SUSTAINABLE FOREST MANAGEMENT NETWORK
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SFMN Research Note Series
No. 14

Tree Nutrient Availability: Concepts and Interpretation

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Highlights

- An understanding of nutrient jargon (available, exchangeable, mineralizable and total) is key to effectively interpreting soil and forest floor nutrient data.
- Overestimates of nutrients such as base cations may lead to an overly optimistic nutrient picture for a particular site. Seedlings on such sites may show deficiency symptoms and establish more slowly than expected (based on overestimates).
- Forest floor and mineral soil nutrient values can neither be taken at face value nor compared to other data unless the methods/nutrient extractants are known.

Terminology and jargon: what subject matter, including forestry, isn't rife with these nowadays? Forest nutrition, in particular, has no shortage of confusing and unclear terms, as it encompasses a range of other forest disciplines. Not only are there words to worry about but also different methods of analysis to consider. This means that knowing the theoretical meaning of, say, available phosphorus, is not enough. More information about the method with which phosphorus was extracted is needed before an interpretation of research results can be made. Different extraction methods give different results. Vastly different results could, in turn, affect forest management decisions – the choice, for example, between one site preparation method and another. This note gives an overview of the common terminology used in forest nutrition, compares the different terms and discusses the implications for forest management.

Let's start with terminology

Both the terms 'available' and 'exchangeable' are used with respect to soil nutrients. The term 'mineralizable' also arises, largely in reference to nitrogen (N). Total nutrients are commonly reported as well.

Available nutrients

When nutrients are said to be available, they are literally 'floating' in the soil solution (the water in mineral soil or forest floor) or are sometimes loosely attached to soil particles or organic matter – ready for uptake by plant roots. There are many available nutrients but the most important ones include nitrate (NO_{3-}), ammonium (NH_{4+}) and phosphate (PO_{42-}). Nutrients are not always available and hence, forest nutrition problems can arise. When unavailable, nutrients are considered 'tied up'. This means they are tied up in the soil biota, literally, and in soil organic matter. It is only once microorganisms decompose organic materials (e.g. plant and animal remains) that nutrients such as N and phosphorus (P) are made available. While nutrients in rocks and minerals, such as calcium (Ca^{++}) and potassium (K^{+}) are also part of the total nutrient pool, they are generally released much more slowly than those from organic matter.

Exchangeable nutrients

Exchangeable nutrients, like available ones, are those held on soil particles and organic matter. The difference is that exchangeable nutrients can be readily replaced by others. Once a nutrient is 'let go' by the charged surface of a soil particle (most commonly clay), it becomes available for plant use. The term 'exchangeable' most

often refers to the base cations – Ca++, K+ and magnesium (Mg++). Thus, exchangeable nutrients are available but available nutrients are not necessarily exchangeable. For instance, NO_{3-}, NH_{4+} and PO_{4-} are most often found in the soil solution (although they can be found to a limited degree on clay and organic matter exchange sites) and thus, are generally referred to as available, not exchangeable.

Mineralizable nutrients

The term 'mineralizable' is most commonly used in reporting N (and to a lesser degree carbon (C)). It refers to the amount of N that is 'mineralized' or made available by microorganisms as they decompose organic materials. Researchers usually arrive at this number using either lab or field (in-situ) incubations of forest floor or mineral soil over a given period of time. Methods can vary from one study to the next, and must be kept in mind when interpreting results.[1]

Extractable nutrients

The term 'extractable' is often used and is synonymous with available and exchangeable. It refers to the amount of nutrient that can be extracted from the soil solution and is ready for plant uptake.

Available versus total

Available nutrients are exactly that – available to plants. When the total amount of a nutrient is reported, it represents all that is readily available in addition to that which is 'tied-up'. Total nutrients are significant since some portion of them eventually becomes available as decomposition or soil mineral weathering proceeds. N is an important case in point. Total N in the top 40 cm of the mineral soil under an aspen/white spruce mixedwood might be 1500 kg/ha. At the same time only about 30 kg/ha of this might be found in the available form. In this case, knowing the total amount of N in the soil is key as this is the pool from which the available form will come.

Methods matter

As a brief glance at different materials and methods sections of research papers or reports will show, methods of analysis for soil nutrients are varied. For example, there are at least three different methods used to determine exchangeable cations and four different extractants for available phosphorus determination. Organic matter can also be estimated by several different methods. Why do methods matter? One method may be more efficient than another at extracting a certain nutrient, leading to underestimates by the less efficient method. Some extractants are more suited for acidic soils than others and so may give misleading results in basic soils. Methods are, unfortunately, not always chosen for their suitability to extract a certain nutrient but sometimes more for convenience and economic reasons.

The importance of extractants

An extractant is a solution made of water and a certain concentration of a chemical(s). A known amount of extractant is added to a given weight of soil and shaken for a predetermined time. The dissolved plant nutrients are subsequently separated out through filtration or centrifugation and analyzed on the appropriate equipment. Extractants remove nutrients from different compounds or granules in the soil and are developed for use on specific soils. For those soils, solutions are designed to extract the portion of the nutrient pool that is available for plant uptake and that subsequently translates into growth. The amount of nutrient extracted can also correlate with some measure of tree growth such as height or dbh. However, when those extractants are used on other soils with different chemical and mineralogical characteristics, they may not remove all of the available nutrient in question and would, therefore, underestimate availability and potential tree growth.

Send one mineral soil or forest floor sample to one lab and a replicate to another and the results may be dramatically different. This is the result of the use of different extractants that have not been calibrated to the region or soil type. Most frequently, such discrepancies are encountered with P and micronutrients. Interpretation of, and any management recommendations arising from, the soil test results in such cases are, at best, difficult--if not futile.

Some examples

Available phosphorus

Mehlich, Morgan's, Bray-P I or II and Olsen's are common P extractants. Mehlich extractants are composed of strong acids compared to Morgan's and therefore, generally extract more P from soils than the latter – roughly 1.5 times more. The Bray P1 extractant uses fluoride in its chemical mix to 'tie-up' aluminum and base cations while phosphorus is brought into solution. When there are too many base cations (e.g. fine-textured or calcareous soils), the Bray extractant is not nearly as effective. The result is an underestimate of available phosphorus. Consequently, the Bray P1 extractant is better suited (than Mehlich 3) for more acidic soils (pH < 6.8 in water) with a silty clay loam or finer texture while in higher pH and calcareous soils, Olsen's extractant is most suitable.[2]

Exchangeable base cations and cation exchange capacity

The concentration of base cations is one measure of soil productivity. Cation exchange capacity (CEC) is another. While related to the amount of cations, CEC specifically refers to the number of these nutrients that soil particles (clay and organic matter) can hold. In conjunction with other indicators, CEC is a good measure of soil nutrient supplying ability with clay soils generally having higher CEC's than sandy soils.

Several extractants are used to determine the amounts of Ca^{++}, Mg^{++} and K^{+}, and the CEC in forest floor and mineral soil samples – most frequently Olsen's, Morgan's, Mehlich, buffered ammonium acetate and unbuffered ammonium acetate. Extractions with ammonium acetate at pH 7 are very common largely because this method has been used historically. It is now known that exchangeable base cations and CEC are most accurately determined at the actual pH of the soil. Extractions with ammonium acetate, therefore, almost always overestimate base cation levels and CEC in acid soils and those with high organic matter. Extractions with barium chloride are recommended for accurate results as are extractions with unbuffered 1.0 M ammonium chloride.[3]

pH

The two common methods for pH estimates are made in a 1:1 water:soil paste or a 0.1M $CaCl_2$:soil paste. The latter method almost always results in lower pH readings. $CaCl_2$ not only measures the acidity in the soil solution (hydrogen ions floating around in the soil water film) but also H+ ions on soil particle exchange sites – the exchangeable acidity. Exchangeable acidity is an important consideration in highly acid soils (pH 5.5 or less), particularly fine-textured ones. This means that pH measured in water:soil paste may significantly overestimate soil or forest floor pH.[4] An overestimate of soil acidity could affect site nutrient availability (some nutrients being less available at low pH) and tree growth if management leads to further acidification (increased organic matter decomposition) and nutrient leaching.

Summary

There is an abundance of jargon with respect to tree nutrition – jargon that is important to understand in order to correctly interpret nutrient data. Knowledge of different extractants and their efficacy as well as the different methods of determining organic matter and pH is useful in making sense of research results, comparing data and interpreting soil test results.

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