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NUTRIENT MINERALIZATION DYNAMICS IN ORGANIC MANURES: A COMPREHENSIVE REVIEW

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ABSTRACT

Nutrient mineralization in organic manures is a fundamental process in sustainable agriculture, contributing significantly to soil fertility and plant nutrition. Nutrient mineralization in organic manures refers to the process by which nutrients bound within organic materials, such as animal manure or compost, which are converted into forms that are readily available for plant uptake. The process of nutrient mineralization involves the microbial decomposition of organic matter present in manures, leading to the liberation of essential nutrients crucial for plant growth and soil health. Nitrogen, phosphorus, potassium, sulphur and micronutrients are among the key nutrients released during this process. Microbial communities play a vital role in breaking down complex organic compounds into simpler forms, thus making nutrients accessible for plant uptake. Several environmental and biological factors significantly influence the rate and efficiency of nutrient mineralization. Temperature, moisture content, oxygen availability, carbon-to-nitrogen ratio, particle size, pH levels and the composition of organic materials plays a critical role in shaping the dynamics of this process. Understanding and managing these factors are essential for optimizing nutrient availability in agricultural systems. Furthermore, different types of organic materials, such as animal manures and compost, exhibit distinct nutrient compositions and decomposition rates, thereby necessitating customized management strategies. Proper utilization of organic manures not only enhances soil fertility and crop productivity but also reduces reliance on synthetic fertilizers, mitigates nutrient runoff and support the ecosystem resilience.

Key words : Mineralization, Organic Manures, Nitrogen, Phosphorus, Potassium.

Introduction

The present Indian population is 1.42 billion and it is expected to reach 1.5 billion by 2030 and 1.67 billion by 2050. Whereas, the present Indian food grain production is 330 MT and it is need to increase the food grain production up to 400 MT to meet the food requirement. The world's population is projected to be 9.7 billion by 2050, consequently, food production has to increase by 60 per cent from contemporary production levels to fulfil the nutritious need of the billions of people (Anonymous, 2022). The highest rise of the population will be in the developing countries, where people are facing major

challenges in socio-economic, food insecurity and poverty. Thereby, today's agriculture sector needs to produce higher yield and food grain production. The world's population is increasing day by day but the per capita arable land is decreasing and it is necessary to increase the food production per unit time and per unit space in order to attain the food security and nutritional security. Green revolution has increased food grain production by four-fold since 1950-51 with adoption of HYVs, intensive input use, extensive tillage. The discriminate use of chemical fertilizers has led to degradation of natural resources such as soil, water, vegetation etc. So, we have

to produce more food from less land through more efficient use of natural resources and minimum impact on environment. In order to avoid land degradation and also attaining the food and nutrition security we have to provide the production resources for the growth and development of the crop plants.

Production resources

Soil : Which supports the root system and supply the essential nutrients required by the crop plants.

Water : It helps for the maintenance of body temperature of the plant and also for photosynthesis – to produce photosynthates and which are effectively transported to the sink from source. And it also helps in nutrient transport from soil to plant body.

Seed : primary production resource, healthy seeds result in higher yield of the crop.

Agrochemicals : Which required for the effective control of weeds, insect pest and diseases in order to minimize the losses due to these pests.

Fertilizers and Manures : These provide the essential nutrients required for the growth of the crops.

Sources of Nutrients to Soil

- ❖ Rain water
- ❖ Fertilizers
- ❖ Biofertilizers
- ❖ Crop residues
- ❖ Green manures
- ❖ Organic Manures

Organic manures

The word manure derived from the French word “Manoeuvrer” means to manipulate, to work, to produce crop. Organic manures which are organic in origin, bulky and concentrated in nature, capable of supplying plant nutrients, improving soil physical environment having no definite chemical composition and Low analytical value, produced from animal, plant and other organic wastes and by products.

Organic nutrient sources

Bulky Organic Manures

- ❖ FYM
- ❖ Compost (rural and urban)
- ❖ Green manure
- ❖ Vermicompost
- ❖ Sheep and goat manures
- ❖ Poultry manures

Table 1 : Potential organic resources available in India.

Organic resources	Quantity (million tonnes) 2015	Quantity (million tonnes) 2025
Crop residues	343	496
Livestock wastes	396	426
Human excreta	18.5	24
	2000	2050
Urban / rural wastes	10	50
Green manures	25	50
Agro- industrial wastes		
Rice husk	15	
Press mud	2	
Saw dust	2.2	
Oil cakes	0.3	
Biofertilizers	1.2 (2003- 2004)	

- ❖ Sewage and sledges

Concentrated Organic Manures

Plant based concentrated Organic Manures

- ❖ Oil cakes (Edible and Non edible)

Animal based concentrated Organic manures

- ❖ Blood meal
- ❖ Meat meal
- ❖ Fish meal
- ❖ Steamed bone meal
- ❖ Raw bone meal

Liquid Organic Manures

- ❖ Panchagavya
- ❖ sasyagavya
- ❖ Jeevamruth
- ❖ Bijamrita
- ❖ Sanjivak
- ❖ Amritpani
- ❖ Kunapajal
- ❖ Vermiwash
- ❖ Seaweed Extract

Mineralization

Mineralization term refers to the process of decomposition of organic matters by microorganisms to release nitrogen, sulphur, phosphorus and other inorganic compounds that can be readily assimilated by plants.

- Increases the bioavailability of nutrients
- Enhances the growth and yield of the crop

Table 2 : Nutrient composition of different organic sources.

NPK content of commonly used manures/compost			
Manure/compost	% N	% P	% K
FYM	0.5	0.2	0.5
Compost	0.5	0.2	0.5
Vermicompost	3	1	1.5
Sheep-goat manure	3	1	2
Poultry manure (Richest)	3	1	1.5
Biogas slurry	1.8	1	1
Night soil	5.5	4	2

Table 3 : Nutrient composition of different oil cakes.

Oil cakes	% N	% P ₂ O ₅	% K ₂ O
Non -edible oil			
Castor cake	4.3	1.8	1.3
Cotton seed cake (Uncorticated)	3.9	1.8	1.6
Karanj cake	3.9	0.9	1.2
Mahua cake	2.5	0.8	1.2
Safflower cake (Uncorticated)	4.9	1.4	1.2
Edible oil cakes			
Coconut cake	3.0	1.9	1.8
Cotton seed cake	6.4	2.9	2.2
Groundnut cake	7.3	1.5	1.3
Linseed cake	4.9	1.4	1.3
Niger cake	4.7	1.8	1.3
Rape seed cake	5.2	1.8	1.2
Safflower cake (Decorticated)	7.9	2.2	1.9
Sesamum cake	6.2	2.0	1.2

Immobilization

Immobilization is the conversion of inorganic compounds to organic compounds by microorganisms or plants by which the compounds become inaccessible to plants

Mineralization process

Decomposition is the process of breaking complex organic matter into simpler inorganic matter. There are five steps of decomposition.

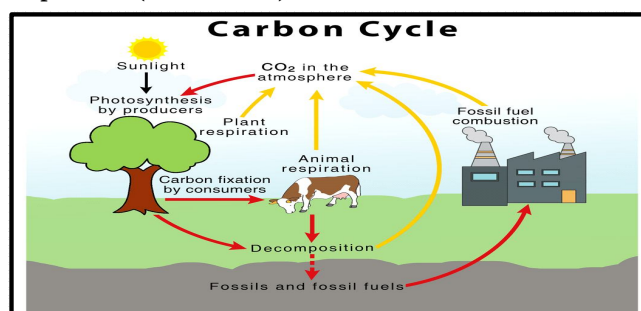
- **Fragmentation:** During the fragmentation process, the breaking of detritus into little pieces by detritivores.
- **Leaching:** Leaching is the process of releasing nutrients in the water and seeping into the soil.

Nutrient values of different crop residues			
Crop residue	% N	% P	% K
Rice	0.42	0.066	0.65
Sorghum	0.21	0.086	0.33
Maize	0.21	0.060	0.83
Finger millet	1.40	0.120	0.66
Foxtail millet	0.98	0.070	0.17

- **Catabolism:** Catabolism is the process of breaking down complex molecules into simpler molecules.
- **Humification:** The process of the formation of dark-colored humus on the soil is called humification.
- **Mineralization:** Mineralization is the process of degradation of the hummus to release inorganic nutrients.

Mineralization of nutrients from organic manures

Mineralization of carbon : The CO₂ in the atmosphere was contributed by the industries by burning of fossil fuels and also by respiration of animal and plants. The CO₂ in the atmosphere was absorbed by the crop plants for the photosynthesis in the presences of sunlight and water and that is converted into energy. After completion of life cycle of the plant it will add huge biomass to the soil. Upon decomposition of the biomass the is CO₂ released into the atmosphere by the microbial respiration (Bolin, 1970).

**Fig. 1 :** Carbon Cycle.

Basak and Biswas (2014) reported that the application of 50 per cent RDF + vermicompost @ 5 t ha⁻¹ recorded significantly higher carbon mineralization (86.6 mg 100 g⁻¹ of soil) and lower in absolute control (47.5 mg 100g⁻¹ of soil). Carbon mineralization in soil occurs mainly due to decomposition of organic matter by soil microbes (Gaudel *et al*, 2024). Application of integrated sources of organic manures and fertilizers provide the optimum supply of nutrients for microbial activity, which, in turn

resulted in greater C mineralization in soil over the soils amended with either organic manures or 100% NPK. Blending with fertilizer-N may change the net mineralization of compost-N because N fertilization lowers the C: N ratio of the soil, thereby, enhances the mineralization (Liu *et al.*, 2024).

Integrated application of value-added organic manures and chemical fertilizers showed higher C mineralization than 100% recommended dose of fertilizers, while the latter was found superior over soil amended with organic manures alone (Adhikari *et al.*, 2022). Substrates like organic manure as well as mineral nutrients are equally important for proliferation of microbial activity in soil which is the key factor of CO₂ evolution as a result of organic matter decomposition (Basak *et al.*, 2012). In the integrated source of input provides the optimum supply of nutrients for microbial activity which could be the reason for higher C mineralization in soil amended with both organic manures and chemical fertilizers than soils amended with organic manures alone (Howe *et al.*, 2024).

Basak and Biswas (2014) also reported that irrespective of treatments, moisture regimes and incubation periods, the mean C mineralization increased significantly from 63.6 to 73.4 mg CO₂ 100 g⁻¹ soil *i.e.* 15.4 per cent when temperature was increased from 20 to 35°C. On the other hand, C mineralization increased from 50.1 to 86.8 mg CO₂ 100 g⁻¹ soil *i.e.* by 73.3 per cent when moisture regime was maintained at 1.0 and 0.33 bar (field capacity), respectively. This may be attributed to increase in microbial respiration with increase in temperature (Cruz-Paredes *et al.*, 2021). Higher temperature may enhance mineralization by stimulating microbial activity and accelerating diffusion of soluble substrates in soil. It is found that an increase in temperature also induces a shift in the composition of microbial communities, which results an increase in microbial activity (Xu *et al.*, 2023). Across the incubation periods and treatments, CO₂ evolution increased as the moisture content shifted from 1.0 bar to field capacity (Dong *et al.*, 2014). Heterotrophic bacteria and fungi mostly take part in the mineralization process of organic materials (Wang and Kuzyakov, 2024). Soil moisture plays an important role in oxygen diffusion in soil with maximum aerobic microbial activity occurring at soil moisture levels between 50 and 70% of water holding capacity (Neira *et al.*, 2015). On the other hand, diffusion of soluble substrates will be reduced at low soil moisture which will inhibit microbial activity, microbial mobility and intracellular water potential (Bian *et al.*, 2022).

Lavanya *et al.* (2023) reported that the application of 100 per cent NPK + FYM 15 t ha⁻¹ + lime recorded significantly higher carbon mineralization (820 µg g⁻¹ of soil), which was on par with the application of 100 per cent NPK + FYM 15 t ha⁻¹ (802 µg g⁻¹ of soil) and lower in absolute control (250 µg g⁻¹ of soil) in finger millet-maize cropping system in *Alfisols*. This might be due to the long-term extraneous application of balanced fertilizer (100% NPK) that could prevent the depletion of soil nutrients and at the same time maintained higher level of organic carbon through recycling of root biomass which facilitated the growth of microbes (Rudrappa *et al.*, 2006). The higher mineralization due to the combined application of FYM and NPK fertilizer is attributable to a higher turnover of root biomass produced under the FYM + NPK treatment (Kaur *et al.*, 2009). Integrated application of chemical fertilizer and organic manures apart from creating favorable environment for growth and activity of microorganisms also provided substrates for the mineralization processes (Lu *et al.*, 2023). Low mineralization in the control treatment is because of unfavorable environment arising out of depletion of nutrients due to continuous cropping without any fertilization (Kartini *et al.*, 2024).

Islam *et al.* (2021) reported that the application of mung bean residues recorded significantly higher carbon mineralization (216.9 mg g⁻¹ manure), followed by cow dung (146.7 mg g⁻¹ manure) and lower in cow dung slurry (34.5 mg g⁻¹ manure). The overall results indicate that mung bean was more responsive to C mineralization followed by cow dung and poultry manure considering mineralization potential values (Islam *et al.*, 2021). The cumulative C mineralization at various time intervals varied for different levels of C. Between cattle and poultry sources, cumulative C mineralization was lower in slurry compared to their original. The reason can be attributed to the slurry production after extraction of biogas (chiefly CH₄) resulting in a comparatively stable state for C mineralization (Gale and Gilmour, 1986). The cumulative CO₂ flux was lower in the poultry manure than in the cow dung treatments because poultry manure decayed more slowly than cow dung (Naher *et al.*, 2004). The higher C mineralization in mung bean might be due to the higher concentration of nitrogen and lower C:N ratio leads to more decomposition and higher C mineralization (Datta *et al.*, 2019).

Benito *et al.* (2005) reported that at the end of the incubation period, the carbon mineralization rate was 682, 391, 331 and 332 mg C kg⁻¹ day⁻¹ for C₁, C₂, C₃ and C₄, respectively. This might be due to the high concentration of readily degradable carbon in the freshest material (C₁)

led to high microbial activity (Butler *et al*, 2001). A fraction whose labile organic compounds are rapidly mineralizable during the first step and another fraction with slow mineralization, which is more resistant to microbial attack. This expresses the idea that recalcitrant fractions of residues remain after the initial period of decomposition (Hadas and Portnoy, 1994).

Jakhar *et al* (2006) reported that the application of pigeon pea crop residue recorded significantly higher carbon mineralization (72.80%) and lower in cowpea (53.90%) at 56 days after incubation study. The higher carbon mineralization in pigeon pea might be due to the higher concentration of nitrogen and lower C:N ratio leads to more decomposition and higher C mineralization (Lynch *et al*, 2016).

Saikat (2022) reported that higher carbon mineralization recorded in in rice residues, dhaincha, biochar and FYM showed 90.4, 78, 14.4 and 12.7 per cent more as compared to soil respectively. Highest carbon mineralization was recorded in rice residue followed by Dhaincha, biochar and FYM. This result is expected due to rapid mineralization of readily hydrolysable carbon (C) of organic residues like rice residue and Dhaincha (Liyanage *et al*, 2021). FYM and biochar amended soil showed significantly lower amount of C mineralization as it contains lower amount of easily hydrolysable carbon to be mineralized as compared to other organic amendments (Qayyum *et al*, 2012). The residue (rice residue) having more amount of hydrolysable carbon showed much increased in mineralization rate as compared to biochar which has more recalcitrant carbon (Purakayastha *et al*, 2015).

Saikat (2022) reported that the nitrogen added treatments showed significantly higher CO₂ evolution (140 mg CO₂/100 g soil) than treatments without nitrogen addition (127 mg CO₂/100 g soil) in soil + rice residues treatment. Such type of result is expected as nitrogen added organic amendments reduced the C: N ratio and provide the optimum supply of nitrogen for microbial activity as compared to without nitrogen added amendments (Sommerfeldt *et al*, 1988). Substrate like organic manures as well as nitrogen both are important for expression of microbial activity in soil which is the primary driver of CO₂ evolution as a result of organic matter decomposition. who showed that reduction of the C: N ratio of rice residues and rice husk by the addition of mineral N increased the dehydrogenase activities and mineralization of carbon indicating the quick use of mineral N by microbial activity (Gaillard *et al*, 1999).

Effect of temperature was significant on the carbon

mineralization and found that irrespective of nature of organic amendments, nitrogen addition and incubation periods, the mean carbon mineralization increased significantly from 85.3 to 110 mg CO₂/100 g soil when temperature was increased from 20°C to 30°C. The mean CO₂ evolution at 30°C was 28.6 per cent higher over CO₂ evolution at 20°C (Thangarajan *et al*, 2015). It was clear from the study that increase in temperature increased the mineralization rate of carbon. Increases in mineralization at high temperature might be explained by the fact that rising temperatures cause an increase in microbial respiration and activity (Yu *et al*, 2022). Higher temperatures may promote mineralization by stimulating microbial activity and increasing the diffusion of soluble substrates in soils (Curtin *et al*, 2012).

Sathya and Maheswari (2017) confirmed that among the various doses of solid and liquid fermented poultry manure, application of solid fermented poultry manure at 680 kg ha⁻¹ recorded significantly higher CO₂ evolution (68 mg kg⁻¹ of soil) followed by the application of solid fermented poultry manure at 544 kg ha⁻¹ along with liquid fermented poultry manure at 170 l ha⁻¹ (63.5 mg kg⁻¹ of soil) and lower in control (44.5 mg kg⁻¹ of soil) as compared to other treatments. This might be due to solid fermented poultry manure contains 2.5:2:2 percent of NPK. Whereas, liquid fermented poultry manure contains 2:1.5:1.5 percent of NPK, which shows higher concentration of nutrient in fermented poultry manure results in more mineralization (Sathya *et al*, 2018). The highest bacterial populations of 26.80×10^6 CFU g⁻¹ of soil, 19.4×10^3 CFU g⁻¹ of soil fungal population and 9.85×10^2 CFU g⁻¹ of soil actinomycetes were observed in the treatment that received solid fermented poultry manure @680 kg ha⁻¹ results in more mineralization of carbon (Sathya and Maheswari, 2017).

Shubham *et al* (2023) reported that the application of 30 g sewage sludges kg⁻¹ of soil recorded significantly higher carbon mineralization (7.86, 7.94 and 8.04 g kg⁻¹) after 30, 60 and 90 days after incubation, respectively as compared to other treatments. This might be due to sewage sludge contain higher amount of organic matter, after humification increased the organic carbon content due to more carbon load of sewage sludge, FYM and vermicompost (Grigatti *et al*, 2004). Udupa *et al* (2022) reported that the cumulative CO₂ evolution was significantly greater in neem, madhuca and simarouba amended soil than the control soil at 60 days of incubation. High C-mineralization occurred initially in the undecomposed simarouba (S-0) and 30-days old neem (N-30) and madhuca (M-30) oil-seed cake composts. Carbon mineralization occurred initially in the

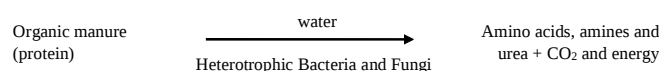
undecomposed simarouba (S-0) and 30-days old neem (N-30) and madhuca (M-30) oil-seed cake composts. This could be due to the presence of easily degradable C in the fresh oil-seed cakes of simarouba. However, in the case of neem and madhuca, the 30-days old composts were rich in highly active C-fraction which could be due to partial degradation of cytotoxic compounds and complex carbohydrates (cellulose, hemicellulose and lignin) during the early composting process (Vasudha *et al.*, 2022). High C-mineralization values in the case of madhuca and simarouba cakes could be due to the low degree of maturity and stability in comparison to that of neem at the same composting period. The presence of a high amount of complex sugars such as lignin in madhuca and simarouba oil-seed cakes as compared to neem oil-seed cake could be accounted for high C-mineralization (Yadav *et al.*, 2011).

Mineralization of nitrogen

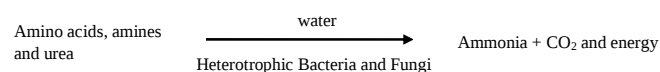
Nitrogen mineralization occurs in 3 steps

When we apply organic manures to soil, the nitrogen present in the form of proteins and other complex nitrogen

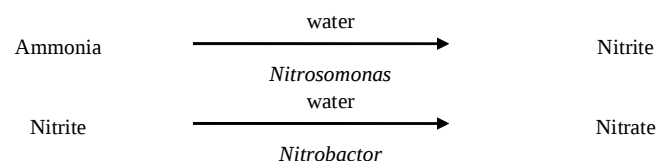
Aminization



Ammonification



Nitrification



Factors affecting soil nitrogen mineralization

Several factors influence the rate of nitrogen mineralization in organic manures, including:

- **Temperature** : Warmer temperatures generally promote faster microbial activity and nutrient release (Nydhall *et al.*, 2013).
- **Moisture** : Adequate moisture levels are necessary for microbial activity. Excessively dry or waterlogged conditions can hinder the process (Borowik and Wyszowska, 2016).
- **Oxygen** : Aerobic conditions (presence of oxygen) support efficient microbial decomposition and nutrient release. Anaerobic conditions (lack of oxygen) can slow down the

process and may result in the loss of nitrogen through denitrification (Klawonn *et al.*, 2015).

- **C:N Ratio** : The carbon-to-nitrogen ratio of the organic material affects microbial activity. A balanced C:N ratio (around 25-30:1) ensures optimal decomposition and nutrient release (Azis *et al.*, 2023).

C:N Ratio less 20:1 = Mineralization of nitrogen

C:N Ratio more 30:1 = Immobilization of nitrogen

- **Particle size** : Finely ground organic materials decompose more rapidly than coarse ones because they provide a larger surface area for microbial colonization (Tarafdar *et al.*, 2001).
- **pH** : Soil pH influences microbial activity and nutrient availability. Most microbes prefer a neutral to slightly acidic pH range (Khaled and Sayed, 2023).
- **Type of Organic material** : Different organic materials have varying nutrient compositions and decomposition rates. For example, animal manures typically contain higher levels of nitrogen compared to plant-based compost (Shaji *et al.*, 2021).

What is C:N ratio?

The C:N ratio is the mass of carbon to the mass of nitrogen in a particular substance.

For example, if we have a C:N ratio of 24:1, this means we have 24 units of carbon to 1 unit of nitrogen. It is often used as an indication of mineralization or immobilization whether will occur.

Why does this ratio matter in the soil?

- It mainly controls decomposition rate in soil
- It is a source of food and energy for soil microbes
- Influence of C/N ratio on N release
- The decay of organic matter can be delayed
- Influence of C/N ratio on Soil ecology
- It is related to release of available N, total organic content and accumulation of humus (Liang *et al.*, 2017).

Saikat (2022) reported that the mean nitrogen content ranged from 56.4 ppm under control (soil) treatment to 69.8 ppm under *Dhaincha* amended soil. *Dhaincha* amended soil was found to maintain significantly higher mineral N content compared to all other organic residue amended soil. The higher nitrogen mineralization in *Dhaincha* amended soil might be due to the higher

Table 4 : C:N ratio of different material / soil.

S. no.	Particulars	C:N ratio
1	Indian soil	10-12:1
2	Organic matter and humus	10:1
3	Micro organisms	7:1
4	Paddy straw	80:1
5	Saw dust	600:1
6	FYM	100:1
7	Legumes	10-30:1
8	Young green leaves	10-30:1
9	Arable land or cultivated land	8-15:1
10	Well decomposed compost	10:1
11	Freshly added residues	>30:1

Table 5 : Potential nitrogen contribution of N fixing legumes in Indian soil.

S. no.	Crop	N Fixed (kg ha ⁻¹ year ⁻¹)
1	Alfa Alfa (<i>Medicago sativa</i>)	100-300
2	Clover (<i>Trifolium spp.</i>)	100-150
3	Chick pea (<i>Cicer arietinum</i>)	20-63
4	Cowpea (<i>Vigna sinensis</i>)	50-85
5	Groundnut (<i>Arachis hypogaea</i>)	112-152
6	Guar (<i>Cyamopsis tetragonoloba</i>)	37-196
7	Lentil (<i>Lens culinaris</i>)	35-100
8	Pea (<i>Pisium sativum</i>)	46
9	Pegionpea (<i>Cajanas cajan</i>)	68-200
10	Soybean (<i>Glycine max</i>)	49-130
11	Green gram (<i>Vigna radiata</i>)	50-66
12	Black gram (<i>Vigna mungo</i>)	119-140

Table 6 : Biomass production and nitrogen accumulation of green manure crops.

Crop	Age (days)	Dry matter (tonnes ha ⁻¹)	N accumulation (kg ha ⁻¹)
<i>Sesbania aculeata</i>	60	23.2	133
Sunhemp	60	30.6	134
Pillipesara	60	25.0	102
<i>Sesbania rostrata</i>	50	5.0	96

Source: Principles of Agronomy (Book) Reddy (1999)

concentration of nitrogen because of green manure crop and lower C:N ratio leads to more decomposition and higher nitrogen mineralization (Chanda *et al*, 2021).

Saikat (2022) reported that the effect of nitrogen addition on N mineralization was found significant and nitrogen addition recorded significantly higher mineral N content (71.2 ppm) compared to without nitrogen

treatments (55.2 ppm). Nitrogen added treatments showed 28.9 % more mineral N than without nitrogen. Whereas addition of mineral N fertilizer (urea) stimulates nitrogen mineralization by increasing microbial activity in soil and increased the mineral N content. Without nitrogen addition, mineral N content was highest in Dhaincha amended soil whereas N content in FYM and biochar amended soil were at par. N may alter the net mineralization of compost-N because nitrogen fertilization reduces the C:N ratio and increases the mineralization of organic matter (Ali *et al*, 2021).

It was found from the study that the mean nitrogen mineralization increased significantly from 62.5 to 64.0 ppm when temperature was increased from 20°C to 30°C, irrespective of nature of organic amendments, nitrogen addition and incubation periods (Eghball *et al*, 2002). Mineralization of organic residues mainly takes place with the help of heterotrophic bacteria and fungi which was favoured at high temperature than that of lower temperature, which may be responsible for the increase in net mineralization of N at high temperatures (Whalen *et al*, 2013).

Basak and Biswas (2014) reported that the mean N mineralization ranged from 15.2 mg kg⁻¹ under control to 57.6 mg kg⁻¹ under T₂ (100% NPK) followed by 42.1 under T₆ (50% RDF + Vermicompost @ 5 t ha⁻¹) throughout the incubation period of 90 days. Application of integrated sources of organic manures and fertilizers provide the optimum supply of nutrients for microbial activity, which, in turn resulted in greater N mineralization in soil over the soils amended with either organic manures or 100% NPK. Blending with fertilizer-N may change the net mineralization of compost-N because N fertilization lowers the C: N ratio of the soil, thereby, enhances the mineralization (Shiva kumar *et al*, 2022).

The mean mineral N content increased from 30.7 to 32.5 mg kg⁻¹ soil *i.e.* by 5.9 per cent due to increase in temperature from 20°C to 35°C, across the treatments, moisture regimes and incubation periods (Basak and Biswas, 2014). Mineralization of organic residues mainly takes place with the help of heterotrophic bacteria and fungi which was favoured at high temperature than that of lower temperature, which may be responsible for the increase in net mineralization of N at high temperatures. Higher temperature may enhance mineralization by stimulating microbial activity and accelerating diffusion of soluble substrates in soil (Whalen *et al*, 2013).

Amit *et al* (2022) reported that the application of vermicompost @ 9.09 t ha⁻¹ recorded higher mineralization mean ammonical nitrogen (50.3mg N kg⁻¹

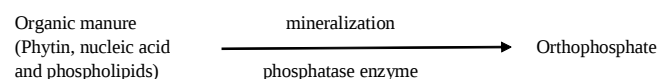
soil) and nitrate nitrogen ($57.38 \text{ mg N kg}^{-1}$ soil) as compared to other treatments. The higher quantity of application of vermicompost produces more organic matter and which contain more number of microorganisms and microbial activity results in more nitrogen mineralization (Saranraj and Stella, 2012).

Jakhar *et al* (2006) reported that the application of pigeon pea crop residue recorded significantly higher nitrogen mineralization (60.10%) and lower in clusterbean (11.20%) at 56 days after incubation study. The higher nitrogen mineralization in pigeon pea might be due to the higher concentration of nitrogen and lower C:N ratio leads to more decomposition and higher N mineralization (Sakala *et al*, 2000).

Sathya and Maheswari (2017) confirmed that among the various doses of solid and liquid fermented poultry manure, application of solid fermented poultry manure at 680 kg ha^{-1} recorded significantly higher nitrogen mineralization (63 mg kg^{-1} of soil) followed by the application of solid fermented poultry manure at 544 kg ha^{-1} along with liquid fermented poultry manure at 170 l ha^{-1} (60.5 mg kg^{-1} of soil) and lower in control (58.5 mg kg^{-1} of soil) as compared to other treatments. This might be due to solid fermented poultry manure contains 2.5 per cent of nitrogen, whereas liquid fermented poultry manure contains 2 per cent of nitrogen, which shows higher concentration of nutrient in fermented poultry manure results in more mineralization (Singh, 2017). The highest bacterial populations of $26.80 \times 10^6 \text{ CFU g}^{-1}$ of soil, $19.4 \times 10^3 \text{ CFU g}^{-1}$ of soil fungal population and $9.85 \times 10^2 \text{ CFU g}^{-1}$ of soil actinomycetes were observed in the treatment that received solid fermented poultry manure @ 680 kg ha^{-1} .

Chendra (2021) reported that among the different green manure, sunhemp incorporation recorded higher mineralized ammonical nitrogen of 317, 247, 175 and 145 mg kg^{-1} , respectively at 10, 20, 30 and 40 days after incubation, respectively and also recorded higher mineralized nitrate nitrogen of 120, 66.8, 60.3 and 63.1 mg kg^{-1} , respectively at 10, 20, 30 and 40 days after incubation, respectively as compared to other green manures.

Mineralization of Phosphorus



If the C:P ratio less than 200:1 = Mineralization

If the C:P ratio more than 200:1 = Immobilization (Nur *et al*, 2025).

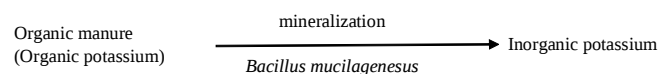
Moharana *et al* (2015) reported that the application of 50% NPK + rock phosphate enriched rice straw compost @ 2.5 g kg^{-1} soil recorded higher mineralization of phosphorus (20.4 mg kg^{-1}) and lower in control (6.1 mg kg^{-1}). It is evident that RP enriched compost had high P content and relatively low C/P ratio. Due to its lower C/P ratio compared to other organic composts, it is also expected to decompose easily and contribute towards available pool of P.

Pal *et al* (2018) confirmed that application of pig manure at 80 t ha^{-1} recorded higher phosphorus mineralization from 1.3 to 6.8 mg kg^{-1} (an increase of 4.23 times) during 2 to 2160 hours of incubation as compared to other manures application. The rapid increase in rate of mineralization in poultry manure is probably because of low C/P ratio (13.2) and high P content (1.69% P).

Padmaja *et al* (2020) confirmed that application of gliricidia topping mixture recorded higher phosphorus mineralization (6.99, 7.33, 7.55 and 7.45 mg kg^{-1}) at 30, 60, 90 and 120 days after incubation, respectively as compared to other treatments. Green gram stalks mixture was found at par with gliricidia topping mixture. The P content of green gram stalks mixture was highest, its C:P ratio was higher than that of gliricidia topping mixture. This might be a reason behind fast and steady mineralization of P in gliricidia topping mixture (Singh *et al*, 2021).

Gosavi (2019) reported that among the different green manure crops, cowpea recorded higher cumulative phosphorus mineralization ($156.55 \text{ mg kg}^{-1}$) followed by sunhemp ($152.64 \text{ mg kg}^{-1}$), while it was least in control ($126.66 \text{ mg kg}^{-1}$). This might be due to cowpea is pulse crop, which contain more amount of phosphorus, which produces more biomass and which contain more amount of P in it. Upon decomposition they will be release of carbon dioxide and organic acid leads to release of P.

Mineralization of Potassium

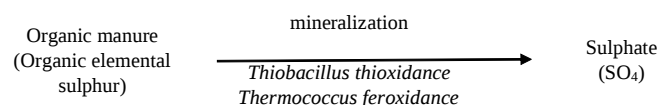


Singh *et al* (2021) reported that the K release was maximum with addition of cereals residues (Rice, Wheat, Barley and Maize) as compared to pulses residues (Green gram, Lentil and Pigeon pea) during entire period of incubation up to 90 days. It was also observed that cereals residue contributed towards higher release of K in soil. This might be due to higher content of K in the cereals residue as compared to pulses residue. Potassium from added cereals and pulses residue is released continuously

with increasing incubation period up to 90 days in soil. Crops residue contain more K than grains and are important source of soil K when they are returned after grain is harvested in soils.

Kusum *et al* (2020) reported that application of vermicompost at 3.75 t ha⁻¹ recorded higher potassium mineralization of 226.34, 235.86, 244.89, 239.90 and 233.13 kg ha⁻¹, respectively at 0, 30, 65, 100 and 120 days after incubation, respectively as compared to other treatments. The beneficial effect of vermicompost on the available K was also due to reduction in fixation and release of K due to interaction of organic matter with clay as well as direct addition of K in the available K pool of soil. On vermicompost application there is increase in microbial activity which resulted in increased solubilization and mineralization of P and K present in soil.

Mineralization of Sulphur



Kiruthika *et al* (2022) reported that application of press mud at 10 t ha⁻¹ recorded significantly higher available sulphur content (7.93 mg kg⁻¹) as compared to other treatments. This might be due to mineralization of sulphur from native as well as from added organic source. Pressmud acts as an energy source for sulphur oxidizing microorganisms which in turn make in their activities and increased the sulphur mineralization rate in soil.

Gosavi (2019) reported that among the different green manure crops, glyricidia recorded higher cumulative sulphur mineralization (75.988 mg kg⁻¹) followed by subabul (67.87 mg kg⁻¹), while it was least in control (47.83 mg kg⁻¹). This could be due to high amount of added S through green manures and narrower C:S ratio and it also may be due to biological activity. Mineralization of S in soil is largely mediated by biological activity and the work carried out on aerobic and anaerobic soil indicates that S mineralization is controlled by soil chemical and physical properties and type of organic residue added. Which might be attributed to difference in chemical composition of green manure crop residue and their C:S ratio. Organic material having a C:S ratio below 200 are prone to result in mineralization of S. The S release pattern from green manure residues amended soil also recorded identical trend and rate of mineralization followed the order: glyricidia > subabul > cowpea > sunnhemp > dhaincha > neem leaves > control.

Sultana *et al* (2021) reported that the application of

Municipal solid waste 50% + mustard oil cake 20% + poultry manure 30% (MSW + MOC + PM) recorded higher cumulative sulphur mineralization (209.46 mg kg⁻¹) and lower in control (32.87 mg kg⁻¹). Addition of Municipal solid waste, upon decomposition it produces more organic matter which contain more number of Sulphur oxidizing bacteria namely *Thiobacillus thiooxidans* and *Thiobacillus ferrooxidans* results in more S mineralization.

Reddy *et al* (2002) reported the cumulative amount of sulphur mineralized ranges from 7 mg kg⁻¹ in *Inceptisol* soil amended with wheat straw to 34.4 mg kg⁻¹ in *Vertisol* soil amended with FYM. The results with organic manures showed that S mineralization is not only related to the type of manure but also to the soil type receiving the manure. Irrespective of organic material, in general, the cumulative amounts of mineralized S were higher in *Vertisol* than in *Inceptisol*. Irrespective of soil type, among the two green manures subabul loppings amended soils had higher cumulative amounts of mineralized S than gliricidia-treated soils.

Pooja *et al* (2017) reported that the application of 50% NPK + Vermicompost 2.5 g kg⁻¹ recorded higher cumulative sulphur mineralization (6.77, 8.65, 8.30, 8.00 and 5.83 mg kg⁻¹) at 7, 15, 30, 60 and 120 days after incubation study. The continuous release of greater extant of available sulphur by application of vermicompost influence in soil then NPK might be due to prolong the sulphur solubilization. Application of integrated sources of organic manures and fertilizers provide the optimum supply of nutrients for microbial activity, which, in turn resulted in greater S mineralization in soil over the soils amended with either organic manures or 100 per cent NPK.

Mineralization of Calcium and Magnesium

Lavanya (2019) reported that the application 100 % NPK+ FYM + lime recorded higher mineral calcium (27.4 c mol (p+) kg⁻¹) and magnesium (18.5 c mol (p+) kg⁻¹) content in soil in 2016 as compared to other treatments. Mineral calcium and magnesium content in control has decreased over the years at faster rate which might be due to release of calcium and magnesium form mineral fraction to exchangeable pool, as the treatments are not applied with any Ca source and due to continuous cropping. Significantly higher mineral calcium and magnesium content in the soil was recorded in the treatments receiving continuous application of lime, calcium and magnesium containing fertilizer and organic manures as a source of calcium results in more release of nutrients.

Conclusion

Nutrient mineralization from organic manure plays a crucial role in sustainable nutrient management by converting organically bound elements into forms that are readily available to plants. Essential nutrients like nitrogen, phosphorus, potassium, sulphur, calcium and magnesium are released through microbial decomposition and biochemical processes in the soil. Nitrogen is mineralized through ammonification and nitrification, phosphorus and sulphur through enzymatic breakdown into phosphate and sulphate, while potassium, calcium and magnesium are liberated primarily through leaching and exchange reactions. This natural process ensures a slow and steady nutrient supply, enhances soil fertility, supports microbial activity and reduces dependency on chemical fertilizers, thereby promoting long-term soil health and sustainable crop production.

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