713	14.455	.000
Ca	17.708	9	1.968	62.696	.000
Mg	1.947	9	.216	522.309	.000

*P< 0.05

High accumulation of organic matter leads to higher CEC at neutral pH conditions, in *Solanum lycopersicum* 9.6± 0.028 cmol (+)/kg followed by *Solanum melongena* (7.18± 0.063 cmol (+)/kg; P<0.05). Thus, CEC is considered a good indicator to monitor soil quality and productivity (Ross and Ketterings, 1995). CEC was found to be ranged between 5.354± 0.452 to 9.6± 0.024 cmol (+)/kg in other agricultural soil. Concentration of divalent cations (Magnesium) was highest in green vegetables *Abelmoschus esculentus* (0.896± 0.001 cmol(+)/kg) and (*Phaseolus vulgaris* 0.419±0.003; *Vigna unguiculata* 0.518±0.005 cmol(+)/kg) but less in *Solanum tuberosum* (0.099± 0.004 cmol(+)/kg) and *Allium cepa* (0.046± 0.003 cmol(+)/kg, Table 1) may be due to leaching. Moreover, concentration of calcium was higher *in Vigna unguiculata* (3.18± 0.044) cmol(+)/kg and less in *Allium* species (0.962±0.001) cmol(+)/kg may be due less availability in top soil. Calcium concentration in different soil types was found to be ranged between 0.962± 0.001-1.921 ± 0.007 cmol (+)/kg.

CEC positively impacts the accessibility of vital nutrients (N, P, K) for plant development. In the absence of cation exchange, plants would not acquire an adequate supply of nutrients, as these nutrients drain from the soil and become less accessible to them (Radulov et al., 2011). Soil organic carbon is a fundamental component of soil that serves as a significant energy source and enhances nutrient availability through the process of mineralization. SOC consists of a diverse amalgamation of organic compounds, including simple molecules (monosaccharides, amino acids, etc.), polymeric substances (proteins, sugars, cellulose, lignin, etc.), plant detritus or root exudates, and microbial remnants. Soil organic matter comprises organic components, including partially degraded plant and animal tissues, their byproducts, and soil biomass. In present investigation, Organic carbon content was found to be ranged between (0.72±0.117)% - (1.98±0.038) % in ten different agricultural soil types. Highest concentration was found in *Zea mays* (1.98±0.038) % and lowest was found in *Solanum* *melongena* (0.72±0.117) % (Table 3). The level of significance was shown in the form of Table 4.

Nitrogen is an essential ingredient that plants absorb from the soil and serves as a limiting factor for plant growth (Kekane, 2015).Nitrogen is an important element for regulating metabolism in living organism and plants and acts as building blocks for proteins and amino acids. In present study, total nitrogen concentration was higher in soils grown with crops like *Phaseolus vulgaris*, *Zea mays*, *Solanum lycopersicum*, *Abelmoschus esculentus* and *Solanum melongena* (302.38± 0.058;290.36± 0.568; 190± 0.794;192.5± 0.853; 179± 0.544) kg/ha (Table 2). This may be due to falling of litters, below ground microbial activity and accumulation high organic matters in soil (Mensah *et al.,* 2015).

Phosphorus is a fundamental element in soil organic matter and terrestrial ecosystems, originating from the weathering of parent rock material. Phosphorus, present in both organic and inorganic forms, is associated with soil surfaces including aluminium, iron, calcium, and organic matter, depending on the soil type (Tale and Ingole, 2015). The available phosphorus content in the current study was found to be highest in *Solanum lycopersicum* (156±0.816) kg/ha and lowest in *Colocasia esculenta* (30±0.894) kg/ha in ten different soil types. Potassium is a most important element that plays an important role in physiological processes in plants. Available potassium content was higher in *Vigna unguiculata* (600.1±0.804) kg/ha and lowest was in *Solanum lycopersicum (*139.5±0.544)kg/ha (Table 3). Analysis of variance (ANOVA) was performed to know the level of significance of ten different agricultural types (Table 4).

Table 3 Mean concentration of Organic carbon, Total nitrogen, Available phosphorus (AP) and Available potassium (AK) in ten different vegetable soil (0-20 cm)

Soil types	OC	TN	AP	AK
Solanum melongena	0.72±0.117^{a}	179± 0.544^{f}	126±0.814^{c}	445.4±0.473^{e}
Zea mays	1.98±0.038^{d}	290.36±0.894^{i}	120±0.856^{b}	424.3±0.698^{g}
Vigna unguiculata	1.42±0.270^{bc}	133.7±0.154^{c}	39±0.0.865^{g}	600.1±0.804^{c}
Solanum lycopersicum	1.64±0.310^{c}	190±0.794^{h}	156±0.816^{f}	139.5±0.544^{c}
Phaseolus vulgaris	1.4±0.183^{bc}	302.38±0.058^{j}	78.9±0.544^{i}	168.2±0.835^{j}
Capsicum annuum	1.24±0.096^{b}	163.7±0.178^{a}	60±0.389^{a}	396±0.894^{a}
Solanum tuberosum	1.43±0.242^{bc}	148.7±0.070^{b}	42±0.562^{e}	404.2±0.929^{h}
Allium cepa	1.18±0.054^{b}	165±0.894^{e}	123±0.938^{g}	144±0.899^{d}
Colocasia esculenta	1.05±0.023^{bc}	147.7±0.135^{c}	30±0.894^{d}	525.5±0.894^{b}
Abelmoschus esculentus	1.52±0.147^{bc}	192.5 ±0.853^{g}	147±0.616^{h}	165.2±0.853^{i}

Values are Mean ± SD, Superscript letters shown significance of mean values; DMRT, P<0.05

Table 4 Analysis of Variance of available nutrients of ten different agricultural soil types (0- 20 cm)

Parameters	Sum of Squares	df	Mean Square	F	Sig.
OC	2.858	9	.318	8.619	.000
AN	104238.421	9	11582.047	2.810	.000
AP	15580.993	9	1731.221	3.859	.000
AK	100427.274	9	11158.586	1.617	.000

*P<0.05

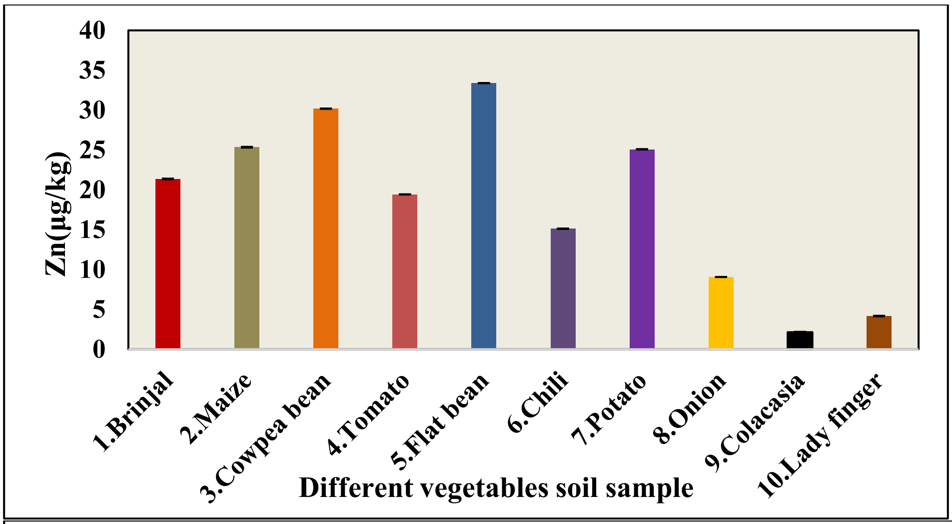
Metals which have specific weight of greater than 5 g cm^{-3} are called heavy metals (Holleman and Wiberg, 1985) and about 40 elements are comes under this category. Heavy metals like Cu and Zn play a major role as cofactors and serve as activators of some enzyme reactions, e.g., during the formation of the enzyme-substrate complex (Mildvan, 1970), or some metals have the properties of catalysis, such as the prosthetic group in metalloproteins, and also take part in redox reactions, the transfer of electrons, and metabolism. Heavy metals like Cu, Fe, Mn, Mo, Ni, and Co are also known as micronutrients (Reeves, 2003), but intake in excess of requirements is only toxic for the body (Nagajyoti *et al.,* 2010). In the present study, accumulation of heavy metals in agricultural soils from ten different vegetable crops was determined and expressed in mg/kg (Figure 1).Mean values were significant at 0.05 level of significance observed from Analysis of variance (ANOVA) and presented in Table 5.

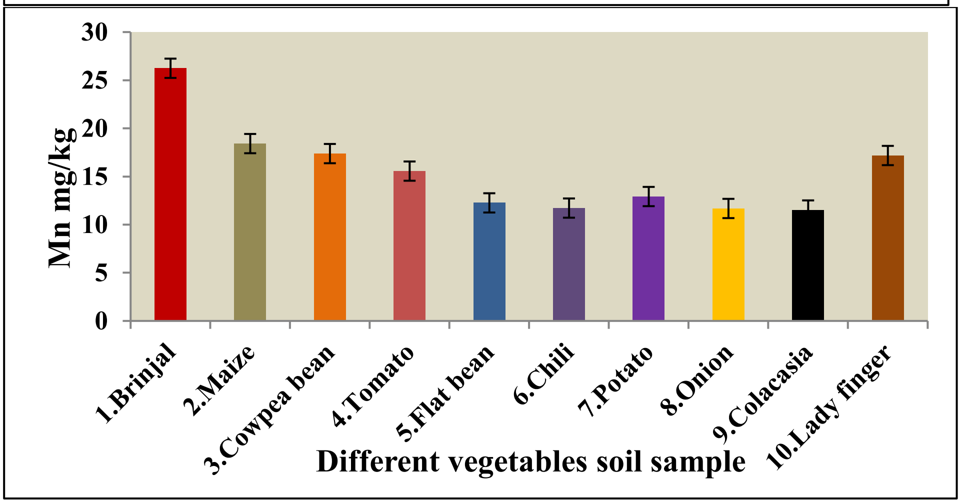
Table 5 Analysis of Variance of heavy metals of ten different agricultural soil types (0- 20 cm)

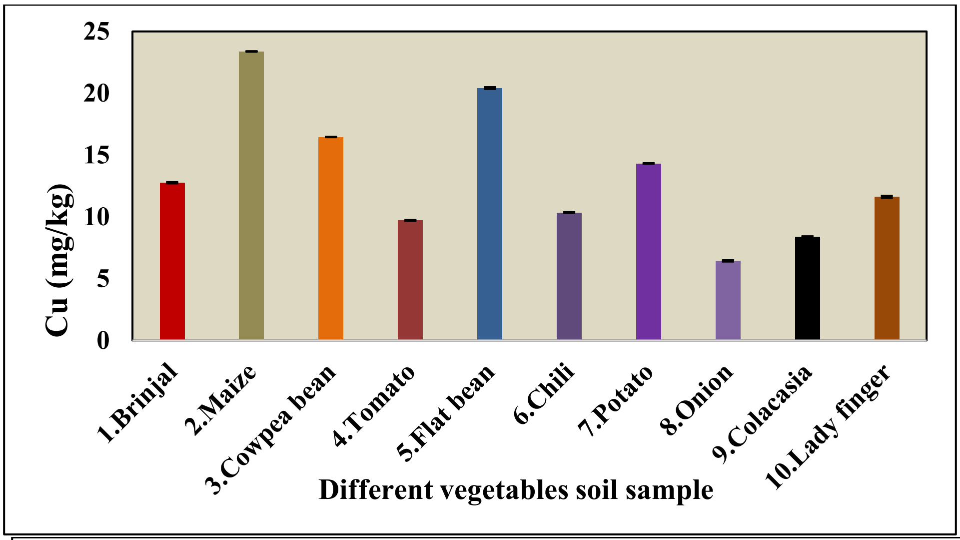
	Sum of Squares	df	Mean Square	F	Sig.
Zn	3085.888	9	342.876	3.528E3	.000
Mn	607.406	9	67.490	2.682E3	.000
Fe	3782.235	9	420.248	4.650E3	.000
Cu	799.268	9	88.808	6.722E3	.000
Cd	.464	9	.052	4.035E3	.000
Pb	1.281	9	.142	915.833	.000

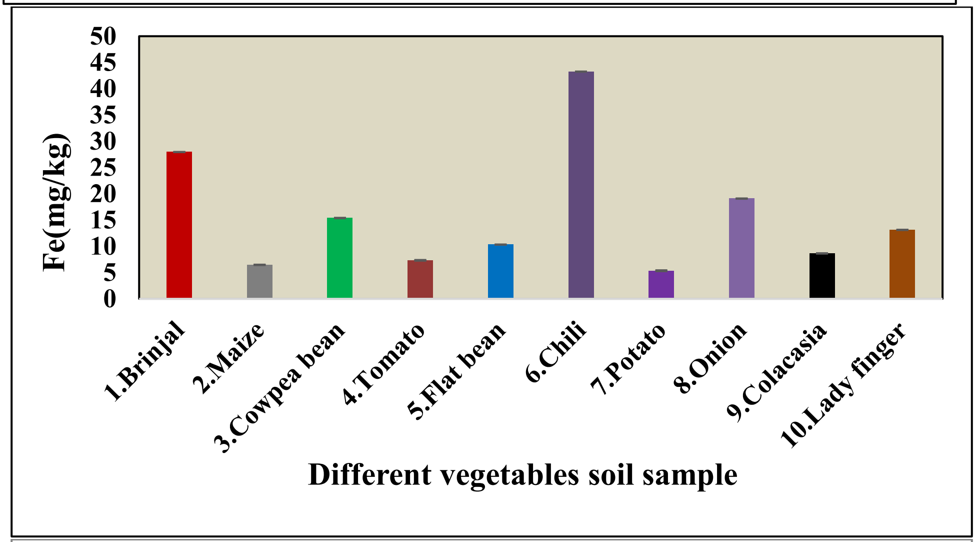
*P<0.05

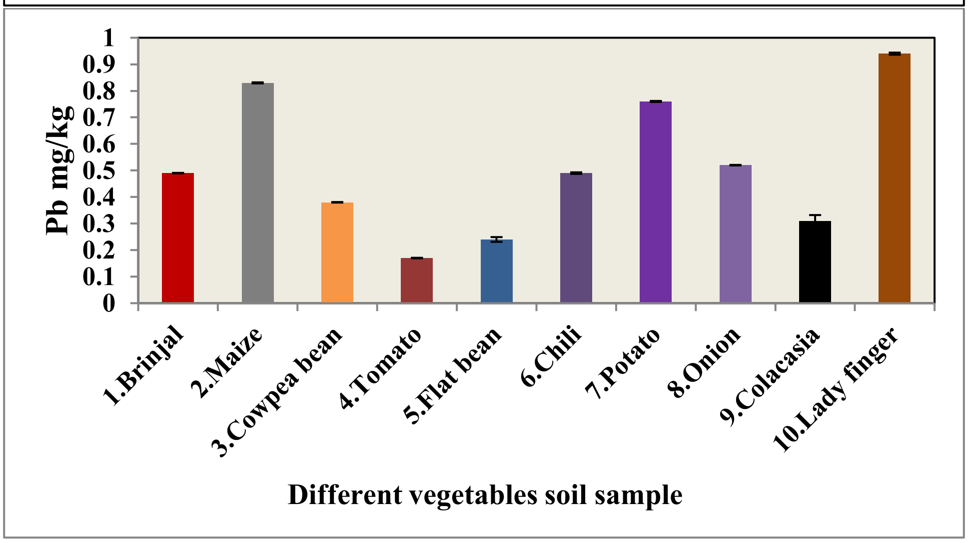
Zinc concentration was higher at *Phaseolus vulgaris* (33.38± 0.015) mg/kg followed by *Vigna unguiculata* (30.18± 0.008; Figure 1) mg/kg. *Colocasia esculenta* (2.14± 0.046) mg/kg contains less concentration Zn as compare to other crop. Higher accumulation of Mn leads translocation of Fe in plants in crops of Solanaceae family (*Capsicum annum*- 43.2± 0.015) mg/kg. Manganese (Mn) concentration in the current investigation was found to be higher in *Solanum melongena* (26.24±0.023 mg/kg) among species of Solanaceae family that positively influences metabolic processes of plant however excessive concentration negatively affects quality of soil by affecting pH of soil (Mensah et al.,2015). Copper (Cu), (6.44±0.023) mg/kg concentration was lower in *Allium cepa* and accumulated higher in *Zea mays* (23.38±0.026 mg/kg) followed by 20.42±0.079 mg/kg in *Phaseolus vulgaris.* In vegetable soil of Chilli, Fe concentration was found to be higher as 43.26±0.015 mg/kg, where as in other crops of Solanaceae family Fe concentration was found to be in range between 5.34±0.088- 27.94±0.023mg/kg.






Cu (mg/kg)
0
5
10
15
20
25
1.Brinjal
2.Maize
3.Cowpea bean
4.Tomato
5.Flat bean
6.Chili
7.Potato
8.Onion
9.Colacasia
10.Lady finger
Different vegetables soil sample


Fe(mg/kg)
0
5
10
15
20
25
30
35
40
45
50
1.Brinjal
2.Maize
3.Cowpea bean
4.Tomato
5.Flat bean
6.Chili
7.Potato
8.Onion
9.Colacasia
10.Lady finger
Different vegetables soil sample


Pb mg/kg
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.Brinjal
2.Maize
3.Cowpea bean
4.Tomato
5.Flat bean
6.Chili
7.Potato
8.Onion
9.Colacasia
10.Lady finger
Different vegetables soil sample

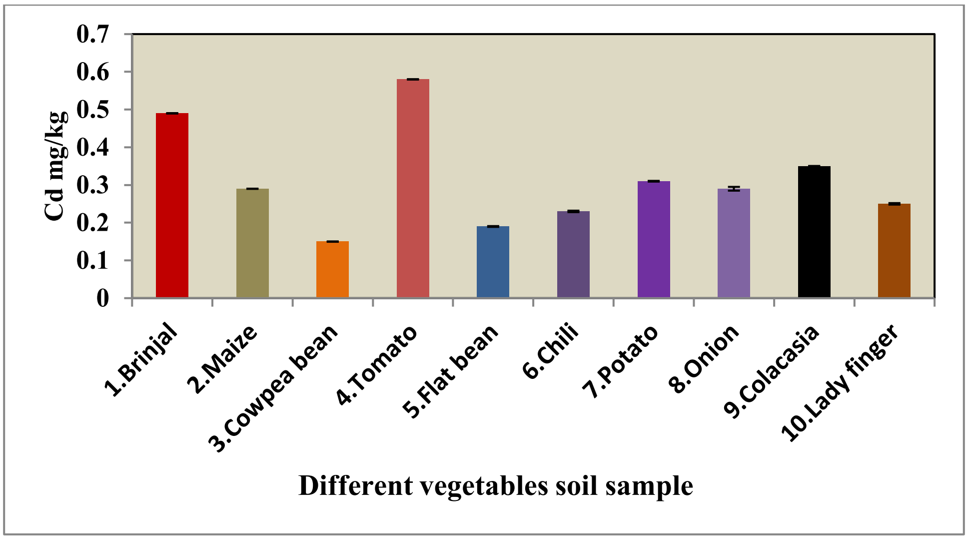


Figure 1 Mean concentration of ten different vegetables soil sample (0-20 cm)

Excess Mn concentration in crops may be the principal reason for less accumulation of Zn and Cu in crops, also supported by studies from Liu *et al.* (2020). The concentration of Cadmium (Cd) was shown highest in Solanaceae family crops (*Solanum lycopersicum* - 0.058± 0.0006*; Solanum melongena* – 0.049±0.0004) and lowest in Fabaceae family crops (*Phaseolus vulgaris 0.019± 0.009; Vigna unguiculata-0.015±0.0005).* Lead (Pb) concentration was highest in Allium species (*Allium cepa*, 0.132± 0.0001) .The results are also supported the findings of Zwolak *et al.* (2019). Variation was observed in accumulation of metals in soil of crops of same family due to exposure to different concentration of pesticide during cultivation process that affects plant growth and metabolism to a large extent. The present study indicates that the effective concentration of nutrients and heavy metals positively influences soil fertility, and further examination of growth metrics and performance may yield beneficial insights for future research analysis.

CONCLUSION

Diverse plant species possess the capacity to absorb and eliminate heavy metals. Research indicates that certain plant types can acquire certain heavy metals. Metal absorption is influenced by various parameters, including plant species, nutrient availability, soil type, pH, and soluble concentration. The present study cantered on assessing physicochemical properties, available nutrients, and heavy metal buildup in 10 distinct agricultural soils in Sambalpur, Odisha. pH, organic carbon, electrical conductivity (EC), and cation exchange capacity (CEC) positively contribute to soil health and texture such as clay content by facilitating appropriate cation exchange, which boosts the accumulation of organic matter and maintains soil pH. Heavy metal contamination arises from agricultural practices that employ pesticides, fertilizers, and soil chemicals. Natural phosphate fertilizers may contain contaminants, including heavy metals. The current study indicates that heavy metals such as Zn, Fe, Mn, and Cu positively influence plant growth, while minimal concentrations of Cd and Pb in vegetable soil may not adversely effect soil fertility, rendering the vegetables palatable.

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