A Review of Factors Influencing Organic Matter Decomposition and Nitrogen Immobilisation in Container Media

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INTRODUCTION

The organic fraction of a potting mix is subject to decomposition and, therefore, is important in relation to nitrogen (N) immobilisation. Immobilisation of N is the reduction in plant available N (i.e., nitrate or ammonium) as a result of microorganisms using this N as they decompose organic materials with a high carbon (C) content. The organic portion of potting mixes usually constitutes 50% or more of their volume and in New Zealand *Pinus radiata* bark and sphagnum peat are the most commonly used materials. *Pinus radiata* sawdust, tree fern fibre, composted mixed vegetation, and other sources of bark or sawdust are also used on a limited scale. Spent mushroom compost has also been successfully used in bark and peat container media overseas although there have been reports of problems with its use in New Zealand. It has good physical properties and is a useful source of nutrients except for N (Henny, 1979; Chong et al., 1991; Chong and Rinker, 1994; Stewart et al., 1998ab). Spent mushroom compost may cause temporary N immobilisation, after which N is slowly mineralised from it (Stewart et al., 1998a). Spent mushroom compost also has a high soluble salt content that can be ameliorated by leaching, and a pH of 6.5-8.1 (Henny, 1979; Chong et al., 1994; Chong and Rinker, 1994; Stewart et al., 1998b).

This paper seeks to review the factors causing decomposition of these organic materials and the implications of these processes on N immobilisation.

FACTORS INFLUENCING DECOMPOSITION RATES

Chemical Composition. Cellulose is a constituent of organic matter and is the key component of cell walls. Bunt (1988) states that cellulose plays a major role in N immobilisation since it breaks down very rapidly and has a high C : N ratio. The secondary thickening that occurs in growing wood, produces thicker cell walls and hence greater amounts of cellulose. Hardwood trees have denser cell walls and their bark contains up to 40% cellulose compared with softwoods which have low-density bark containing only about 5% cellulose (Bunt, 1988). Hardwood and softwood are plant classification terms and the wood of each type of tree may not be particularly hard or soft, e.g., balsa is a hardwood. Hardwoods are dicotyledonous flowering trees (e.g. *Eucalyptus*) while softwoods are conifers e.g., *Pinus radiata* (Raven et al., 1992).

Lignin is another component of organic matter and is closely associated with cellulose. Lignin is more resistant to decomposition than cellulose and may protect cellulose, slowing its decomposition. Bragg and Whitely (1995) provided an example of the different rates of decomposition of constituents within one organic material. They showed readily decomposable carbon in rape straw incorporated into the soil can be broken down rapidly whereas the residual high-lignin straw fibre resisted further decomposition.

Polyphenols are plant tannins that are also relatively resistant to decomposition (Haynes, 1986). The polyphenol content of plant material decreases in response to additional N, and so may vary within a source of plant material (Haynes, 1986). The rate of decomposition of organic material is related to its cellulose, lignin, and polyphenol content (Mtambanengwe and Kirchmann, 1995; Tian et al., 1995). Rather than trying to predict decomposition from one of these components a useful approach has been to use a residue quality index which is a combination of C : N, lignin, and polyphenol concentrations (Tian et al., 1995). Another approach for predicting decomposition is to calculate the amount of C available for microbial decomposition (Mtambanengwe and Kirchmann, 1995).

Particle Size. This influences decomposition because it relates directly to the surface area exposed to the surrounding environment and microbial attack. The smaller the particle, the greater the surface area that is exposed and the greater the potential rate of decay. However, some materials (e.g., peat) are resistant to decomposition despite their fine particle size. The chemical composition is, therefore, a more important factor than particle size (Maas and Adamson, 1972).

Ease of Wetting. Allison et al. (1963) in comparative studies of wood decomposition from different species of trees concluded that wettability was a key factor. They reported a slower breakdown of wood from softwood species compared with hardwoods. The water insoluble resins in the wood of softwood species results in strong resistance to water, making their wood particles a poorer substrate for microbial growth. Similarly, peat contains wax and bark contains suberin, both of which are water repellent and hence the stability of peat and bark. Sawdust, which is more wettable than bark, decomposes much faster. Also, wood from hardwood species decomposed six times faster than that from softwoods (Allison et al., 1963). Straw has a slow rate of decomposition when cultivated into the soil because both its resistance to wetting and its high lignin content.

C : N Ratio. Early texts on N immobilisation tended to place a heavy emphasis on the C : N ratio. Bunt (1988) reported how two pine barks with the same C : N ratio (about 300 : 1) and under similar conditions had very different C decomposition rates (i.e., 24% and 4%). However, Bunt (1988) also stated that immobilisation is more likely in materials with a high C : N ratio as they are more deficient in N. Examples of C : N ratios of soil, sedge peat, and young sphagnum peat in the U.K. are 10 : 1, 20 : 1, and 40 : 1, respectively (Bunt, 1988). There are limitations with the C : N ratio as not all C is available to microorganisms and the available C : N ratio may be a more useful concept (Mtambanengwe and Kirchmann, 1995).

Fog (1988) described the interactions between the composition of materials and the microorganism population decomposing them. Where there is a large amount of cellulose in a substrate (i.e., high C : N ratio) then ascomycetes fungi will be the dominant decomposition agents. In contrast, wood decomposition is dominated by basidiomycetes fungi and although it may have a similar C : N ratio as a cellulose substrate, it has a slower rate of decomposition because of its higher lignin content. The different microorganism populations can operate in succession as they change the nature of the substance they are decomposing. It can be concluded that the C : N ratio is not an appropriate indicator of decomposition for all types of media, but it is more useful for predicting N immobilisation.

Added N. Fog (1988) reviewed the influence of added N on organic matter decomposition and found that the effect was dependent on the composition of the material. Easily decomposable materials generally with a low C : N ratio and lignin content will decompose much more quickly if additional N is supplied. However, resistant materials generally with high C : N ratios and/or lignin contents often decompose more slowly following N addition (i.e., sawdust). This may result from the added N disturbing the balance of competition between specific microorganisms, blocking the production of ligninase enzymes, increasing the breakdown of easily available cellulose and the accumulation of recalcitrant ligno-cellulose, and stimulating the formation of toxic substances (Fog, 1988). This may partly explain why a substrate consisting of only *P. radiata* sawdust has proved a successful growing medium for liquid-fed container-grown tomatoes. Bark, however, contains little or no lignin (depending on its wood content) and shows a more variable response to added N. Addition of N to composting bark is important when the bark has a high cellulose content (Hoitink and Poole, 1980).

MEASUREMENT OF DECOMPOSITION RATE

The C : N ratio has been shown to be a poor indicator of the decomposition rate and it does not necessarily correlate well with the amount of carbon dioxide (CO_2) release (Handreck, 1991). It is generally inconvenient and complex to measure C release as CO_2. The N-Drawdown Index (NDI) was developed as a laboratory method to measure the N immobilisation potential of container media following incubation with 75 mg litre^{-1} KNO_3. Handreck (1992ab) recommends the NDI test as a means of predicting the N fertiliser requirements of mixes. Materials such as fresh sawdust (from both hardwood and softwood species) have a high N immobilisation potential, and NDI values of close to zero. They consume large amounts of N (about 300 mg N litre^{-1} week^{-1}) and are difficult to obtain adequate growth from. Composted pine barks typically have NDI values of 0.3 to 0.6. Peat-based media often have NDI values close to one and hence have a low rate of decomposition and N immobilisation (Bodman and Sharman, 1993).

There are situations where the NDI test can give misleading results. Firstly, if a material has poor wettability, such as dry fresh *P. radiata* sawdust, it could have an NDI of 0.5 to 0.6 indicating that little or no decomposition has occurred. Handreck (1991) recommends that all test materials should be maintained at potting moisture content for at least 8 days before testing. The second potential problem is with materials that have been composted with a source of mineral N. If the material still contains high levels of ammonium following composting it can also produce an inflated NDI reading. Bragg and Whitely (1995) concluded from their experiments using NDI tests on a range of decomposing materials, that this test provides a "snapshot" of the N immobilisation potential at one time. Successive NDI tests may be needed to determine the N needs of a decomposing substance which may vary with time. An alternative to the NDI test could be to calculate the potential N immobilisation from the C available for decomposition (Mary et al., 1996), however this would require knowledge of the chemical analysis of the ingredients in the medium.

PLANT GROWTH RESPONSES

Richards (1981) outlined the problems of growing plants in pure *P. radiata* sawdust including the difficulty in providing sufficient N to overcome N immobilisation while avoiding osmotic stress from the salinity of the nutrients applied. Decreasing aeration was an additional problem. Thomas et al. (1980) found that seedling plants grown in peat/sand media were consistently superior to those grown in a similar mix but containing one third *P. radiata* sawdust. A range of fertiliser types and N levels did not significantly improve growth in the sawdust medium. The authors have measured strong *Ficus benjamina* growth response to increasing N levels in composted-bark-based and fresh-sawdust-based mixes (both from *P. radiata*), but at low N levels plants were superior in a peat-based mix (unpublished data). Plants growing in the sawdust-based mix generally showed greater leaf chlorosis indicative of N deficiency. Further unpublished work on container-grown liquid fed apple rootstocks found that Malling 9 rootstocks grew larger in a composted-bark-based mix compared with a 100% fresh sawdust medium (both from *P. radiata*). There was, however, no significant difference between media when MM106 rootstocks were used. Sharman and Bodman (1991) grew a range of woody ornamentals in media containing 50% composted *Eucalyptus* sawdust, other organic materials, and only 10% to 15% mineral materials. They applied controlled-release fertilisers at a range of rates and reported satisfactory growth particularly where leafy plants were grown at high N rates. Bragg and Whitely (1995) grew plants for 40 days in seven different organic media and also made sequential NDI tests and found that growth was correlated with the availability of N.

PRACTICAL RECOMMENDATIONS

Growers who suspect they have a N immobilisation problem or who wish to change the organic component in their container media can make sequential NDI tests over the duration of use of their media and/or have plant foliage samples analyzed for N. An N deficiency may be ameliorated in the short term by the use of additional inorganic N fertiliser, which may also reduce the rate of decomposition of the organic material. In the longer term the medium may need to be changed for example by using organic matter that is more resistant to decomposition.

The general recommendation is that media such as peat and composted pine bark, which have relatively low N immobilisation potential, are the preferred organic components for potting mixes. Additions of other organic materials such as fresh sawdust or SMC may appear economically attractive but it may be difficult to produce high quality plants using them. This is because of the difficulty of supplying sufficient inorganic N for plant growth to compensate for N immobilisation during the life of the media.

CONCLUSIONS

Nitrogen immobilisation, the temporary loss of available N to soil microorganisms, is associated with the decomposition of organic materials. The rate of decomposition, and hence N immobilisation, is related to factors including the chemical structure, particle size, wettability, and C : N ratio of the organic material. The environment surrounding the material including pH, nutrient availability, moisture, temperature, and microbial populations can also affect the decomposition rate. The C : N ratio may provide a reasonable estimate of the potential N immobilisation. The NDI test actually measures inorganic N uptake by container media but it also has limitations particularly because the media may decompose and hence have a varying NDI with time. Plant tissue N content measured during crop growth is also a very useful tool.

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