Nutrient Management Improvements in Forestry Species

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Proper soil management and forest nutrition are key to maintaining the productivity of planted or natural forests. This article reviews related concepts and developments for Central American forests and focuses on relevant topics for forest managers including land evaluation, nutrient cycling, diagnosis of nutrient deficiencies, and limitations of general recommendations for liming and fertilizing.

Analyzing nutrient accumulation dynamics for *Terminalia amazonia* (J.F. Gmel.) Excell in South Pacific, Costa Rica.

Proper land evaluation is the first step towards a successful forest plantation. Poor forest growth is very often the result of planting in sites that were improperly assessed (Segura et al., 2013). Early success within a new plantation site is most easily achieved by conducting a site assessment step well before making any land purchase. New land evaluation tools are being developed for forest managers that involve statistical and modeling approaches. These models can predict species suitability based on soil and climate at a specific location. For example, our research is combining digital soil maps with modeling techniques to predict the suitability for teak (*Tectona grandis*) plantations based on remote sensing (Landsat images) and digital elevation models.

For small landowners who cannot afford to invest in new land, they have to make the best decisions based on the land they already own. In many cases their land has low soil fertility and problems related to soil acidity. Establishing species with high nutrient requirements like teak (**Figure 1**) or melina (*Gmelina arborea*) on marginal land is a common mistake. The alternative of using native species such as white olive or amarillón (*Terminalia amazonia*) and mahogany (*Swietenia macrophylla*) with less nutrient demands, could be more profitable (Griess and Knoke, 2011). Consideration of both the soil conditions at the site and species demands is critically important.

Nutrient cycling in forestry plantations is a topic that is often discussed in literature. In reality, even though forest managers and researchers typically agree on the need to assess the balance between the quantity of nutrients taken up by a growing forest and that which is removed from the site during timber extraction, there is a common lack of concern about this issue among plantations (Fölster and Khanna, 1997).

Agronomists have traditionally analyzed when, where, and at what rates nutrients are accumulated by annual crops, and extracted as harvested products. Such studies of nutrient accumulation dynamics of a forest species can be used to estimate: (i) nutrient removal caused by thinning or harvesting; (ii) nutrient requirement of the species during a rotation; (iii) amount of nutrients left at a site after harvesting; and (iv) minimum nutrient inputs (fertilizers) that a system needs to be sustainably managed (Alvarado and Raigosa, 2012).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum; B = boron; Cu = copper; Fe = iron; Mn = manganese; Na = sodium; Zn = zinc; ECEC = effective cation exchange capacity.

Even with all site and species information available, managers often need more dynamic and *in situ* tools for nutrient status evaluation. Foliar concentrations are considered key parameters for evaluating the nutritional status of a forest stand. Values considered as adequate for several species, as a combination of the results of several research projects, are provided in **Table 1**. This table acts as a simple guide, designed as a management reference for a range of forest species, regimes and ages. Managers can compare their foliar tissue analysis results with this reference guide. If the empirical value is within the range given then nutrition is considered adequate. However, if a nutrient concentration is below or above the range then professional advice should be sought or a more detailed study of the specific site and soil conditions should be recommended.

As soil critical levels are also commonly used as a conceptual framework in plant nutrition, similar work in Central America has focused on, for example, establishing soil nutrient critical levels for teak plantations—the main species for the

Table 1. Approximate average and range (in parentheses) for foliar nutrient concentrations in forest plantations of six species for Central America.

Species†	Age, years	N	Ca	K	Mg	P	S
		- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - -	% Dry weight - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -
Alnus acuminata (Alder, Aliso)	1-19	3.66 (3.57-3.75)	0.29 (0.27-0.31)	0.46 (0.44-0.48)	0.20 (0.19-0.20)	0.20 (0.19-0.24)	0.20 (0.20-0.21)
Gmelina arborea (Melina)	1-12	2.85 (2.78-2.92)	1.3 (1.23-1.38)	0.96 (0.90-1.03)	0.34 (0.33-0.36)	0.21 (0.-20-0.22)	0.15 (0.14-0.15)
Cedrela odorata (Cedar acajou)	1-19	2.74 (2.48-3.01)	0.92 (0.59-1.24)	1.06 (0.83-1.30)	0.15 (0.12-0.18)	0.18 (0.16-0.20)	0.22 (0.19-0.24)
Vochysia guatemalensis (White mahogany)	1-20	2.26 (2.14-2.38)	0.13 (0.11-0.15)	1.09 (0.95-1.22)	0.35 (0.31-0.38)	0.86 (0.65-1.08)	0.22 (0.20-0.24)
Tectona grandis (Teak)	1-19	1.97 (1.83-2.15)	1.34 (1.13-1.54)	0.88 (0.73-1.02)	0.29 (0.22-0.34)	0.16 (0.12-0.20)	0.12 (0.11-0.13)
Terminalia amazonia (White olive)	1-23	1.68 (1.54-1.83)	1.23 (1.02-1.43)	0.75 (0.68-0.83)	0.22 (0.19-0.24)	0.16 (0.12-0.20)	0.11 (0.10-0.12)
Species	**Age, years**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Al**
		- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - mg/kg	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -
Alnus acuminata (Alder, Aliso)	1-19	79 (73-85)	22 (21-23)	37 (35-39)	59 (40-77)	15 (14-16)	4 (3-4)
Gmelina arborea (Melina)	1-12	72 (61-83)	78 (65-91)	10 (9-10)	53 (49-57)	41 (38-44)	40 (32-48)
Cedrela odorata (Cedar acajou)	1-19	90 (79-101)	24 (17-31)	25 (17-34)	8 (6-9)	24 (15-33)	59 (43-76)
Vochysia guatemalensis (White mahogany)	1-20	97 (68-125)	6 (5-7)	20 (16-23)	113 (84-142)	29 (24-34)	22,907 (21,278-24,536)
Tectona grandis (Teak)	1-19	130 (85-175)	43 (39-46)	11 (10-12)	32 (24-39)	20 (18-21)	na
Terminalia amazonia (White olive)	1-23	76 (51-101)	275 (163-387)	9 (8-11)	26 (19-34)	33 (27-39)	na

† References: Avellán (2012); Camacho (2014); Ramirez (2014), and Fernández-Moya et al. 2013.
Note 1: Some of the values for *T. amazonica*, and *A. acuminata* are part of documents in preparation.
Note 2: Most of these reports have also information on nutrient dynamics, but see also Portuguez (2012) with specifics on teak dynamics. Our group has also information soon to be published, on the nutrient dynamics for *G. arborea*.

forestry sector (**Table 2**).

The results of many fertilization and liming trials in Latin America are generally inconsistent (Alvarado and Raigosa, 2012). The response of forests to fertilizer is known to vary according to a wide range of factors, and can be highly site-specific. Hence, more research is needed to understand the underlying differences between various fertilization trials in order to be able to predict any nutrient response prior to its application. Despite this lack of consistency, fertilizer application is still generally common in Central America, especially in large-scale forest plantations where it typically occurs only at planting.

Soil heterogeneity is a key factor determining fertilization success, especially in large forest plantations, even though a single recommendation is used across large areas. Establishing stand-specific nutrient management plans would be very complicated in many forests at present.

Table 2. Critical values for selected soil fertility variables for teak plantations in Central America.

	- Critical values -			
	Literature generic values (Bertsch, 1998)	Literature specific values (Alvarado and Fallas, 2004)	Literature specific values (Fernández-Moya et al., In review)	Experience of the authors
pH	5.5			
Ca, cmol(+)/L	4			10
Mg, cmol(+)/L	1			3
K, cmol(+)/L	0.2			
Acidity, cmol(+)/L	0.5			
Ca saturation, %		68		
Mg saturation, %				
K saturation, %			3.09	
Al saturation, %		3		
Na saturation, %			1.1	
P, mg/L	10			5

Ca saturation [Ca Sat=Ca/ECEC]; Mg saturation [Mg Sat=Mg/ECEC]; K saturation [K Sat=K/ECEC]; Acidity saturation [A Sat=Acidity/ECEC]; Na saturation [Na Sat=Na/ECEC]; ECEC = Acidity+Ca+Mg+K].
Analysis for pH in water, and all cations, Al, and acidity was a modified Olsen procedure (Díaz-Romeu and Hunter, 1978).

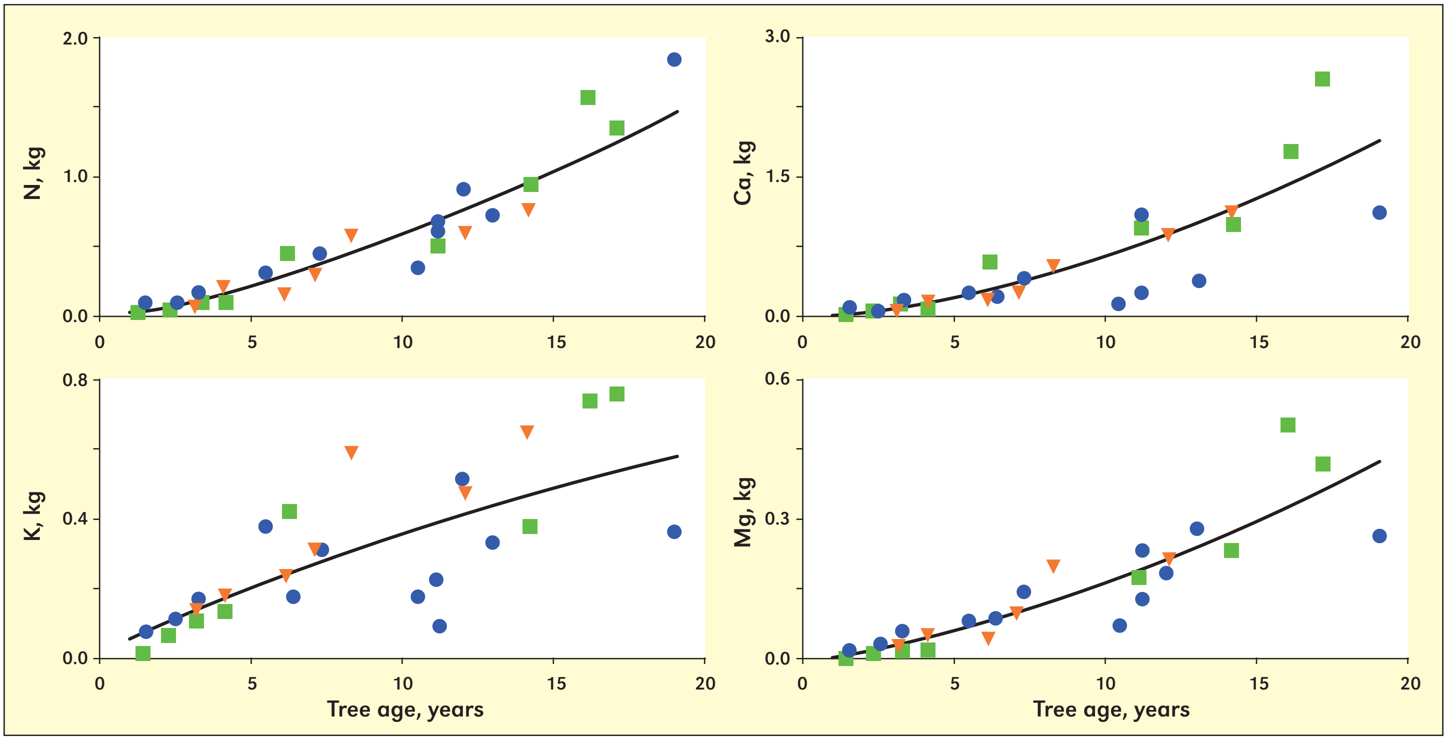

Figure 1. Tree bole and bark nutrient (N, Ca, K, and Mg) accumulation (kg/tree) related to tree age (years) in teak plantations (*Tectona grandis* L.f.). Points represent sampled trees at three different locations: Guanacaste, Costa Rica (■); Northern Region, Costa Rica (●); Panama (▼). Lines represent fitted models (Fernández-Moya et al., 2014 b).

In many large-scale and intensively managed forests, stands can be grouped by similarities in soil fertility through which managers can define management blocks. Fernández-Moya et al. (2014a) showed how multivariate analysis techniques could effectively contribute to the manager's decision on how to create these management units.

Finally, even though foliar and soil analyses can identify certain nutritional deficiencies, fertilization will not always have a positive effect if the factors that affect the success of fertilization are not taken into account. Plantation density is a key factor and a mandatory step in the design of fertilization programs should consider the thinning scheduling in order to identify synergies between different treatments. The usual low dosage of N-P-K fertilizers may not be adequate either, as higher dosages or perhaps other products may be more appropriate in many plantations. Hence, fertilizers containing more nutrients (e.g., Mg, Zn, B) or products that increase the availability of elements that are immobilized in the soil (e.g., biofertilizer or mycorrhizae) may be better choices in some cases. We have collected mycorrhizae throughout teak plantations in Costa Rica and proposed the inoculation of seedlings as a way to improve P uptake and enhance productivity, particularly in acid soils (Alvarado et al., 2004).

Summary

Forest plantation success depends on the use of several right decisions. With the sound support of land use evaluation tools and knowledge on the tree nutrient demand, we can select the best combination of species for each site. After planting we have diagnostic tools for tissue and soil that can help us decide on the nutrients we may need, or investing on further studies to implement site-specific management, instead of generalized fertilization regimes. We provide here the basic numbers for adequate diagnosis on six important forest tropical crops in Central America. BC

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