Perspectives on Waste Recycling in Indian Agriculture

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RECYCLING OF ORGANIC WASTES: A POTENTIAL SOURCE OF MICRONUTRIENTS, WITH REFERENCE TO ZINC FOR FOOD, NUTRITION AND HEALTH SECURITY

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Abstract

The recycling of organic wastes is crucial not only for sustainable soil health but also for the replenishment of essential plant nutrients. Large quantities of organic wastes are generated daily from plant, animal, human, and industrial sources. Much of these wastes remain neglected and unutilised. Occasionally, these are burnt, contributing to environmental pollution. However, they can be beneficially recycled and used as a renewable source of plant nutrients to meet the nutritional requirements of crops. Today, micronutrient deficiency in soils and crops is more common than not. Globally, soils are experiencing multi-micronutrient deficiencies, predominantly zinc, adversely affecting crop yield and quality. A recent report by the ICAR indicates zinc and boron deficiencies in the majority of Indian soils at 37% and 23%, respectively. Additionally, 13% of soils are deficient in iron, 7% in manganese, 4% in copper, etc. Such widespread micronutrient deficiencies, including zinc and iron, are impacting human health, leading to micronutrient malnutrition.

Zinc has become the most widespread deficient micronutrient in soils and crops worldwide, causing severe yield losses and deterioration in nutritional quality, thereby adversely affecting human health. Almost half of the world's soils are deficient in zinc, with India being no exception. There is a significant correlation between zinc deficiency in soils and in humans.

Approximately one-third of the global population suffers from zinc deficiency. In the context of the recent pandemic, zinc has played a crucial role in boosting human immunity to combat diseases like COVID-19.

This paper discusses the recycling of organic wastes in relation to the supply of micronutrients for replenishing essential plant nutrients. It also emphasises the importance of micronutrients, particularly zinc, in food, nutrition, and health security.

1. Introduction

The recycling of wastes in agriculture introduces much-needed organic and mineral matter into soils. As most recyclable wastes are organic, they directly add organic matter and the contained plant nutrients. While nutrient input improves soil fertility, the organic input plays a critical role in enhancing soil physical and biological properties. Thus, waste recycling leads to overall improvement in soil productivity, with soil fertility being a key component. Plants are a direct or indirect source of several recyclable materials. Direct sources include crop residues such as straw and stover. Oil crop seeds, when crushed, leave behind oil cakes. Biomass from several uncultivated plants is also recyclable. Animal and human wastes are primarily residues of plant products ingested by humans or domesticated animals. Recycling waste can significantly benefit agriculture and land management in the long term. Additionally, it contributes to a cleaner environment, healthier habitat, and intelligent use of available recyclable resources, eliminating the label of 'waste'. A material is only waste until it is recycled or utilised; thereafter, it becomes a valuable resource. The potential for agricultural waste recycling is so extensive and user-friendly, as well as eco-friendly, that the term 'waste' itself could be rendered obsolete (Tandon, 1995).

1.1. Recycling of Organic Wastes

Residues of plant or animal origin are increasingly important as nutrient sources, leading to nutrient saving through recycling. Additionally, a broad range of products obtained from recycling crop, animal, human, and industrial wastes serve as sources of different plant nutrients. Nutrient sources are typically classified as organic, mineral, or biological. Organic nutrient sources are often referred to as manures, bulky organic manures, or organic fertilisers. Most organic nutrient sources, including waste materials, have widely varying compositions and often low concentrations of different nutrients, which also differ in their availability. Some, like cereal straw, release nutrients slowly due to a wide C:N ratio, while others, such as N-rich leguminous green manures or oilcakes, decompose rapidly, releasing nutrients swiftly (Roy et al., 2006). Table 1 presents the nutrient contents, both macro and micro-nutrients, in various organic wastes.

Table 1. Composition of nutrient elements of various organic wastes

S.No.	Organic waste	N (%)	P (%)	K (%)	S (µg/g)	Zn (µg/g)	Fe (µg/g)	Mn (µg/g)	B (µg/g)
1	Biosolids compost	1.7	1.8	6.4	6291	1281	7714	364	33
2	Yard waste compost	0.5	1.8	6.6	2860	120	9031	324	50
3	Food waste vermicompost	1.3	2.7	9.2	2587	279	23264	610	23
4	Cow manure vermicompost	1.9	4.7	1.4	5524	516	3454	160	58
5	Paper waste vermicompost	1.0	1.4	6.2	1929	127	17811	447	31

Source: Arancon et al., 2005

Effects of organic waste recycling on the availability and behaviour of different micronutrients in agriculture are discussed in this article.

2. Micronutrients in Balanced Plant Nutrition

The role of micronutrients in food production is well-recognised, but their importance for nutritional security and human health is increasingly acknowledged. Most nutrients essential for human health originate from the soil, either through plants or animal products consumed by humans. Micronutrient deficiency is widespread. The deficiency of two elements, particularly zinc (Zn) plus boron (B) in acidic soils and zinc plus iron (Fe) in semi-arid soils, is emerging as a concern in many cropping systems. The availability of micronutrients in soil is reflected in their concentration in seeds or fodder, which in turn determines their bioavailability and bio-assimilation in humans and livestock. A bio-assimilation study suggests that the consumption of micronutrient-rich food could significantly combat micronutrient malnutrition. Strategies to unlock native zinc and iron from the soil and external application through foliar spraying could enhance a considerable amount of bioavailable micronutrients in plant food (Shukla et al., 2014).

Soil Organic Matter (SOM) is known to modify various physico-chemical reactions that influence the availability of micronutrients. It favours a reduced redox potential environment and enhances the accessibility of micronutrient cations in the soil. Additionally, SOM has direct and indirect impacts on nutrient transformations. It also serves as a source of Soil Organic Carbon (SOC), comprising about 60% on a mass basis. Soil organic carbon is the most important component in maintaining soil quality because of its role in improving physical, chemical, and biological properties. In a reduced environment, the addition of SOM increases the complexed forms of micronutrients. The build-up of SOM in soil converts adsorbed fractions to more plant-accessible forms of micronutrients. The addition of soil organic matter increases the water-soluble and exchangeable forms of micronutrients in the soil, which further improves their uptake. A high amount of SOM in soils assists in various reactions of micronutrients, resulting in the formation of more stable complexes of micronutrients (Dhaliwal et al., 2019).

The concentrations of available nutrients in soils were categorised into six groups: acute deficient, deficient, latent deficient, marginally sufficient, adequate, and high. Approximately 7.90%, 28.6%, and 14.7% of the sampled sites were acute deficient, deficient, and latent deficient in available zinc, respectively (Figure 1). Moreover, 12.7%, 14.8%, and 21.3% of the sampled sites were marginally sufficient, adequate, and high in available zinc, respectively. Over 30% but less than or equal to 40% of the sampled sites in 68 districts, more than 40% but less than or equal to 50% of samples in 57 districts, and over 50% of the sampled sites in 131 districts were deficient (acute deficient + deficient) in available zinc. More than 50% of the sampled sites in 16 districts of Bihar, 40 districts of Madhya Pradesh, 13 districts of Maharashtra, and 23 districts of Tamil Nadu were deficient in available zinc.

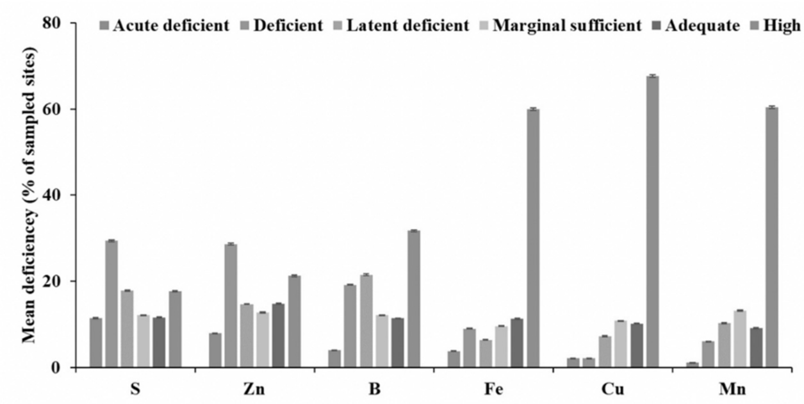

Figure 1. Mean deficiency of available S and micronutrients in agricultural soils of India.
Source: Shukla et al., 2021

The study further revealed considerable variation in the concentrations of available micronutrients in the agricultural soils of India. The levels of deficiencies (acute deficient + deficient + latent deficient) were notable for available zinc (Zn) at 51.2%, boron (B) at 44.7%, iron (Fe) at 19.2%, copper (Cu) at 11.0%, and manganese (Mn) at 17.4%. The distribution of single and multi-nutrient deficiencies of micronutrients varied across different districts, states, and Agro-Ecological Regions (AERs) of India. Assessing single and multi-nutrient deficiencies in agricultural soils is essential for the efficient use of micronutrients, aiming to achieve food and nutritional security and improve human and animal health (Shukla et al., 2021).

The increasing trend in the consumption of micronutrient fertilizers versus food grain production in the country over the years highlights the importance of micronutrients in sustainable food production (Shukla et al., 2019). According to an estimate, the contribution of zinc and boron fertilizers to current food crop production is around 29 million tonnes of rice equivalent yields (Shukla and Behera, 2011). Of the total zinc used, 70% is applied to field crops and the remaining 30% to vegetable and fruit crops.

3. Integrated Nutrient Management (INM)

The fundamental principle of Integrated Plant Nutrient System (IPNS)/INM is the maintenance or adjustment of soil fertility/productivity and optimal plant nutrient supply to sustain the desired level of crop productivity (FAO, 1995). The objective is to maximise the benefits from all possible sources of plant nutrients, including locally available ones, in an integrated manner while ensuring environmental quality (Roy et al., 2006).

In the rice-growing areas of Bhubaneswar, Odisha, the application of graded levels of zinc and its combination with organic materials significantly increased rice grain yield (Table 2). The highest yield of 45.33 quintals per hectare (q ha-1) was obtained when zinc was applied at 2.5 kg ha-1 with Farm Yard Manure (FYM). Therefore, applying zinc at 2.5 kg ha-1 along with FYM is recommended for better yield response. The highest zinc uptake of 0.543 kg ha-1 was recorded with the application of zinc at 2.5 kg ha-1 along with FYM incorporation.

Table 2. Effect of Integrated Nutrient Management of Zinc on Yield and Zinc Uptake by Rice

Treatments	Grain Yield (t ha^{-1})	Zn uptake (g ha^{-1})		Total uptake (g ha^{-1})
		Grain	Straw	
Control (No Zinc)	3.25	74.0	180.0	254.0
Zn @ 2.5 kg ha^{-1}	3.73	87.0	280.0	367.0
Zn @ 5.0 kg ha^{-1}	4.35	115.0	330.0	445.0
Residue incorporation	3.82	90.0	200.0	290.0

Zn @ 2.5 kg ha^{-1} + Residue incorporation	4.36	114.0	400.0	514.0
FYM @ 5 t ha^{-1}	4.01	98.0	280.0	378.0
Zn @ 2.5 kg ha^{-1}+ FYM @ 5 t ha^{-1}	4.53	123.0	420.0	543.0
0.25 % spray as $ZnSO_4$	4.03	122.0	400.0	522.0
CD (0.05)	0.47	0	-	-

Source: Shukla and Tiwari, 2014

The Organic Carbon (OC) content increased to 0.49% in organic farming treatments from its initial value of 0.39% and chemical treatment of 0.38%. Organic sources helped build up the OC by 23.1% over the initial level by the end of the third crop cycle, proving the hypothesis of consistent improvement in soil fertility. The addition of organic manures also improved the status of zinc, copper, iron, and manganese in soil (Table 3).

Table 3. Micronutrient Status as Influenced by Sources of Plant Nutrients in a Maize-Potato-Onion Cropping System

Treatments	Treatment details	Micronutrient status (µg/g)			
		Zn	Cu	Fe	Mn
T_1	50% recommended NPK + 50% N as FYM / crop residues / composts / other organic sources	0.76	0.44	13.92	5.02
T_2	1/3 of recommended N (FYM + vermicompost + nonedible oil cake)	0.58	0.46	14.30	6.30
T_3	T_2 + Intercropping or trap crop	0.61	0.56	12.84	6.08

T_4	T_2 + Agronomic practices for weed and pest control	0.74	0.44	11.66	4.70
T_5	50% N as FYM / other organic sources + biofertilizer for N + rock phosphate for P + PSB	0.61	0.46	13.50	5.84
T_6	T_2 + Biofertilizer containing N and P carriers	0.53	0.40	10.68	5.60
T_7	100% NPK + secondary and micronutrients	0.68	0.38	11.48	5.54
T_8	Dummy plot (T_2)	0.62	0.42	11.76	6.12
Control		0.56	0.42	6.70	3.80

Source: Dhaliwal et al., 2010

The inclusion of organic amendments in Integrated Nutrient Management (INM) should be highly encouraged to mitigate the widespread deficiency of micronutrients in food grains. While many studies have reported the exogenous supply of Organic Matter (OM) as an advantageous strategy over the conventional application of water-soluble forms of micronutrients, some researchers claim that a coupled application of these two is most effective compared to their sole application. Thus, the build-up of organic matter should be highly encouraged, not only to improve plant nutrition value by enhancing the micronutrient availability but also for a sustainable future (Dhaliwal et al., 2019). Considering the widespread deficiency of zinc in Indian soils and globally, the aspect of micronutrient management through organic waste recycling has been dealt with particular reference to zinc.

4. Zinc in Food, Nutrition and Health Security

Zinc is one of the 17 essential elements necessary for the normal growth and development of plants and is one of the eight essential micronutrients for plants. Zinc plays a key role in plants as a structural constituent or regulatory co-factor in a wide range of different enzymes and proteins involved in many important biochemical pathways. These are mainly concerned with carbohydrate metabolism, both in photosynthesis and in the conversion of sugars to starch, protein metabolism, auxin (a growth regulator) metabolism, pollen formation, maintaining the integrity of biological membranes, and resistance to infection by certain pathogens.

Zinc deficiency in plants retards photosynthesis and nitrogen metabolism, reduces flowering and fruit development, prolongs growth periods causing delayed maturity, results in lower yield and poor produce quality, affecting sub-optimal nutrient-use efficiency. Common deficiency symptoms of zinc in plants include light green, yellow, or bleached spots in interveinal areas of older leaves and a smaller size of emerging leaves, often termed as "little leaf". In severe deficiency cases, the internodal distance becomes so short that all the leaves appear to emerge from the same point, a condition termed as "rosetting".

4.1. Zinc in Soils and Crops

Zinc deficiency has now emerged as the most widespread micronutrient problem in soils and crops, resulting in severe yield losses and deterioration in nutritional quality worldwide. It is estimated that almost half of the soils in the world are deficient in zinc. Since cereal grains inherently have a low concentration of zinc, growing these crops on potentially zinc-deficient soils further decreases grain zinc concentration. India is no exception, with about 37% of soil samples analyzed for available zinc found to be deficient (Figure 3). There is a significant response to applied zinc in soils deficient in zinc.

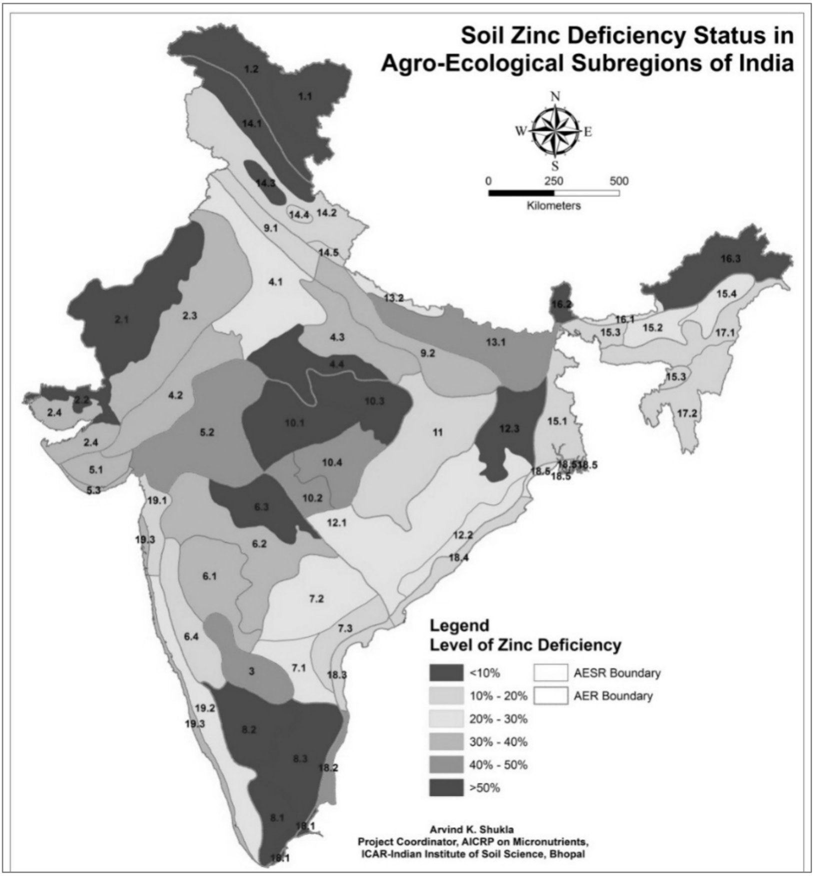

Figure 3. Soil zinc deficiency status in India (Shukla and Tiwari, 2016)

The reasons contributing to the increase in incidences of zinc deficiency include substantial zinc removal due to high crop yields and intensive cropping systems, diminished application of organic manures, reliance on high-analysis fertilisers, increased use of phosphatic fertilisers leading to P-induced zinc deficiency, and the utilisation of poor-quality irrigation water.

In India, the critical level of zinc in soils is currently considered to be 0.6 parts per million (ppm). However, there is a growing consensus that this threshold should be raised to 1.2 ppm or higher. Presently, about 37% of soils in India are categorised as zinc-deficient, based on the existing critical limit of 0.6 mg Zn kg^-1 soil. Intriguingly, crop response to applied zinc has also been observed in soils exceeding this critical limit. Therefore, it is widely believed that the critical level of zinc is site-specific, and a singular critical limit may not accurately represent every soil type or crop. The results depicted in Table 4 demonstrate that depending on soil types and crops grown, the critical limit of zinc may vary significantly, with levels as high as 1.24 mg Zn kg^-1 in soybean crops in Uttarakhand state.

Table 4. Refined Critical Limit of Zinc for Various Soils and Crops at Different Locations

S.No.	Location	Crop	Zn (mg kg^{-1})	
			Soil	Plant
1	Akola, Maharashtra	Soybean	0.65	24.3
2	Coimbatore. Tamil Nadu	Maize	0.90	24.8
3	Pantnagar, Uttarakhand	Lentil	1.20	9.6
4	Pantnagar, Uttarakhand	Chickpea	1.20	19.2
5	Nainital, Uttarakhand	Soybean	1.24	22.3

(Shukla and Tiwari, 2016)

4.2. Zinc in Human Health

Zinc is an indispensable nutrient for human health, and its deficiency, particularly in infants and young children under five years of age, has gained global attention. Zinc deficiency ranks as the fifth leading cause of death and disease in the developing world. The World Health Organization (WHO) estimates that zinc deficiency causes the death of about 800,000 people annually, including 450,000 children under the age of five. An estimated 60–70% of the population in Asia and Sub-Saharan Africa could be at risk of low zinc intake, translating to approximately 2 billion people in Asia and 400 million in Sub-Saharan Africa (Prasad, 2006). There is a significant correlation between zinc deficiency in soils and in humans

(Figure 4). It is estimated that about one-third of the global population suffers from zinc deficiency.

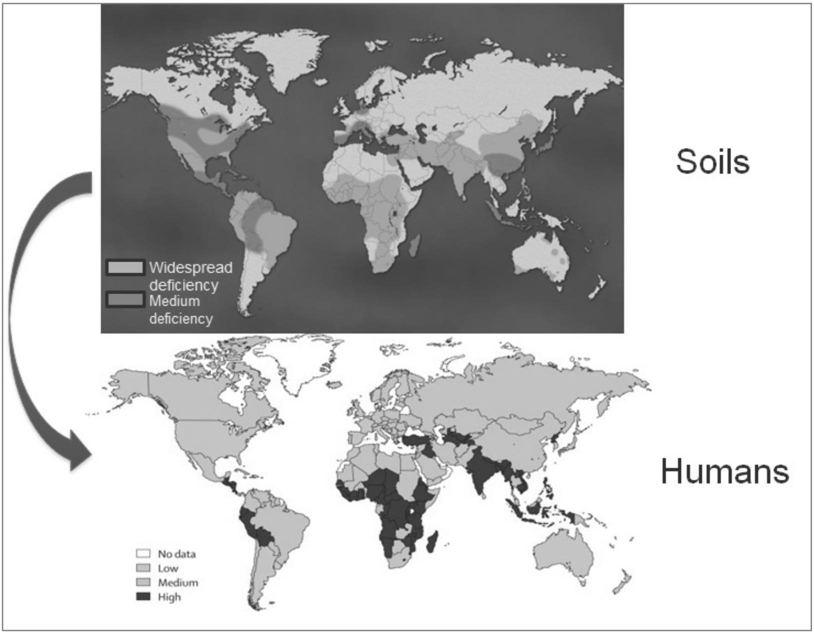

Figure 4. Global Zinc Deficiency in Soils and Humans (Alloway, 2008and Black et.al.,2008)

Zinc is critical for numerous biological functions and cellular processes in the human body. It is vital for more than 300 enzymes, playing a key role in protein synthesis, wound healing, DNA synthesis, cell division, and is essential for a proper sense of taste and smell. Zinc is also a crucial component of white blood cells that combat infections. Amidst the recent pandemic, zinc has played a vital role in boosting human immunity to fight diseases like COVID-19. The widespread deficiency of zinc in the human population has resulted in diminished immunity against such diseases. Reported symptoms of zinc deficiency in humans, particularly in infants and young children, include diarrhea, pneumonia, stunted growth, a weakened immune system, retarded mental development, dwarfism, impaired cognitive function, behavioral problems, memory impairment, difficulties in spatial learning, and neuronal atrophy (Figure 5).

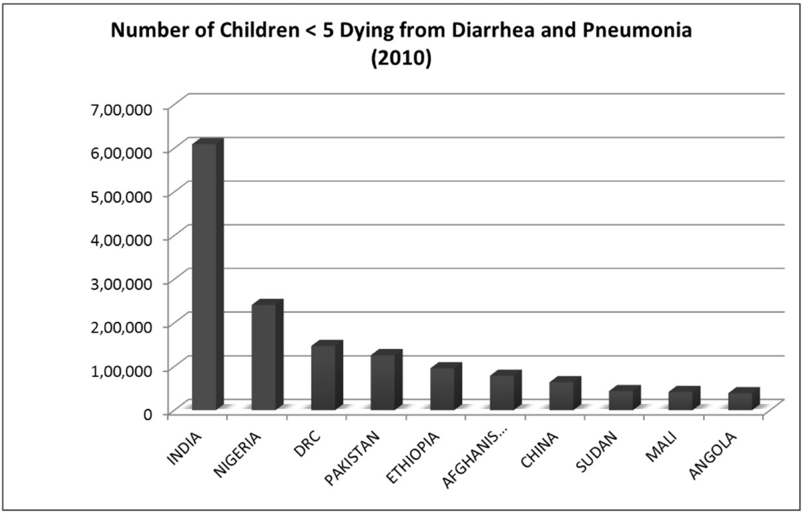

Figure 5. Deaths from Diarrhea and Pneumonia in Children Under 5 (UNICEF 2012)

4.3. Zinc Malnutrition – Possible Solution

The potential solutions to zinc malnutrition in humans are: i) Food supplementation, ii) Food fortification, and iii) Biofortification. The first two programmes require infrastructure, purchasing power, access to markets and healthcare centres, and uninterrupted funding, all of which have their own constraints. Additionally, these programmes are most likely to benefit the urban population, particularly in developing countries. In contrast, the latter programme, Biofortification—fortifying crops, especially food crops, with zinc—is the optimal approach for alleviating zinc deficiency. It serves both rural and urban populations and can be achieved through two methods: genetic biofortification and agronomic biofortification.

There is an emerging field of research focused on the biofortification of plant foods with zinc. This includes breeding new crop varieties with the genetic capacity to accumulate high zinc density in cereal grains (genetic biofortification), and the application of zinc fertilizers to enhance zinc density (agronomic biofortification). While the plant breeding approach is likely to be the most cost-effective in the long term, using fertilizers provides the quickest way to increase zinc density in diets. To replenish the zinc absorbed by these improved cultivars, a higher and sustainable use of fertilizers is essential (Das and Green, 2016).

4.4. Soil-Plant-Animal-Human Continuum

The analysis of zinc content in soil, crops, animals, and human blood serum has established a strong interdependence within the soil-plant-animal-human continuum, as demonstrated in Table 5.

Table 5. Soil Zinc Status vs Zinc Content in Crops and its Effect on Serum Zinc Level in Human Blood

<table>
<tr><th rowspan="3">Location</th><th rowspan="3">Zinc level in soil</th><th rowspan="3">No. of people tested</th><th colspan="4">Mean Zinc status (ppm)</th></tr>
<tr><th rowspan="2">Soil</th><th rowspan="2">Plant</th><th colspan="2">Blood Serum</th></tr>
<tr><th>Men</th><th>Women</th></tr>
<tr><td rowspan="2">Ranga Reddy (Andhra Pradesh)</td><td>Deficient</td><td>18</td><td>0.37</td><td>18.2</td><td>0.49</td><td>0.52</td></tr>
<tr><td>Sufficient</td><td>44</td><td>0.69</td><td>26.7</td><td>0.55</td><td>0.65</td></tr>
<tr><td rowspan="2">East Godavari (Andhra Pradesh)</td><td>Deficient</td><td>16</td><td>0.45</td><td>13.6</td><td>0.84</td><td>0.97</td></tr>
<tr><td>Sufficient</td><td>44</td><td>1.12</td><td>25.9</td><td>1.08</td><td>1.06</td></tr>
</table>

(Singh, 2009)

In light of the critical role of soil zinc in human health and the widespread deficiency of this micronutrient in Indian soils, increasing its supply in arable lands is now an urgent priority. Studies have shown that the efficiency of zinc in agricultural soils can be optimised in the presence of organic materials (Table 3). Hence, integrating zinc supply with organic residue is likely to emerge as an effective approach. Although some research has been undertaken in this area, further studies are needed to develop comprehensive organic waste integrated zinc and other micronutrient management programs.

5. Epilogue

In light of the increasing nutrient depletion from soils due to intensive agriculture, it is vital to consider recycling of organic waste as a supplementary source of essential plant nutrients. This approach, in conjunction with the use of fertilizers and other available sources, can be integrated into an effective Integrated Nutrient Management (INM) strategy. Such a strategy is crucial for enhancing soil health, boosting crop production, and ensuring environmental sustainability.

A critical issue in this context is the widespread micronutrient deficiency, particularly zinc deficiency, in both crops and humans. This deficiency presents a global challenge. The sustainable solution lies in increasing the use of zinc as part of a balanced plant nutrition regimen within the framework of INM. By doing so, we can safeguard soil health and ensure food, nutrition, and health security.

To achieve this, concerted efforts are needed from all stakeholders, including farmers, extension workers, scientists, and policymakers. A favourable and conducive policy environment is essential to encourage balanced plant nutrition.

Key challenges and suggested ways forward in promoting the use of micronutrients like zinc through INM include:

1. Utilizing the majority of available organic wastes, which are currently neglected or unutilized, sometimes even burnt, thereby contributing to environmental pollution. Farmers should be encouraged to maximize the use of available organic wastes in INM.
2. Encouraging organic matter build-up to enhance plant nutrition by improving micronutrients availability, thereby contributing to a sustainable future.
3. Conducting further research for a better understanding of the complex relationship between soil organic matter and micronutrients availability.
4. Addressing the issue of low micronutrients use efficiency, which generally does not exceed 1-5%. Exploring the possibility of increasing micronutrient use efficiency through integrated nutrient management with organic residues.
5. Generating site-specific information on the ‘Soil–plant–animal–human continuum study on zinc’ through a multidisciplinary approach, as such information is currently scarce.

6. Improving the awareness level among extension and promotional workers as well as farmers to ensure effective last-mile delivery.

In conclusion, embracing INM with a focus on organic waste recycling and balanced micronutrient usage, especially zinc, is not just a necessity for agricultural sustainability, but also a step towards securing human health and environmental wellbeing.

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