

# How Important is the Quality of Organic Amendments in Relation to Mineral N Availability in Soils?

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**Summary** Wastes generated from municipal and agricultural activities have the tremendous potential for application in agriculture as a source of nutrients and as amendments to improve soil organic matter (SOM). A decline in SOM can represent a serious threat to soil fertility and quality. Nitrogen (N) mineralization from organic amendments is important for understanding the N dynamics in terrestrial ecosystems. In this review, quality of the amendments such as C/N ration, N content, and biochemical compositions, etc. are discussed. Since, C/N ratio cannot explain all differences in N mineralization; emphasis has been laid on characterizing different compounds in organic amendments that govern the mineralization process. The importance of simulation models has also been described in modeling N mineralization from some complex materials like compost, animal manures and farmyard manures. These complex simulation models once modified according to the quality of the organic amendments can simulate N mineralization and thus, they can be used for simulating N dynamics in terrestrial eco-systems.

**Keywords** Organic amendments · Nitrogen · Quality · Mineralization · Soils · Modelling

## Introduction

Globally, about 19 billion tonnes of solid wastes are expected to be generated annual by the year 2025. Annually, Asia alone generates ~4.4 billion tonnes of solid

wastes and municipal solid wastes (MSW) comprise 790 million tonnes (MT) of which about 48 (~6 %) MT is generated in India [18, 122]. By the year 2047, MSW generation in India, is expected to reach 300 MT and land requirement for disposal of this waste would be 169.6 km<sup>2</sup> as against which only 20.2 km<sup>2</sup> were occupied in 1997 for management of 48 MT [122]. With increases in urban activities and agricultural production, the generation of solid wastes is expected to be increased with time. Apart from MSW, the organic wastes from agricultural sources alone contribute 350 million tonnes per year. The wastes generated from agricultural sources in India are mostly from sugarcane bagasse, rice husks, rice and wheat straw, cotton stalk, groundnut shell and jute fibres etc. [4]. These organic wastes/materials have tremendous potentials to be applied as organic amendments in soils for sustainable crop production.

Application of organic amendments to soil increases soil organic matter (SOM) which plays a key role in enhancing crop production and productivity [35] and mitigating the effect of climate change [63, 104]. In recent years, application

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of organics (crop residues, manures, green manures etc.) in agriculture has increased significantly in India. This is attributed to the increase in area under organic farming from 0.042 Mha in 2003 to 4.48 Mha in 2010 [81]. Therefore, the use of organics in agriculture can play important roles in supplying of plant available nutrients, and sequestering C in soils. Though some of the organic wastes are being composted for organic manures, others have the potentials for direct application to soils or in combination with mineral fertilizers [74] viz. crop residues/straw [101], green manures/green leaf manures, mulching [71, 95]. Applications of these materials to soils not only improve soil quality and productivity but also reduce the land requirement for disposal of these wastes.

The amount of N potentially mineralized from organic amendments is an important variable to be considered when recommending the appropriate rate to apply to meet N needs for optimal crop production [67]. This applies particularly to cropping systems where mineral fertilizers are completely excluded, i.e. organic farming [83], where fertilizers are available in limited quantity and where farmers cannot afford to purchase fertilizers such as in the developing countries [82], and it will also be important where both inorganic and organic forms of nutrients are applied. Consequently, a good knowledge of the factors affecting decomposition dynamics of organic amendments is required.

Application of organic materials/wastes as amendments to soils undergoes decomposition process before it releases N in soils for plant nutrition. Availability of N in soil depends on the decomposition of organic matter as more than 95 % of N is present in organic form [15]. Mineral N supply from organic amendments depends on both the initial availability of inorganic N in the amendments and the rate of mineralization or immobilization. This indicate that, at least initially, organic amendments can either be a source of plant available N or compete with plants for it. To successfully manage nutrient cycling from these amendments, it is therefore necessary to quantify their decomposition rate as well as the influence, this will have on N cycling processes within the soil [3, 32]. Nitrogen mineralization-immobilization turnover depends on a variety of factors such as C/N ratio [99], and the biochemical composition of organic amendments such as cellulose, lignin and polyphenol concentrations [28]. Thus, the challenging task is that the rate and timing of application of organic amendments should be based on an estimate of N-releasing characteristics. In this review, the importance of N mineralization process, release of N from organic amendments based on their quality, factors affecting N mineralization from soil and organic amendments, and modeling N mineralization from decomposition of organic amendments in soils are presented and reviewed.

## Mineralization/Immobilization: Concept and N Availability in Soils

Mineralization is the process of conversion of organic forms of N to  $\text{NH}_3$ , or  $\text{NH}_4^+$ , and  $\text{NO}_3^-$ . The first step in the process, called ammonification, is an enzymatic process, and involves the conversion of organic N to  $\text{NH}_4^+$ . It is carried out exclusively by heterotrophic microorganisms that utilize C substances as an energy source, and both C and N to increase microbial biomass, including microbial metabolites. The subsequent conversion of  $\text{NH}_4^+$  to  $\text{NO}_3^-$ , termed nitrification, is mediated primarily through two groups of autotrophic bacteria (*Nitrosomonas* and *Nitrobacter*). Mineralization is always coupled with immobilization, which operates in the reverse direction, with the soil microbial biomass assimilating inorganic N forms and transforming them into organic N constituents in their cells and tissues during the metabolism of suitable C substrates. However, immobilized N is likely to be available subsequently for mineralization due to the turnover of the microbial population. There is always a competition between microbes and crop plants for assimilation of mineral N released from the decomposition process. The continuous transfer of mineralized N into synthesized organic matter, and the release of immobilized N back into inorganic forms, is known as mineralization-immobilization turnover (MIT) [50].

Total release of  $\text{NH}_4^+$  through microbial activity, prior to any immobilization back into the organic forms, is termed gross mineralization. The difference between gross mineralization and immobilization constitutes net mineralization (or net immobilization). Since gross mineralization is difficult to measure, most often it is the net mineralization that is measured or estimated.

## Transformation of Carbon and Nitrogen During Decomposition

Organic matter serves as a C and N source for biomass synthesis, biomass byproducts and redox reactions. Microbes use organic C as an energy source, and for biomass synthesis. The catabolic metabolism of organic C generates  $\text{CO}_2$ , water and energy. Organic N is used as electron donor molecules (oxidizing agents) and is converted into  $\text{NH}_4^+$  (ammonification), an inorganic form of N. Subsequently, the  $\text{NH}_4^+$  is assimilated by microbes, being re-transformed into the organic form, or further oxidized into  $\text{NO}_3^-$  (nitrification). The transformation of organic C and N into inorganic forms (mineralization) is a normal consequence of aerobic respiration.

Labile pools of SOM, i.e. water-soluble C released from decomposition process, are especially important because

they control ecosystem productivity in the short-term, and could be most affected by soil management practices. For example, the labile C pools extracted by the hot and cold water degrade rapidly [49], and may be immediate energy sources for microorganisms [43]. Although the hot water extracted SOM pool had more intensive signals of carbohydrates, phenols and lignin monomers than cold water extracted SOM [56], the turnover of both hot and cold water extracted SOM pools has been reported as a major pathway of nutrient cycling [26]. The concentration of dissolved organic C, or more precisely water-extractable organic C, has been reported by a number of researchers as a parameter which consistently decreases during the decomposition process, and has therefore been related to the process of stabilization [123]. The conversion of solid organic matter into dissolved organic matter has been shown to be the rate limiting step to the supply of N [24, 54] and is therefore, likely to influence C and N dynamics in soil [77]. For example, the addition of a labile fraction of SOM to soil did not affect gross N mineralization, but markedly increased immobilization [37]. An addition of this SOM fraction, bacteria incapable of utilizing more complex organic substrates were able to utilize the labile form, resulting in higher rates of immobilization. So, organic amendments varying in biochemical composition may influence the amount of labile C during the decomposition process and thus, influence the availability of mineral N in the system.

Another important fraction coming out of the mineralization process is the water-soluble N. Soluble organic N (SON) is a part of the organic N extracted from soils by water or salt solutions [76]. It is highly labile N, and could be used by crops directly or after transformation to mineral N [121]. However, it is easy to lose in runoff or through leaching, leading to environmental pollution [66, 87]. Research into soil organic N mineralization has focused on inorganic N, with limited consideration of SON in the leachates. However, some researchers have found that the pool of SON was of equal size to soluble inorganic N [76], and it became important to evaluate the SON content and its contribution during N mineralization. Some researchers reported that the initial net N mineralization rate from organic amendments was most closely correlated ( $r = 0.76$ ) with the water-soluble N content, for a broad variety of plant materials in soil [52]. Water-soluble C and N pools have been hypothesized to play a central role in the transport and supply of C and N to microbial populations in soils and thus, the regulation of subsequent microbially mediated N transformations [24]. Hot water-extractable C and N have been demonstrated to be sensitive measures for determining impacts of soil management practices on soil fertility [34]. It has been suggested that changes in soil N mineralization may be related to changes in functional

diversity of the soil bacterial community [16]. However, the dynamics of C and N transformations are highly dependent upon the characteristics of the SOM. Organic matter is decomposed at different rates due to varying degrees of bioavailability of nutrients. The varying rates are indicative of disparate pools of C and N [12, 107]. Decomposition rates decrease as the more labile fractions are metabolized first, followed by the more recalcitrant fractions. Rates of decomposition are often quantified by measuring the production of inorganic C ( $\text{CO}_2$ ) and N (total  $\text{NH}_4^+$  and  $\text{NO}_3^-$ ).

### Quality of Organic Amendments on Nitrogen Mineralization in Soils

Numerous studies have reported nutrient contents, resource quality, decomposition, and nutrient release patterns for a variety of organic amendments derived from agro-ecosystems [36, 59] and in natural ecosystems [42, 118]. From these studies, a predictive understanding of decomposition and nutrient release patterns, and the resource quality parameters that influence those release patterns, has been developed [113].

The N release from organic amendments is positively related to material's initial quality [10, 102]. In early stages of organic amendments decomposition, C/N ratio may be the best predictor of N release [108], while lignin indices become increasingly important in later stages of decomposition [10, 48]. The differences in initial organic amendments quality (lignin/N and lignin/cellulose) alter material decomposition and N release rates in the early stages of litter decomposition [70]. However, as substrate quality converges to some low value during decomposition, the initial amendments' quality has a decreasing influence on late-stage decomposition rates, which instead are controlled by climate, soil texture, and exogenous sources of labile C and nutrients.

### Carbon-to-Nitrogen Ratio

The heterogeneity of the organic amendments may explain the different N mineralization patterns. Nitrogen mineralization depends on total N content [6, 23], form of N [97] and the C/N ratio [6, 111] of the organic amendments. It has been reported that net N mineralization occurs if the N concentration is above 2 %, and immobilization occurs below that concentration [96]. A large variation in C/N ratio can be expected from different sources of materials because of differences in species and age. The C/N ratio ranges from as low as 6.5 in composted chicken or pig manure to as high as 82 in cereal-crop residues [5] and 664 in sawdust [44]. It has been reported that crop residues with a C/N ratio of less than

33 will provide net N mineralization [8]. Similarly, other researchers suggested that crop residues with C/N ratio below 30 are expected to result in net N mineralization, while residues with C/N ratio greater than 30 favour immobilization [1]. However, many reports [17, 98] suggest that immobilization of N can still be expected during transformation of organic manures with low C/N ratios. The effect of C/N ratio on mineralization of different organic amendments viz. coir pith [55], crop residues [40], canola (*Brassica rapa*), pea (*Pisum sativum*) and wheat (*Triticum aestivum*) residues [103], and manures [19] have been reported. However, these simple indices of degradability (total N concentration or the C/N ratio) are commonly found to correlate with mineralized C and N at some stage of decomposition [78], but not at most or all stages of decomposition, especially in long-term mineralization of organic amendments. Clearly use consensus critical value of C/N ratio exists with different researchers giving different values. These differing results are due to incubation conditions (temperature, moisture, methodology followed etc.), and the type of amendments used, as they vary widely in biochemical properties. The organic manures, behave differently to plant materials as manures vary widely in composition being a complex mixture of animal excreta (cattle, goat, pig or sheep) and plant residue (different plant species or different plant part of same species such as leaves, stems and roots) that has undergone varying degrees of composting [64].

The existence of a range, instead of a single value for the break-even point is probably related to variation in the C/N ratio of the decomposing microbial biomass (bacterial versus fungi-dominated) as well as the existence of organic components with different susceptibility to decomposition. Organic residues with similar C/N ratios may mineralize differently because of differences in composition that are not reflected by the C/N ratio; for example different lignin contents. Because C/N ratio by itself cannot explain all differences in N mineralization, much effort has been spent on characterizing the different compounds or groups of compounds present in organic amendments. Some studies have identified groups such as polyphenols, proteins, soluble carbohydrates, hemicellulose-like, cellulose-like, and lignin-like compounds, and have related them to organic residue decomposition [109, 117].

Most authors report initial N immobilization followed by net mineralization in experiments with animal manures having low C/N ratios [80, 110]. The faecal samples, with C/N ratios in the range 20–27, had even more complex patterns of mineralization; some amendments showed initial net mineralization before an extended period of immobilization lasting for at least 16 weeks of incubation [27]. Therefore, the organic manure's quality (biochemical composition) plays an important role in decomposition of the amendments and subsequently releases of N.

### Biochemical Properties of Organic Amendments

Apart from C/N ratio of the organic amendments, the factors affecting N release include lignin and lignin-to-N ratio [30, 62], soluble polyphenols and polyphenols-to-N ratio [23, 79] and (lignin + polyphenol)-to- N ratio [28]. It has also been found that the higher amount of cellulose in organic amendments augments the process of immobilization in rice straw [2, 60]. The N concentrations and polyphenol/N ratios are determinants of the N release of plant residues with limited N concentrations, i.e. of <2 % and <1 % in tropical agriculture. It has also been reported that lignin levels and lignin/N ratios were not observed to be good predictors of N release [96]. The litter decomposition rates and N release may also be related inversely to lignin and N-based estimates of initial litter quality. For example, high N content may actually retard litter decomposition rates later in the decomposition process, particularly if lignin levels are also high [11, 48].

From the comparative review of data, critical values for different resource quality parameters which regulate the shift from net mineralization to immobilization have been proposed by various researchers [113]. The net N mineralization is predicted for N concentration greater than 2.5 %, lignin values less than 15 % and soluble polyphenols less than 4 % (Table 1). The focus of the critical values has been on the short-term effects of organic additions on nutrient availability but it could also serve as a framework for testing the long-term effects of organic resource quality on SOM maintenance and composition. According to some researchers, amendments in the high quality category can be applied directly as a substitute for mineral fertilizer, while those of intermediate-high quality, because of an initial and sometimes prolonged immobilization of N, are not suitable for this purpose but have the potential for long-term build up of SOM (Table 1). The amendments in the two low quality categories both the intermediate-low amendments have low lignin resulting in a similar short-term N immobilization to that in the intermediate-high group, but its role in SOM formation is uncertain. The lowest quality group, with low N and high lignin or polyphenolics results in long-term immobilization but may also lead to the formation of SOM, particularly if additional N is supplied as high quality organic amendments or mineral fertilizer.

The N mineralization from four biosolids, wheat straw, paper fines, and needle litter has been related to their initial chemistry, which was characterized by nuclear magnetic resonance (NMR) spectroscopy [93]. They found that net N mineralized was more strongly related to alkyl-C content ( $r = 0.86$ ) than C/N ratio ( $r = -0.75$ ). It is clear from these results that while C/N ratio is an important variable, other composition variable also plays important roles in the

**Table 1** Categories of organic amendments based on biochemical quality and their effects on N supplying capacity [82, 113]

Resource quality category	Resource quality parameters (N, lignin, soluble polyphenols) (g kg <sup>-1</sup> )	Nitrogen supplying capacity	Soil organic matter formation
High quality	N > 25, lignin <150 and polyphenol <40	High and immediate	Little or negative effect on total SOM; increased active fraction (soil microbial biomass)
Intermediate-high quality	N > 25, lignin >150 or polyphenol >40	Delayed, short or long term	Increased particulate (light) and passive fractions
Intermediate-low quality (Short-term)	N < 25, lignin <50 and polyphenol <40	Low–short term immobilization	Little effect on total SOM
Low quality (Long-term)	N < 25, lignin >150 or polyphenol >40	Very low and possible long term immobilization	Increased particulate (light) and passive immobilization fractions

N mineralization process. Research in this area should continue to identify specific N compound or groups of N compounds that affect N mineralization in different types of organic amendments.

Other properties of some organic amendments, such as heavy metal concentration, salt concentration in the tissue, and pH of the cell sap of the organic amendments may also affect microbial activity and decomposition process and hence, N mineralization. Additional research is needed to understand the mechanisms involved.

### Nitrogen Dynamics of Crop Residues

Crop residues are vital resources for the conservation of soil productivity and viable alternatives to fertilizer for nutrient supply to crop plants [94]. About 25 % of N, 25 % of P, 50 % of S and 75 % of K uptake by cereal crops are retained in residues, making them valuable sources of nutrients. Availability of crop residue N to succeeding crops is determined by the outcome of mineralization-immobilization processes. Therefore, it is critical to understand the mechanism of residue decomposition and nutrient dynamics and factor affecting its rate under diverse conditions for efficient residue management.

When residues are added, the net mineralization due to the added materials can be estimated as the difference between the amended soil and a control (without amendment). Residues with low C:N ratio tend to exhibit net N mineralization, while residues with high C:N ratio exhibit immobilization. Addition of high C:N ratio crop residues to the soil will reduce mineral N following application [112]. In farming systems where the straw remains on the field after harvest, its rapid decomposition is important to minimize negative effects on the following crops caused by N immobilization [20]. In rice–wheat cropping system where mechanical harvesting is practiced (in Indo-Gangetic plains of India), a large quantity of crop residues are left in the

field. The presence of a large quantity of high C/N ratio crop residues obtained from both the crops influences the N management in the cropping system. Rice straw has little value as cattle feed [88], and is readily available in quantities varying from 2 to 5 t ha<sup>-1</sup>. Proper fertilizer management practices can reduce N-immobilization due to incorporation of crop residues into the soil. These practices include appropriate method, time, and rate of fertilizer-N application i.e. placement of N-fertilizer below the surface soil layer which is enriched with carbon after incorporation of crop residue and application of N-fertilizer at a higher dose than the recommended dose. Yield depression following straw incorporation has been mitigated by adding inorganic N [7]. An immobilization phase as long as five months has been observed for the application of 8 t ha<sup>-1</sup> of wheat straw [46]. The dynamics of C and N are known to closely interact during the decomposition of plant materials due to the simultaneous assimilation of C and N by the heterotrophic soil micro-flora involved in this process. Crop residues added to soil together with mineral N can interact in different ways. In high C/N crop residues, immobilization associated with residues decomposition increased by the addition of mineral N [68]. Addition of mineral N also increased C mineralization during maize residue decomposition [39] and had no effect on C mineralization [31]. In many cases, the high microbial demand for N causes the availability of N (soil + residue N) to be the factor that limits straw decomposition in the short-term [68]. The rates of C mineralization and N immobilization from high C:N ratio maize straws (*Zea mays*, L.) were attributed to the initial mineral N content of the soil [91]. Similarly, N mineralization from high C:N ratio barley straw was limited by mineral N availability in soil to satisfy the immobilization demand [89]. Release of N from various crop residues different in biochemical qualities [95]. It is reported that simulation modelling should be helpful in designing strategies for N management from various crop residues. The N immobilization potential from rice and



wheat can be mitigated by application of mineral N, and models provide an option for estimating how much N is required [71]. Such simulation would help in describing the complex phenomenon of immobilization of N from high C:N ratio materials in a soil system. Nitrogen release from green manures and FYM in a vertisol of central India has shown that the application of a high rate of FYM caused more rapid immobilization of mineral N in soil than a low rate of application [72]. To counter the immobilization demand, initial application of N from external sources to soils has been reported for manures [53] and crop residues [100], and the model provides an option for estimating how much N is required.

### Conservation Agriculture and C and N Release for Crops

Conservation tillage has been widely adopted throughout globe to increase production efficiency, reduce water, and wind erosion. Fields with surface residues moderated its hydrothermal regime compared to tilled soil, which governs the soil biological and chemical processes such as mineralization and immobilization. Soil microorganisms, which control the decomposition, experience cycle of population growth and activity due to changes in field environment and this cycle may affect the decomposition rate [105]. Conservation tillage practices are responsible for temporary immobilization of fertilizer-N and reduction in N availability to crops at early stages of growth [13]. Further, Surface-placed residues have reduced residue-to-soil contact, with greater fluctuations in temperature and moisture content, limiting the amount of time during which conditions are favourable for the decomposers [106]. Thus, it is imperative to understand the interaction between soil microorganism and its environmental factor to maintain soil fertility in relation to the sustainable crop production systems. Decomposition rates are regulated by a combination of three factors—chemical, environment and the decomposer community [38]. Furthermore, the influence of edaphic factors on microclimate has been identified as important regulator of the decomposition process as the case of conservation agriculture [21]. Many researchers have developed temperature and moisture factors to quantify environmental limitation to decomposition. It has been estimated that decomposition of residue in grasslands is an empirical function of soil water tension, N in the soil and has quadratic effect of temperature from 0 to 38 °C [45]. Effect of temperature and water content on decomposition of residue can be simply explained as follows [85].

Decomposition =  $K \times T_m \times W_m \times \text{other factors}$

where  $K$  potential decomposition rate,  $T_m$  mathematical function which demonstrates the relative rate of microbial activity with increasing soil temperature, usually between a value of 0 and 1.  $W_m$  mathematical function which demonstrates the relative rate of microbial activity with increasing water availability, usually between a value of 0 and 1 Other factors = C:N ratio factor, contact factor etc., usually between a value of 0 and 1.

With the aim of assessing the benefits of crop remains left on the soil surface, a study carried out on the decomposition and characteristics of residue deposited on a clay soil indicated that the legume residue (*Pisum sativum* L. cv. Ideal) supplied the highest amount of N to the soil since, throughout its decomposition cycle, it lost 76.6 % of its initial content in N, compared to the 48 and 56 % of N released by wheat residues (*Triticum durum* L. cv. Amilcar) and sunflower (*Helianthus annuus* L. cv. Sanbro), respectively [90]. In addition to soil protection, another important characteristic of residues is to supply the soil with nutrients and carbon. The high percentage of N loss and its total amount from the pea make it the most efficient residue for increasing soil fertility. The larger proportion of N released determined that the C/N ratio of the pea residue increased over time as it decomposed [90]. It was estimated that most of the C released was lost in the atmosphere in the form of CO<sub>2</sub>, and that only 20–30 % of the C from the residue contributed to increasing organic C in the soil [116]. However, this contribution is vital for the long-term maintenance of the organic matter and fertility of the soil.

### Biochemical Quality of Organic Amendments and Mechanistic Approaches to Simulating Mineralization-Immobilization Turnover

While simple functional models are designed to predict net N mineralization, mechanistic models attempt to simulate gross mineralization and associated immobilization (viz. mineralization-immobilization turnover). These are process-based models which try to include the best possible description of the processes involved. Based on our current understanding of organic matter decomposition in soil, hypotheses and assumptions about various processes are made that are then used to develop mathematical formulae for the decay process. The origin of computer simulation modeling of C and N dynamics in the United States and in Europe [9, 29]. These models were first to combine C/N and related sub processes of a soil-crop-nutrient system into an integrated model. Since then, various models have been developed based on various soil parameters each differing from others in various respects.

**Table 2** Conceptual functional pools as considered in different simulation models

Model	Functional pool	C/N ratio	References
Century model	Active SOM	8	[84]
	Slow SOM	11	
	Passive SOM	11	
	Structural AOM	150	
	Metabolic	10–25	
Rothamsted model (Roth C model)	DPM	–	[22, 114]
	RPM	–	
	Microbial biomass	–	
	Humified OM	–	
	Inert OM	–	
	Roots	25	
	Litter (plant residue and roots)	60	
	Faeces	50	
DAISY	Soil microbial biomass pool 1	6	[14, 75]
	Soil microbial biomass pool 2	10	
	Non-living native SOM pool 1	11	
	Non-living native SOM pool 2	11	
	Added organic matter 1	100	
	Added organic matter 2	–	
ANIMO	Humus	16	[92]
	Fraction 2	12	
	Fraction 3	58	
	Fraction 4	76	
	Fraction 5	76	
	Fraction 6	24	
	Fraction 7	24	
SWATNIT	Litter	8	[115]
	Manure	10	
	Humus	12	
EPIC	Stable humus	<12	[47, 120]
	Fresh organic N	–	
	Active organic N	12–25	
NDICEA	Fresh organic matter pool	–	[33, 61]
	Young organic matter pool	–	
	Old organic matter pool	–	
PASTIS	Fresh, soluble and humified organic matter with two living pools		[25]
NCISOIL	Residue pool	6	[73]
	Pool I labile	6	
	Pool I resistant	6	
	Pool II labile	6	
	Pool II resistant	12	
	Pool III (stable humus)		
DNDC	Very labile litter	2.35	[65]
	Labile litter	20	
	Resistant litter	20	
	Labile microbial biomass	8	
	Resistant microbial biomass	8	
	Labile humads	8	
	Resistant humads	8	
	Passive humads		
APSIM	Fresh organic matter	Variable	[58, 69]
	BIO	8	
	HUM	Derived from the C/N ratio of soil	

*SOM* soil organic matter, *AOM* added organic matter, *OM* organic matter, *DPM* decomposable plant material, *RPM* recalcitrant plant material, *BIOM* microbial biomass, *HUM* humus

## Multi-Compartment Simulation Models

The decomposition of organic matter is simulated by defining different fractions of organic matter as functional pools, each with its specific quality as substrate for soil biota. Generally, small pools with high turnover rates (referred to as “decomposable” or “labile” or “active”) and larger pools with slower turnover rates (referred to as “recalcitrant” or “resistant” or “slow”) are distinguished [14, 51, 92].

Some models consider microbial biomass as one of the defined pools while others do not include a biomass pool and model it as part of the stable organic matter/humus pool [41, 51, 92, 119]. Some models with a distinct biomass pool consider microbial growth and maintenance. These are only represented by parameter values of the C and N reservoirs. Some of the models with their pool structures and C/N ratio of pools have been given in Table 2. In most decomposition models, the freshly added organic amendments (plant C and N) are partitioned into two or three conceptual pools. Generally, compounds found in the cell cytoplasm (e.g. simple carbohydrates, nucleic acids, amino acids and proteins) are grouped together in a metabolic pool, while cell wall components (cellulose, hemicelluloses and lignin) constitute a structural pool [84]. In some models, lignin is treated explicitly because of its resistance to degradation [84, 114]. In the most common class of decomposition models, each plant residue pool is considered to decay at a specific rate, which is constant over time, uniform within each pool and across litter types, and determined by its inherent resistance to microbial attack (first-order rate kinetics) rather than by the biochemical potential of the decomposer community [86].

Some models contain few organic matter pools [14, 57], some contain multiple pools of microbial biomass and protected and non-protected organic matter [114]; but most have fixed numbers of pools and so their structure is not easy to alter.

Some researchers reported that measured C mineralization varied greatly between the plant materials and was well predicted by a simulation model in which litter C was subdivided into three pools according to the results of stepwise chemical digestion (Van Soest analysis) [57]. To test the predictive performance of the model, they found that neutral detergent-soluble C (Van Soest analysis) was best correlated with the estimated pool ( $R^2 = 0.78$ ) followed by water-soluble C ( $R^2 = 0.69$ ) and C digestible in vitro in rumen fluid ( $R^2 = 0.66$ ). In the model, the degradability of litter N-based on the measured C to N ratios of the litter pools has been described. In the simulations of N mineralization a significant deviations from measured values occurred for some of the plant materials, especially during the first few days of decomposition. This suggests that the description of microbial N availability and the microbial requirement in the model were reasonable, but

emphasizes the need for more detailed knowledge of these properties during the very dynamic initial phase.

The simulation models are able to capture the pattern of N release that is attributable to the N concentration of plant materials, or more generally the C/N ratio of the organic input. However, the models are unable to simulate the more complex pattern of N release that has been observed for some animal manures, notably materials that exhibit initial immobilization of N, even when the C/N ratio of the material suggests it should mineralize N [89]. The APSIM Soil N module was modified so that the three pools that constitute added organic matter could be specified in terms of both the fraction of carbon in each pool and also their C/N ratios (previously it had been assumed that all pools have the same C/N ratio). It was shown that the revised model was better able to simulate the general patterns of N mineralized reported for various organic sources [27]. By associating the model parameters with measured properties (the pool that decomposes most rapidly equates with water-soluble C and N; the pool that decomposes slowest equates with lignin-C), the model performed better than the unmodified model in simulating the N mineralization from a range of feeds and faecal materials measured in an incubation experiment [89] and farmyard manures from India [72]. Still more effort is needed to simulate N mineralization from diverse organic manures, and from materials of varying C/N ratio and biochemical composition, under different rates of application. The modified structural pools of the model should be able to simulate the N dynamics under different rates of application, and for the integrated use of organics with inorganic fertilizer nutrients [72].

The NDICEA (Nitrogen Dynamics in Crop rotation in Ecological Agriculture) model (Table 2.) is a dynamic, process-based model that calculates N and organic matter balances during a crop rotation [33, 61]. The core of the model is the decomposition module in which the mineralization process is described. Mineralization is calculated for each successive application of organic amendments, according to the type and quantity of that organic amendment. For each type of organic amendment, the C/N ratio and the apparent initial age (ranging from 1 for green matter to 24 years for soil organic matter) are used as input. The model has been used in a few cases under temperate conditions [33, 61].

## Conclusions

The quality of the organic amendments plays an important role in their decomposition and subsequent release of N to soils. The various quality parameters such as simple soluble carbohydrates, cellulose, hemi-cellulose, poly-phenols, lignin and many other C and N groups and compounds are



responsible for decomposition of organic amendments in soils and mineralization of N. Any amendments added to soils based on these quality parameters undergo decomposition at various levels depending upon the microbial community and thus, influence the N dynamic in crops and cropping systems. So, these parameters must be assessed before applying such amendments to soils. In this respects, simulation models are very handy once their conceptual pools are once modified based on the quality parameters observed in these amendments.

### Future Research Needs

- The quality of the organic amendments should be considered prior to mixing with other amendments with different biochemical compositions to prevent N losses and synchrony of supplying N according to crop demand. In this regards, the crop simulation models will be handy in providing precise prediction of N supply from organic amendments in different soils and cropping systems.
- Water-soluble C and N play important role in supplying C and N to microbial population in soils, thus, the regulation of subsequent microbial mediated N transformations. Therefore, more research efforts on net N mineralization rate on water-soluble N for a broad variety of organic materials are needed.
- The balance between mineralization and immobilization is central to the flows and availability of mobile forms of N in the soil. Much research effort has been undertaken to determine rates in the field and under controlled conditions and much information already exists. However, it is not yet possible to provide adequate reliability for prediction which is of immediate relevance to, and needed for, decisions on fertilizer requirements and recommendations,  $\text{NO}_3^-$  leaching, recycling of N from crop residues and animal manures, maintenance of soil organic matter contents and the future management of changing agricultural practices.
- Apart from determining the biochemical quality of organic amendments, microwave enhanced advanced oxidation process aided with dilute sulfuric acid should be used for treatment of dairy manures and other composting materials to break the more resistant material like lignin chain to release N, reducing sugar, and other plant available nutrients to soils.

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