

Recycling of Plant Nutrients: Present Status and Conceptual Framework for Future Research to Maintain Soil Health, Crop Productivity and Minimize Climate Changes

ISSN: 2578-0336



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Submission:  November 18, 2024

Published:  January 10, 2025

Volume 12 - Issue 5

How to cite this article: SG Borkar*. Recycling of Plant Nutrients: Present Status and Conceptual Framework for Future Research to Maintain Soil Health, Crop Productivity and Minimize Climate Changes. Environ Anal Eco Stud. 000799. 12(5). 2025.
DOI: [10.31031/EAES.2025.12.000799](https://doi.org/10.31031/EAES.2025.12.000799)

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Abstract

During the last 6-7 decades, the use of inorganic farm inputs viz. fertilizers, pesticides, and herbicides, to increase farm production and crop yields, has not only deteriorated the soil health, particularly the crop-useful soil microbes, but also affected human health with several disorders, as per the research data available. Soil microbial status is an important parameter in determining soil health as these microbes play an important role in crop growth-promoting activities and farm produce qualities. Therefore, the application of inorganic inputs in crop production systems has to be lessened. This can be only achieved, if the plant nutrients are recycled and returned to crop plants through either soil or/and foliar application. Recycling of plant nutrients is not composting the farm waste, but obtaining these from the farm crop residues, farm weeds, and farm animal waste viz. its urine and dung through the process of ferments obtained with the help of animal gut microbes, digestive enzymes, and plant probiotics. Presently no such protocol for recycling plant nutrients is available. The present paper discusses all the aspects of plant nutrient recycling that will help marginal farmers and those who plan to do organic farming worldwide.

Keywords: Plant nutrients; Recycling; Soil health; Crop productivity; Human health; Climate change

Introduction

Plant accumulates various nutrients in their plant parts during their growth and reproductive phase. The nutrient content of a plant varies not only among its various plant parts but changes with age and stage of development. A plant analysis interpretation is a useful tool to determine the available plant nutrient content. One method of such interpretation is based on critical values. A critical value of any nutrient in the plant is the concentration of that nutrient below which the deficiency of the concern nutrient is likely to occur. Therefore, a critical value of a particular nutrient is desired to maintain plant growth/health. These critical values differ with the type of crop plants (Table 1).

The data in Table 1 indicate that trace elements and minor Crop nutrients are required in small quantities or in ppm while the major nutrient requirements are in the range of 2 to 4 percent. If we maintain this critical nutrient value in the plant, we can obtain the proper plant growth and yield. Therefore, the application of inorganic fertilizers in huge quantities is a waste as these are beyond the required critical values, percolate in the water system, and also affect the soil microbial health which is an important factor in maintaining soil's ecological balances and liveliness of soil for plant growth. High concentrations of mineral elements in the soil can inhibit plant growth and reduce crop yield [1-3]. Applying inorganic fertilizers harms soil micro-biota including the soil's beneficial microbes which are prerequisites for good plant growth. Soils without microbes are dead soils [4,5] unable to support the required plant growth. The soil microbial growth is affected by various inorganic farm inputs.

Table 1: Critical values for different plant nutrients in different crop plants.

Critical Level for	Concentration	Remarks
Nitrogen (N)	2 to 4%	legume: 3-4.25%
		Fruits & ornamentals: 2%
Phosphorus (P)	0.12 to 0.30%	Tree crops: 0.12-0.15%
		Grasses: 0.20-0.25%
		Legume & vegetables: 0.25-0.30%
Potassium (K)	0.75 to 2%	tree crops: 0.75 to 1.25%
		Grasses: 1.20 to 2%
		Legumes: 1.75-2.0%
		(Young plant may content 3.0 to 5.0%K)
Magnesium (Mg)	0.10 to 0.15%	legume: 0.25-0.30
		Cotton: 0.30%
		Vegetables: 0.40%
Sulfur (S)	0.10 to 0.30%	grasses: 0.10%
		Legume, cotton, tobacco, tomato: 0.20-0.25%
		Cabbage, spinach, turnip: 0.30%
Calcium (Ca)	0.20 to 2.0%	grasses: 0.20-0.25%
		Soybean: 0.50%
		Apple, peach: 1 and 1.5%
		Tomato: 1%
		Cotton: 2%
Manganese (Mn)	15ppm	Cotton: 500ppm
		Pecan: 1000ppm
Ferrous (Fe)	50ppm	grasses: 20ppm
Boron (Bo)	20 to 100ppm	
Copper (Cu)	5 to 20ppm	
Zinc (Zn)	20 to 100ppm	
Molybdenum (Mo)	0.10ppm	

Source: Plant Analysis Handbook-Nutrient Content of Plants: Agriculture & Environmental Services Laboratories, University of George-Extension. Aesl ces uga.ed., 2024.

Effect of inorganic fertilizers on soil microbes

Since 1950's the mineral fertilizers, especially nitrogen inputs have been the major contributor to crop yield increase [6] and simultaneously are the limiting nutrient for many terrestrial ecosystems like soil bacteria and fungi [7]. These tiny below-ground communities are greatly affected by the chemical inputs in the form of fertilizers, in other words, about 84% of the studies in this regard reported that microbial community composition is sensitive to Nitrogen (N), Phosphorus (P), and Potassium (K) fertilization. The chemical fertilizers although one of the primary factors contributing to the increase in agricultural production are however, known to exhibit a deleterious effect on soil and the environment if used injudiciously [8]. Ge et al. [9] reported that the long-term application of chemical fertilizers significantly alters the

structure and diversity of bacterial communities. The result of 10-year field experiments conducted by Ren et al. [10] clearly showed that long-term N fertilization significantly affected most of the dominant soil bacterial species by changing the soil pH. Besides the inorganic fertilizers, pesticides, and herbicides also have adverse effects on soil microbial health.

Effect of pesticides and herbicides on microbes

Pesticides and herbicides are reported to degrade the microbe's structure, cellular processes, and distinct biochemical reactions at the cellular and biochemical levels [11]. Several biocides disrupt the relationship between plants and their microbial symbionts hindering beneficial biological activities that play a role in the plant growth process. Indiscriminate, long-term, and over-application of pesticides have severe effects on soil ecology that may lead to alterations in or the erosion of beneficial or plant probiotic soil micro-flora [12]. The effects of pesticides on soil are particularly important because soil organisms drive many processes relevant to crop production such as nutrient cycling, soil formation, pathogen suppression, and formation of organic matter [13,14]. Increased abundance of soil bacteria and protists [15] as well as elevated soil activity can significantly increase nutrient cycling and thus potentially improve crop yield and quality [16]. Pesticide applications such as conventional copper-containing fungicides can reduce organismal activity [17], thereby reducing litter decomposition rates [18] and structural integrity and air permeability in soil [19]. Whatever the mode of application of insecticide, and whether they are used in agriculture or public health, insecticides never remain at the site of application and ultimately sink into the soil. In the soil they come across the soil flora and fauna and the stage are set for their interaction with the soil ecosystem [20].

Pesticide use has increased approx. 50% since 1990, with an anticipated 4,000,000 tonnes being sprayed across farmland yearly [21]. These were generally administered multiple times during a single growing season in most crops which impacts the ecosystem [22]. In addition to the impact of herbicides on weeds, these herbicides also affect soil microorganisms which are responsible for numerous biological processes essential for crop production [23]. The herbicide treatment significantly inhibits the development of microbial population in the soil and the degree of inhibition varies with the type of herbicide. Besides their adverse effect on soil microbial health, these herbicides and pesticides are epigenetically active [24] and affect the humoral immune and endocrine systems [25] besides carcinogenic and mutagenic effects on human beings coming in contact with these.

The pesticides belonging to the Organophosphates and carbamates group affect the nervous system. Others may irritate the skin or eye. Some pesticides may be carcinogens. Others may affect the hormone or endocrine system in the body. Any harmful effects that occur from small doses repeated over a period of time are termed "chronic effects". Suspected chronic effects from exposure to certain pesticides include birth defects, toxicity to the fetus, production of benign or malignant tumors, genetic changes,

blood disorders, nerve disorders, and endocrine disorders. Long-term pesticide exposure has been linked to the development of Parkinson's disease, asthma, depression, anxiety, Attention Deficit and Hyperactivity Disorder (ADHD); and cancer including leukemia and non-Hodgkin's lymphoma, cancer of the brain, breast, prostate, testes and ovaries. Reproductive harm from pesticides includes birth defects, stillbirth, spontaneous abortion, sterility, and infertility (www.beyond pesticide.org).

Therefore, the minimal use of these inputs in the agricultural production system is necessary to save lives in the soil and above the soil. The production of these inputs has an adverse effect on the environment and is a concern for climate change. The use of fertilizers in agriculture can also contribute to environmental pollution. The synthesis of N-fertilizers contributes significantly to the production of Greenhouse Gases (GHG) and nitrogenous fertilizers are the largest single source of GHG emission from arable agriculture [26]. The use of N and P-fertilizers in agriculture is a major contributor to eutrophication processes in the water of both developed and developing nations [27,28]. To minimize the use of inorganic fertilizers, and pesticides including herbicides in the crop production system, a concept of recycling plant nutrients from the available farm resources, for maintaining soil microbial health, and crop productivity is proposed that may indirectly help to deter the process of climate change by the minimal use of inorganic farm inputs produced through the industrial process.

Concept

All plant including weeds accumulates different nutrients in their plant parts for their growth and the ultimate plant produce. Seeds being the end product in most crop plants, a certain amount of these nutrients are stored in seeds while the major portion of nutrients are left in the plant parts themselves or in crop plant residues. Ana Cervera-Mata et al. [29] analysed the different nutrient content of 60 plant seeds belonging to 48 species and 9 families of plants and observed various ranges of these nutrient contents in the seed (Table 2). Besides the amount of nutrient content in seed, certain amounts of nutrients are always present in all other plant parts of the crop or crop residues. If these nutrients in the leftover crop or crop residues are used, we can save a reasonable quantity of fertilizers in crop production. The Research on saving fertilizers via replacement of nutrients through crop residue indicated [30] that nitrogen fertilizer to the tune of 5 to 18% can be saved whereas phosphate fertilizer to the tune of 2 to 9% can be saved and the fertilizer saving percentage depends on crop plant (Table 3).

Table 2: The range of ultimate nutrient content accumulated in seed by plants.

Nutrient Content	g/100g Dry Weight	Remarks
Starch	11.3 to 84.0	
Protein	1.6 to 68.5	
Fat	0.7 to 44.2	
Total Polyphenols	0.01 to 3.85	
Mineral content	0.67 to 4.91	the most abundant mineral elements were P, S, K, Mg, Ca and Zn.

Table 3: Saving of fertilizers via replacement of nutrients through crop residue.

Crop Residues of	Saving of Nitrogen Fertilizer (%)	Saving of Phosphate Fertilizer (%)
Maize	5.6	2.4
Rice	18.4	8.3
Rapeseed	11.2	3
Wheat	14.8	9.2

Source: Yong Luo et al. [30].

For crop plant growth the requirement of major, minor, and trace nutrient elements are in low quantities as indicated in Table 4 for different nutrient elements. A sufficient quantity of these nutrient elements is required for plant growth and any concentration above this sufficiency level is toxic to the plant thereby exhibiting toxicity symptoms [31]. The plant can't retain the nutrients above the sufficiency level, and therefore the excess amount applied is of no use to the plant system, are financial burden to the farmers, and a toxicity burden to the crop soil and environment. In this scenario, one must understand that the particular nutrient content in a plant has to be maintained at a critical leaf concentration level or sufficiency level and this amount of plant nutrients can be made available through plant nutrient recycling.

Table 4: Critical leaf concentration for sufficiency & toxicity of mineral elements in non-tolerant crop plant.

Nutrient Element	Critical Leaf Concentration (mg/g DM) of Nutrient for	
	Sufficiency	Toxicity
Nitrogen	15-40	
Potassium	5-40	≥50
Phosphorus	2-5	≥10
Calcium	0.5-1.0	≥100
Magnesium	1.5-3.5	≥15
Sulphur	1.0-5.0	
Boron	5-100×10 ⁻³	0.1-1.0
Iron	50-50×10 ⁻³	≥0.5
Manganese	10-20×10 ⁻³	0.2-5.3
Copper	1-5×10 ⁻³	15-30×10 ⁻³
Zinc	15-30×10 ⁻³	100-300×10 ⁻³
Molybdenum	0.1-1.0×10 ⁻³	1
Sodium	yes	2-5

Source: White PJ, Brown PH [31].

The important components of plant nutrient recycling are:

Use of cow urine as a source of plant nutrient

Cow urine is a source of various plant nutrients (Table 5) which can be used in crop production to minimize the use of inorganic fertilizers [32]. Generally, a healthy cow passes 10-15L of urine a day while urinating 10-12 times a day. Thus, in a crop season of 3 months, a single cow can give 1500L urine which can be used as a source of plant nutrients by fortnightly/monthly spray application in a hectare crop.

Table 5: Mineral content of cow urine.

Average Content	In Percent	Remark
Water	95	
Urea	2.5	
Enzymes	2.5	Urokinase, phosphatase, lactate dehydrogenase etc
Nitrogen	6.8 to 21.6g/L	
Minerals/salts		
sodium	7605.9ppb	
calcium	1311.9ppb	
Iron	19.5ppb	
magnesium	24836.9ppb	
potassium	3230193.1ppb	
Zinc	81.3ppb	
phosphorus		
maganese		
potash		
amonia		
sulfur		
Amino acids		
Lactose		
cytokine		
Aurum hydroxide		Improve immunity
Allantoin		Promote wound healing
Hormones	traces	

Source: Satyapal Singh [32].

Use of cow dung slurry as a source of plant nutrients

Cow dung contains nitrogen, phosphorus, and potassium as well as micronutrients like magnesium, manganese, calcium, zinc, copper, and trace minerals [33]. The ratio of major nutrient content

in cow dung is often expressed as 3:2:1 NPK meaning 3% nitrogen, 2% phosphorus, and 1% potassium. Cow dung is also a rich source of ammonia, carbon, and nitrogen. It also contains difficult to hydrolyse substrates like cellulose, hemicellulose, and lignin which can be broken down by microbial activity. The C: N ratio of cow dung (Table 6) is 18-21.7:1 while that of sheep dung is 29:1 [34]. The average cow produces around 18-30kg of dung in a day [35]. Thus, 1800kg of dung can be procured from a cow during a crop period of 3 months. If cow dung slurry is made @ 5%, then the quantity of cow dung slurry will be 36000L with ferment probiotics which is sufficient for fortnightly/monthly soil application for a hectare crop.

Table 6: Mineral content of Cow dung.

Average Content	Percent
Organic carbon	29.7
Nitrogen	1.65
Phosphorus	0.5
C:N ratio	18

Source: Lima & Dhar [34].

Use of crop residues as a source of plant nutrients

The plant nutrients available in plants after crop grain harvest can be returned to field-soil through crop root. 44.6%, 48.2%, and 43.4% of Carbon, nitrogen, and phosphorus respectively can be returned to soil through crop roots while some percentage of these nutrients remains in crop residues (Table 7) which can also be recycled through a probiotic fermentation process [36]. The quantity of these nutrients in the residues varies and depends on the crop. Most crop residues are not recycled for these nutrients through the probiotic ferment process and are generally burnt, thereby losing the available and valuable nutrients in these. Cereal crops (rice, wheat, maize, and millet) account for 70 percent of the total crop residue. Of this, 34% comes from rice and 22% from wheat crop, most of which is burnt on the farm.

Table 7: Presence of nutrients in crop residues (lb.t⁻¹).

Crop Residue of	Available Nitrogen	Available Phosphorus	Available Potassium	Available Sulphur
Rice	20 (9.08kg)	6 (2.72kg)	41 (18.61kg)	4 (1.81kg)
Corn	20 (9.08kg)	6 (2.72kg)	40 (18.16kg)	3 (1.36kg)
Soyabean	40 (18.16kg)	9 (4.08kg)	37 (16.79kg)	6 (2.72kg)
Peanut	34 (15.43kg)	7 (3.17kg)	24 (10.89kg)	5 (2.27kg)
Wheat	15 (6.81kg)	4 (1.81kg)	30 (13.62kg)	6 (2.72kg)
Grain sorghum	30 (13.62kg)	8 (3.63kg)	45 (20.43kg)	6 (2.72kg)

Source: Trend Roberts [36]. Arkansas Row crop blog. (numbers in bracket are converted values in kg).

According to estimates, 20 million tonnes of rice stubble is produced every year in Punjab, India, alone and, 80% of which is burnt. According to a report, one-tonne stubble burning leads to a loss of 5.5kg nitrogen, 2.3kg P, and 25kg K and more than 1kg of sulfur as soil nutrients, besides organic carbon. Yadav [37] reported that more than 500 million tonnes of crop residues are produced annually in India. The burning of crop residues not only loses the available plant nutrients but also is a source of environmental

pollution. A study estimates that crop residue burning released 149.24 million tonnes of Carbon Dioxide (CO₂), over 9 million tonnes of Carbon Monoxide (CO), 0.25 million tonnes of oxides of sulfur (SOX), 1.28 million tonnes of particulate matter and 0.07 million tonnes of black carbon. These directly contribute to environmental pollution, and in India are responsible for the haze in Delhi and the melting of Himalayan glaciers. In another report by Abdurrahman et al. [38] the burning of 63Mt of crop stubble releases 3.4Mt of

CO, 0.1 Mt of NO_x, 91Mt of CO₂, 0.6Mt of CH₄, and 1.2Mt of PM into the atmosphere. Air pollution due to stubble burning harms public health. According to a study by the Institute for Social and Economic Change, Bengaluru, people in rural Punjab spend Rs 7.6 crore yearly on treatment for ailments caused by stubble burning. Thus, it is a concern for public and environmental health besides plant nutrient losses.

Furthermore, the heat generated during stubble burning harms soil ecology. The heat produced during paddy straw burning, penetrates 1 centimetre into the soil, elevating the soil temperature by 9 °C (from 33.8 to 42.2 °C). This rise in soil temperature kills the bacterial and fungal populations critical for fertile soil. Burning of crop residue causes damage to other micro-organisms present in the upper layer of the soil as well as its organic quality. Due to the loss of friendly pests, the wrath of enemy pests increases and as a result, crops are more prone to pests/diseases. The solubility capacity of the upper layer of soil is also reduced. Rice cultivation produces large amounts of straw as residues, with one hectare of rice generating approximately 5 tons of residues [39] which may contain 45kg N, 13Kg P, 90Kg K, and 7kg S approximately, which is lost due to non-recycling of plant nutrients. It was estimated that about 352Mt of stubble is generated each year in India out of which 22% and 34% are contributed by wheat and rice stubble respectively. About 84Mt (23.86%) of the stubble is burnt on-field each year immediately after harvest losing a huge amount of plant nutrients, otherwise to be recycled and made available for crop cultivation.

Use of weeds in recycling plant nutrients

Weeds are a group of unwanted plant species growing in sown

crop plants, horticultural plantations, or in the barrow land with various intensities. The density (no. of weed plants) and frequency of weed plants varies with the area and crop grown. Tesfay et al. [40] observed 170.93g weed/sqM and 382.13g weed/sqM in maize crops at Guder and Ambo locations respectively in west Shewa Oromia in Ethiopia. Ustuner [41] reported variations in weed density, frequency, and covering area in cherry orchards in different districts in Turkey and the variation in weed densities (weed/sqM) among the different districts were 76.61 (in Afsin), 166.72 (in Andirin), 72.04 (in Caglayancerit), 139.37 (in Dulkadiroglu), 74.54 (in Ekinozu), 76.65 (in Elbistan), 125.88 (in Goksun), 49.64 (in Nurhak), 104.16 (in Onikisubat), 51.40 (in Pazarcik), and 81.46 (in Turkoglu). Meghana et al. [42] reported weed densities of 4.59, 4.67, and 4.69/sq M which was equivalent to weed dry weight of 9.00, 7.00, and 3.71g/sq M at 30, 45 days after sowing and at harvest respectively. Jangir et al. [43] reported weed densities of 30.60, 47.53, and 74.93/sq M at 20 DAS, 40 DAS, and at harvest in the mustard crop. These weed plants, although not required in sown/cultivated crop plants, accumulated a large quantum of plant nutrients in them during their growth.

Qasem [44] reported that weeds were better nutrient accumulators than the main tomato and bean crops in the studies. The percentage of N, P, K, and Mg in shoots of most weed species was higher than in main crop plants. Weeds associated with beans accumulated more P in roots than did bean crop plants, and weeds grown in tomato fields contained a higher percentage of P and K than the tomato crop itself. Weeds varied substantially in their shoot and root percentage of mineral elements and differences in nutrient percentages between shoots and roots of weeds were greater than the crop plants (Table 8).

Table 8: Nutrient accumulation by weed in its plant parts as compared to the main crop.

Crop/Weed	Plant Parts									
	Shoot					Root				
	Range of Nutrients (Mean Percentage on Oven-Dry Basis)									
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Bean	2.69	0.38	2.88	2.09	0.44	3.12	0.13	8.6	1.22	0.44
Weed therein	2.94-5.18	0.41-0.72	3.06-5.34	2.10-2.44	0.48-1.07	3.18	0.15-0.75	8.6	1.43	0.50-0.72
Tomato	3.61	0.38	3.78	2.91	0.97	1.96	0.22	1.88	1.23	0.53
Weed therein	3.72-4.56	0.45-0.59	3.96-5.40	1.60-1.97	1.10-1.15	1.96-2.72	0.33-0.50	1.90-4.20	0.9	0.69

Source: Qasem JR [44].

The weeds in bean plants were *Beta vulgaris*, *Rumex obtusifolius*, *Cichorium pumilum*, *Malva sylvestris*, *Ammi majus*, *Chenopodium murale*, *Solanum nigrum*, *Sonchus oleracea*, *Portulaca oleracea*, *Anagallis arvensis*, *Sisymbrium irio*, *Sinapis alba*, *Amaranthus graecizans*, *Echinochla colonum* and *Centaurea iberica* while the weeds in tomato plants were *Cichorium pumilum*, *Malva sylvestris*, *Chenopodium murale*, *Sonchus oleraceus*, *Portulaca oleracea*, *Sisymbrium irio*, *Centaurea iberica*, and *Rumex obtusifolius*. *Malva sylvestris*, *Chenopodium murale*, *Portulaca oleracea* and *Rumex obtusifolius* were the nutrient accumulator weeds. These nutrients

are like gold in the waste since these weeds are either killed by herbicides or removed manually to throw away and burn. These nutrients available in the weed or weed residues are never been thought of to be used in the agricultural production system. On the contrary, these weeds are killed by herbicides, hazardous to human health and soil microbial health. Based on weed weight/sq M, as mentioned by Tesfay [40], it can be assumed that weeds in the range of 687-1545kg/acre can be procured which may contain 40kg N, 3Kg P, and 20Kg K besides minor and trace elements which can be recycled for their agricultural crop production use.

Use of natural waste ferments in agricultural crop production

Since Cow dung, cow urine, plant residues, and weeds are rich sources of plant nutrients, these can be used for plant nutrient recycling through the process of making their ferments to derive the plant nutrients available in them. The use of plant probiotics [4,5,45], animal probiotics, and human probiotics [46] can be employed in this task. More research on the preparation of these plant nutrient-recycling ferments for plant nutrient procurements is needed to have a pesticide, herbicide residue-free organic food product. This is more meaningful for the world population and agriculture, to save the world's natural and economic resources for agricultural production and to help minimize the process of climate change.

References

- MacNicol RD, Beckett PHT (1985) Critical tissue concentration of potentially toxic elements. *Plant and Soil* 85: 107-129.
- Marschner H (1995) Mineral nutrition of higher plants. (2nd edn), Academic Press, London, UK.
- Mengel K, Kirkby EA, Kosegarten H, Appel T (2001) Principles of plant nutrition. Kluwer Academic Publishers, Dordrecht, Netherlands.
- Borkar SG, PN Pardhi, Ajayasree TS (2024) Lactic Acid Bacteria (LAB) and its curd, as a Low-cost input for plant growth promotion activity in tomato crop. *Environmental Analysis and Ecology Studies* 11(4): 1301-1307.
- Borkar SG, Reddy P, Ajayasree TS (2024) *Bacillus subtilis*, a bacterial inhabitant in calcareous soil and its ability to demineralize fixed Fe and Zn salt in its habitat. *GSC Advanced Research and Reviews* 18(1): 001-009.
- Robertson GP, Vitousek PM (2009) Nitrogen in agriculture: Balancing the cost of an essential resource. *Annu Rev Environ Resources* 34: 97-125.
- LeBauer DS, Treseder KK (2008) Nitrogen limitation to net primary production in terrestrial ecosystems is globally distributed. *Ecology* 89: 371-379.
- Olumuyiwa IO, BI Olajire-Ajayi OV Dada, OM Wahab (2015) Effect of fertilizers on soil's microbial growth and population: A review. *American J Engineering Res* 4(7): 52-61.
- Ge Y, JB Zhang, LM Zhang, M Yang, JZ He (2008) Long-term fertilization regimes affect bacterial community structure and diversity of agricultural soil in northern China. *J Soil Sedi* 8: 43-50.
- Ren N, Y Wang, Y Ye, Y Zhao, Y Huang (2020) Effect of continuous nitrogen fertilizer application on the diversity and composition of Rhizosphere soil. *Front Microbiol* 11: 1948.
- Jayaseelan A, K Murugesan, S Thayanithi, SB Palanisamy (2024) A review of the impact of herbicides and insecticides on the microbial communities. *Environmental Research* 245: 118020.
- Kalia A, SK Gosal (2011) Effect of pesticide application on soil microorganisms. *Archives of Agronomy and Soil Science* 57(6): 569-596.
- Nielsen UN, DH Wall, J Six (2015) Soil biodiversity and the environment. *Annual Review of Environment and Resources* 40: 63-90.
- Orgiazzi A, RD Bardgett, E Barrios, Behan-Pelletier V, JI Briones, et al. (2016) Global soil biodiversity atlas. Supporting the EU Biodiversity strategy and the global soil biodiversity initiative: Preserving soil organisms through sustainable land management practices and environment policies for the protection and enhancement of ecosystem services. Global Soil Biodiversity Initiative.
- Clarholm M (1985) Interaction of bacteria, protozoa and plants leading to mineralization of soil nitrogen. *Soil Biology and Biochemistry* 17(2): 181-187.
- Woods LE, CV Cole, ET Elliott, RV Anderson, DC Coleman (1982) Nitrogen transformations in soil as affected by bacterial-microfaunal interactions. *Soil Biology and Biochemistry* 14(2): 93-98.
- Schaeffer A, W Amelung, H Hollert, M Kaestner, E Kandeler, et al. (2016) The impact of chemical pollution on the resilience of soils under multiple stresses: A conceptual framework for future research. *Science of the Total Environment* 568: 1076-1085.
- Fernandez D, K Voss, M Bundschuh, JP Zubrod, RB Schafer (2015) Effects of fungicides on decomposer communities and litter decomposition in vineyard streams. *Science of the Total Environment* 533: 40-48.
- Arthur E, P Moldrup, M Holmstrup, P Schjonning, A Winding, et al. (2012) Soil microbial and physical properties and their relations along a steep copper gradient. *Agriculture, Ecosystems and Environment* 159: 9-18.
- Prasad Reddy B, Dhanaraj P, Narayana Rao V (1984) Effect of insecticide on soil microorganisms. In: Lal R (Ed.), *Insecticide Microbiology*, Springer, Germany, pp. 169-201.
- FAO (2022) Pesticide use, pesticide trade and pesticide indicators. Global regional and country trends 1990-2020, FAOSTAT Analytical Brief 46, FAO, Italy.
- Sim JXF, Drigo B, Doolette CL, Vasileiadis S, Donner E, et al. (2023) Repeated application of fipronil, propyzamide, and flutriafol affect soil microbial functions and community composition: A laboratory-to-field assessment. *Chemosphere* 331: 138850.
- Adhikary P, Shil S, Patra PS (2014) Effect of herbicide on soil microorganism in transplanted chili. *Global J of Biology, Agriculture & Health Sciences* 3(1): 236-238.
- Bukowska B, Wozniak E, Sicinska P, Mokra K, Michatowicz J (2022) Glyphosate disturbs various epigenetic process *in vitro* and *in vivo*-A mini-review. *Science of the Total Environment* 851(Pt 2): 158259.
- Cestonaro LV, Macedo SMD, Piton YV, Garcia SC, Arbo MD (2022) Toxic effects of pesticides on cellular and humoral immunity: An overview. *Immunopharmacol Immunotoxicol* 44(6): 816-831.
- Thirunagari BK, Kancheti M, Kumar R, Kota SH (2024) Managing synthetic N-fertilizer emission in India: Insights from field survey across 102 districts. *Journal of Environmental Management* 366: 121909.
- Conley DJ, Paerl HW, Howarth RW, Boesch DF, Seitzinger SP, et al. (2009) Ecology. Controlling eutrophication: Nitrogen and Phosphorus. *Science* 323(5917): 1014-1015.
- White PJ, Hammond JP (2009) The sources of phosphorus in the waters of Great Britain. *Journal of Environmental Quality* 38(1): 13-16.
- Ana Cervera-Mata, Sahu PK, Chakradhari S, Sahu YK, Patel KS, et al. (2021) Plant seeds as source of nutrients and phytochemicals for the Indian population. *International J Food Science & Technology* 57(1): 525-532.
- Yong Luo, Chen D, Wang X (2023) Assessment of crop residues and corresponding nutrient return to the field via root, stubble, and straw in southwest China. *Sustainability* 15(20):15138.
- White PJ, Brown PH (2010) Plant nutrition for sustainable development and global health. *Ann Bot* 105(7): 1073-1080.
- Satyapal Sing (2019) Biochemical appraisal of cow urine. *J Pharmacognosy and Phytochemistry* 8(3): 4089-4092.
- Fulhage CD (2000) Reduce environmental problems with proper land application of animal manure. University of Missouri Extension, Columbia, Missouri, USA.
- Lima A, Dhar VM (2022) Physical properties of cattle dung. *The Pharma Innovation Journal* 11(1): 399-402.

35. Parihar SS, Saini KPS, Lakhani GP, Jain A, Roy B, et al. (2019) Livestock waste management: A review. *Journal of Entomology and Zoology Studies* 7(3): 384-393.
36. Trent Roberts (2024) Residue burning in field crops. Arkansas Row Crops, Div of Agri Res Extn, University of Arkansas, USA.
37. Yadav RS (2019) Stubble burning: A problem for the environment, agriculture, and humans. *Down To Earth*.
38. Abdurrahman MA, Chaki S, Saini G (2020) Stubble burning: Effects on health and environment, regulations and management practices. *Environmental Advances* 2: 100011.
39. Sen SM (2024) Is there a way out of rice stubble burning? Dr. Reddy's Foundation.org
40. Tesfay A, Amin M, Mulugeta N, Frehiwot SW (2014) Effect of weed control methods on weed density and maize yield in west Shewa Oromia, Ethiopia. *African Journal of Plant Science* 8(12): 528-536.
41. Ustuner T (2019) Determination of weed species, their frequency, and densities in cherry orchards in Kahramanmaraş province, Turkey. *Mustafa Kemal University Journal of Agricultural Sciences* 24(3): 198-209.
42. Meghana GK, Sukanya TS, Salman Khan RM, Kiran HP (2020) Effect of weed management practices on weed density, dry weight, and growth of Kodo millet (*Paspalum scrobiculatum*). *International J Curr Microbiol App Sci* 9(11): 3377-3384.
43. Jangir R, Arvadia LK, Tajane D, Saini LK (2022) Weed density, relative weed density, weed indices and yield of mustard as influenced by planting geometry and weed management practices. *Ann Agric Res New Series* 43(3): 302-310.
44. Qasem JR (1992) Nutrient accumulation by weeds and their associated vegetable crop. *Journal of Horticultural Science*. 67(2): 189-195.
45. Srilatha P, Borkar SG (2017) Probiotics: A new approach for post-harvest disease management and quality retention in grapes. *Agriculture Update* 12: 1-8.
46. Borkar SG (2023) Human gut microbes assisted agricultural food production for better human health: A new concept. *Biomedical Journal of Scientific & Technical Research* 48(3): 007655.