

Chapter 2

Nutrient Uptake, Removal, and Cycling in *Eucalyptus* Species

Akbar Ali, M. Naeem, Tariq Ahmad Dar, Mohd. Idrees, M. Masroor A. Khan, Moin Uddin, Prem Kumar Dantu, and Teg Bahadur Singh

Abstract *Eucalyptus* (family Myrtaceae), represented by over 900 species distributed throughout the world, are well known for their essential oils. Nutrient supply is treated as a dynamic variable which is related to relative growth rate. Plants take up the nutrients from the soil and use them for various metabolic processes. The genetic constitution of plants plays a superior role in determining the way assimilates are partitioned between roots, stems, and leaves. Different growth stages of the trees are reflected in processes of change that contribute to the control of nutrient demand, storage, and distribution. The amount of litterfall and nutrient return depends on the degree of biomass production and nutrient uptake in the stand. Cycling of nutrient is an important aspect as significant amounts of nutrients are returned to the soil through different mode and become available for cycling.

Keywords *Eucalyptus* • Biomass • Mineral nutrients • Accumulation • Cycling

A. Ali (✉)

Department of Botany, Dayalbagh Educational Institute, Agra 282005, India

Plant Physiology Section, Department of Botany, Aligarh Muslim University, Aligarh 202002, India

e-mail: akbar.agra.alig@gmail.com

M. Naeem • M.M.A. Khan

Plant Physiology Section, Department of Botany, Aligarh Muslim University, Aligarh 202002, India

T.A. Dar

Centre for Biodiversity Studies, School of Biosciences and Biotechnology, Baba Ghulam Shah Badshah University, Rajouri 185234, India

M. Idrees

Department of Mathematics and Sciences, College of Arts and Applied Sciences, Dhofar University, P. O. Box 2509, Salalah 211, Oman

M. Uddin

Women's College, Botany Section, Aligarh Muslim University, Aligarh 202002, India

P.K. Dantu • T.B. Singh

Department of Botany, Dayalbagh Educational Institute, Agra 282005, India

e-mail: akbar.agra.alig@gmail.com

2.1 Introduction

The genus *Eucalyptus* comprises of more than 900 species and various hybrids and varieties. These are well known for their essential oils. The *Eucalyptus* genus because of its high growth rate is presented as great soil nutrients demanding (Câmara et al. 2000). The nutrients absorption by eucalyptus trees is essential to their development and reproduction. Most metabolic reactions are not possible without mineral elements' presence. Different growth stages of the plant are reflected in processes of change that contribute to the control of nutrient demand, storage, and distribution in trees. Deficiency of important nutrients for tree metabolism determine according level its weakening (and therefore susceptibility increase to plagues and diseases), poor growth, not reaching sexual maturity or even death (Foelkel 2005). Among many roles of plant nutrients are constituents of plants' tissues, catalysts in various reactions, osmotic regulators, constituents of buffer systems, and regulators of membrane permeability (Pallardy 2008). Tree nutrition is important throughout development; the nutritional demands are larger from planting to canopy closure because this early stage of growth is predominantly the chlorophyll-producing tissues formation (Gómez 2006).

The circulation of nutrients in forests and plantations has received increasing attention over the past two to three decades with the major emphasis on the biological cycle between plant and soil of nutrient uptake, nutrient reabsorption before leaf senescence, nutrient use efficiency, etc. (Ovington 1965; Attiwill 1981; Bargali et al. 1992; Bisht 1993). Nutrient use efficiency can be estimated as the amount of aboveground net primary production per kilogram of nutrient taken up (Binkley et al. 1992).

The gross annual supply of a given nutrient from the soil is equal to the net annual demand of the stand. It is assumed that the total amount of the nutrient returned annually in the biogeochemical cycle from forest stand to soil is again available to the stand. The balance between the input of a nutrient in rainfall and the output in stream water (the geochemical cycle) is also considered as an available amount of nutrient. All these processes are ecologically important because plant nutrient uptake and nutrient recovery from senescing leaves are major components of ecosystem nutrient cycles.

In the beginning the gross productivity proportion of the plants is highest in the crown (leaves and branches), with high nutrient concentrations. Redistribution of nutrients linked to leaf senescence is small during this period and great amounts of nutrients are absorbed from the soil. This stage is characterized by increased nutrient accumulation rates, which peak during the crown closing phase (Attiwill 1981; Grove et al. 1996). The second stage includes crown closing when leaf biomass is stable or slightly decreasing and the heartwood generates most of the primary gross production. The heartwood nutrient content is low and this leads to a decrease in the nutrient accumulation rate of the tree. This is the phase of maximum soil exploitation by the fine roots and cycling processes are very intense. During the third growth

Table 2.1 Percentage of nutrients at different age in *E. grandis* plantation (Source: Bellote et al. 1980)

Age (years)/% of the total extracted nutrients							
Nutrients	1	2	3	4	5	6	7
N	21.6	34.6	47.7	60.8	73.9	86.9	100
P	21.8	28.1	46.6	69.7	90	99.9	100
K	13.4	27.8	42.2	56.7	85.6	85.6	100
Ca	8.2	15.9	32.7	49.5	83.2	83.2	100
Mg	1.1	18.7	36.2	53.8	89	89	100
S	9.9	24.9	39.9	54.9	85	85	100

stage of the tree, the greatest part of gross primary productivity is associated to the maintenance of the produced biomass (Miller 1984; Grove et al. 1996).

Annual nutrient uptake = annual nutrient increment + annual nutrient return.
Annual nutrient return = \sum (aboveground litterfall biomass of tree each month in the stand \times nutrient concentration in litterfall each month).
Cycling coefficient (%) = (annual nutrient return/annual nutrient uptake) \times 100%.

2.2 Nutrient Uptake

Plants take up the nutrients from the soil and use them for various metabolic processes. Some of the plant parts such as leaves, branches, seeds, fruits, and roots are returned to the soil during the plant’s growth. The nutritional factor can be expressed as a “flux density” or the amount of nutrient available per unit of time and unit of area.
In the beginning the gross productivity proportion of the plants is highest in the crown (leaves and branches), with high nutrient concentrations. The processes regulating nutrient transfers that require basic knowledge are as follows:

1. The geochemical cycle (in the soil)
2. The biogeochemical cycle (between tree and soil)
3. The biochemical cycle (inside the trees)

The eucalyptus can achieve a high biomass production on a low nutrient uptake. The nutrient use efficiency of eucalyptus increased with the decrease of the availability of the nutrient in the soil (FAO 2011). The majority of the nitrogen, phosphorus, and potassium were found in the eucalyptus trees. Laclau et al. (2000) showed that more than half of the nitrogen and 35% of the potassium in a stand of *Eucalyptus alba* hybrids had accumulated in the tree biomass by the time the stand reached 2 years. Bellote et al. (1980) reported the *Eucalyptus grandis* on the evolution of the nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur content as function of age (1–7 years). The data nutrient content for each year shows as a percentage of totals extracted at the end of 7 years (Table 2.1).

All nutrients showed a maximum accumulation at 7 years old (increasing trend with increasing age) with the exception of phosphorus, which at 6 years had already accumulated 99.9% of the total extracted. By the fourth year more than 50% of the total of all nutrients have been removed except calcium, with an accumulation at that age of 49.5%. Schumacher and Caldeira (2001) reported the nutrient content in different compartments of forest biomass in 4-year-old *E. globulus*. The tree stem represents 69% of total biomass, which contained only 29% of the nitrogen, 28% of the phosphorus, 40% of the potassium, 12.5% of the calcium, and 34% of the magnesium. However leaves with 15% of the total biomass (larger canopy proportion than in other studies because are young trees in this instance) contained 60% of the nitrogen, 45% of the phosphorus, 33% of the potassium, 23% of the calcium, and 29.5% of the magnesium. On the other hand, bark was the element that accumulated 55.3% of the total calcium, representing only about 9% of total biomass.

George (1984) reported that 120 t ha⁻¹ of total biomass in *Eucalyptus* plantation constituted 69% aboveground biomass and accumulated 42, 50, and 35% N, P, and K of total uptake amounting to 168, 47, and 104 kg ha⁻¹, respectively. Nitrogen status of plants affects growth mainly via light interception by strongly influencing the partitioning of assimilates between roots, stem, and leaves (Agren and Ingestad 1987; Ingestad and Agren 1988). The concentration of potassium but generally not of nitrogen and calcium is significantly lower in heartwood than in sapwood in both eucalyptus and conifers (Turner 1981; Wright and Will 1958).

The decreasing concentrations of Ca and Mg in the bark with increasing tree age may indicate a reduced availability of these nutrients for plants due to exhaustion of their exchangeable forms in the soil, as well as retranslocation of nutrients from this tissue as trees grew older. The reduction of K, Ca, and Mg concentrations in the stem wood, however, may have been caused by stronger supply restrictions by the soil, just as much as by higher internal cycling rates stimulated by higher heartwood production rates with increasing age (Reis and Barros 1990). Plants are opportunists and, when possible, take up more nutrients than actually required for growth of new tissues. A positive correlation between the tissue content of minerals and plant growth is generally observed also under field conditions (Aronsson and Elowson 1980; Pereira et al. 1989; Snowdon and Benson 1992; Rytter and Ericsson 1993; Nilsson and Wiklund 1994, 1995).

2.3 Nutrient Removal

The percentage return of nutrients varies with species, site conditions, plant age, etc. (Sugur 1989). Nutrient withdrawal from senescent leaves to stems and roots is certainly an important mechanism by which plants make more efficient use of a limited nutrient resource. Between one-third and two-thirds of the leaf nitrogen and phosphorus contents can in this way be transported back to woody tissues and stored for use in the coming season (Bernier 1984; Ericsson 1984; Pereira et al. 1989; van den Driessche 1984). Stem harvest with de-barking in the intensively fertilized

treatment would result in removal of 127 kg ha⁻¹ nitrogen, 13 kg ha⁻¹ phosphorus, and 65 kg ha⁻¹ potassium reported by Rudhe (2014). Similar values have been estimated by Laclau et al. (2000) where stem harvest with de-barking of *E. alba* hybrids for pulpwood resulted in exports of 82 kg ha⁻¹ nitrogen, 23 kg ha⁻¹ phosphorus, and 31 kg ha⁻¹ potassium. Without knowing all sources of nutrient input to the ecosystem, it is difficult to know if the removal will result in a depletion of nutrients in the long term. Similarly reported by many researchers (Qui et al. 2011; Carneiro et al. 2008; Brady and Weil 2007; Gonçalves et al. 2004), keeping as much biomass as possible at the site could be important to sustain the productivity. As the result indicates, much of the available plant nutrients are received from the litter and the biomass, and if too large amounts of nutrients are removed from the ecosystem, depletion of nutrients in the soil could be expected.

2.4 Nutrient Cycling

Nutrient dynamics in soil-plant system are studied under a common term called “nutrient cycling.” Cycling of nutrient is an important aspect as significant amounts of nutrients are returned to the soil through litterfall and become available for cycling.

Cycling processes in forest ecosystems have been defined (Switzer and Nelson 1972) in terms of:

1. The biogeochemical cycle between plant and soil
2. The biochemical cycle of internal transfer within the forest stand
3. The geochemical cycle of import export to the forest ecosystems

In the process of internal biological cycle, there are two important pathways: The first is tree to soil—along this nutrients are transported to forest floor via leaf/litterfall, twig, fruits, and flower drop, etc. The other pathway is movement of nutrient elements from soil to tree through the activity of root systems.

Nutrient cycling in forest plantations can be defined as the exchange of nutrient elements between the living and nonliving components of the forest ecosystem. The uptake of nutrients by plant roots, their incorporation into living tissue, and the release of nutrients from organic matter through decomposition causes nutrients to cycle within terrestrial ecosystems. Therefore, the nutrient cycling process involves nutrient uptake and storage in vegetation in perennial tissues, litter production, litter decomposition, nutrient transformation by soil fauna and flora, nutrient input from the atmosphere, and the weathering of primary minerals and nutrient export from the site by harvest and other removals, leaching, erosion, and gaseous transfers.

Nutrient retranslocation from senescing or dead tissue (leaves, heartwood, or bark) to growing tissues is one of the ways to increase utilization efficiency of limited nutrients by trees. Nutrient retranslocation from leaves means the largest contribution to the biogeochemical cycle of nitrogen, phosphorus, and potassium (mobile nutrients), followed in importance by retranslocation due to duraminization

process and in lesser extent by redistribution from the outer bark (Grove et al. 1996). Nutrient retranslocation proportion due to leaf senescence depends on the initial concentration and mobility of nutrient in the phloem. Eucalyptus trees are particularly efficient in phosphorus retranslocation in wood during heartwood formation, finding for various species concentrations from five to thirty times higher in sapwood than in heartwood. Potassium generally follows the same behavior as phosphorus, while nitrogen has smaller concentration differences between sapwood and heartwood. Calcium retranslocation in duraminization process shows significant differences depending on species and site. Therefore in cases where the internal calcium redistribution is small, the tree requires continuous absorption from the soil of this nutrient (Turner and Lambert cited by Grove et al. 1996).

The depletion of soil nutrients is one of the most commonly cited criticisms associated with the eucalyptus (Jagger and Pender 2003). In contrast to other trees commonly used, such as *Leucaena* and *Acacia*, *Eucalyptus* species do not fix nitrogen from the atmosphere as the leguminous species do. According to some authorities, monoculture plantation forestry may affect soil chemical properties in two ways: nutrient depletion from the soil into the tree components and change in the chemical status of the soil surface as the litter layer is dominated by leaf fall derived from one species. Forest management practices can aggravate or reduce the magnitude of these effects. For example, the nutrient cycle at a site can be improved by mixing *Eucalyptus* species with nitrogen-fixing species such as *Acacia*.

Forrester et al. (2005) have compared monocultures of *E. globulus* (E) and *Acacia mearnsii* (A) and mixtures of these species planted in a species replacement series: 100% E, 75% E + 25% A, 50% E + 50% A, 25% E + 75% A, and 100% A. The result indicated that highest and the lowest aboveground biomass was obtained from 50:50 mixtures and monoculture, respectively.

The concentrations in the physiologically active leaves and litterfall leaves differed after 4.5 years, indicating the magnitude of biochemical nutrient cycling that occurs during the process of leaf senescence. Values of -43.8%, -63.6%, -53.3%, +24.0%, -22.2% were found for N, P, K, Ca, and Mg, respectively, showing the release sequence: P > K > N > Mg and the absence of Ca mobility. The same sequence was observed for leaves and leaf litter (consisting mainly of leaves) after 2.5 years, (-62.9%, -56.7%, +10.6%, and -18.0% for P, K, Ca, and Mg, respectively) (Leite et al. 1998). For *E. diversicolor* and *E. marginata*, the nutrient percentage retranslocated from senescent to younger leaves was -56.0%, -71.1%, -63.0%, +30.0%, and -4.0% for N, P, K, Ca, and Mg, respectively (Grove et al. 1996). Attiwill (1981) reported that the remobilized N and P quantities of senescent eucalyptus leaves are greater than in other annual or woody species.

There are other minor routes like stem flow, crown/canopy washed, and through rainfall in which the nutrients are dissolved in rains as atmospheric input into forest soil. Nutrient remobilization (on a mass base) from the bark and stem wood has the greatest contribution to the biochemical cycle in eucalyptus trees (Grove et al. 1996).

The nonmobile nutrients in the phloem, similar to Ca in the trunk, are retransferred outward during heartwood formation or from the outer bark to tissues in

growth process. This process is not observed in leaves, where Ca is retained in the aging tissues (Grove et al. 1996). Calcium remobilization in trunk and branches seems to be the greatest source of Ca in many species with marked differences of Ca concentrations between heart- and sapwood or between inner and outer bark, particularly when Ca absorption by the roots is limited. A large fraction of the nutrients required for growth of new tissues can be met by internal cycling of nutrients. The ability to use the same nutrients over and over again, before they are finally discarded in litter or immobilized in heartwood, is a characteristic which is particularly well developed in trees. Although trees are very efficient at cycling nutrients from old to young tissues, sooner or later part of the nutrients contained in the living biomass will be lost in the litterfall.

The contribution of biochemical cycling to gross annual demand is the amount of a given nutrient which is moved from the sapwood before its transition to physiologically inactive heartwood, plus the amount of that nutrient which is moved from that portion of the stand which is to fall as litter. The external geochemical cycle encompasses input of nutrient elements by various means such as precipitation, weathering of rocks, biological N₂ fixation, fertilization, etc., and output of nutrients through harvest, forest fire, volatilization, leaching, drainage, erosion, etc.

The nutrients that most frequently limit forest growth are nitrogen (N) and phosphorus (P) (Fisher and Binkley 2000). Nutrient availability can alter growth rate through changes in dry mass partitioning, in specific leaf area, or in the assimilation rate per unit leaf area (Kirschbaum et al. 1992; Madeira et al. 2002; Sands et al. 1992; Xu et al. 2002).

References

- Agren, G. I., & Ingestad, T. (1987). Root:shoot ratio as a balance between nitrogen productivity and photosynthesis. *Plant, Cell & Environment*, 10, 479–486.
- Aronsson, A., & Elowson, S. (1980). Effects of irrigation and fertilization on mineral nutrients in scots pine needles. *Ecological Bulletins*, 32, 219–228.
- Attiwill, P. M. (1981). Energy, nutrient flow, and biomass. In *Australian forest nutrition workshop productivity in perpetuity* (pp. 131–144). Melbourne: CSIRO Publishing.
- Bargali, S. S., Singh, R. P., & Singh, S. P. (1992). Structure and function of an age series of eucalypt plantations in central Himalaya. II. Nutrient dynamics. *Annals of Botany*, 69, 413–421.
- Bellote, A. F. J., Sarruge, J. R., Haag, H. P., & de Oliveira, G. D. (1980). Extração e exportação de nutrientes pelo *Eucalyptus grandis* Hill ex Maiden em função da idade: 1-macronutrientes. *IPEF*, 20, 01–23.
- Bernier, B. (1984). *Nutrient cycling in populus: A literature review with implications in intensively-managed plantations*. IEA/ENFOR, Report 6 (p. 46). Ottawa: Canadian forest service.
- Binkley, D., Dunkin, K. A., De Bell, D., & Ryan, M. G. (1992). Production and nutrient cycling in mixed plantations of *Eucalyptus* and *Albizia* in Hawaii. *Forest Science*, 38, 393–408.
- Bisht, K. (1993). Growth of *Quercus leucotrichophora* A. Camus and *Pinus roxburghii* Sarg. Seedlings in relation to nutrient and water. *Proceedings of the Indian National Science Academy*, 59, 71–78.
- Brady, N. C., & Weil, R. R. (2007). *The nature and properties of soils* (14th ed.). Upper Saddle River, NJ: Prentice Hall.

- Câmara, C. D., de Paula, L. W., & Vieira, S. A. (2000). Corte raso de uma plantação de *Eucalyptus saligna* de 50 anos: impactos sobre a ciclagem de nutrientes em uma microbacia experimental. *IPEF, Scientia Forestalis*, 57, 99–109.
- Carneiro, M., Fabião, A., Martins, M. C., Fabião, A., Abrantes da Silva, M., Hilário, L., & Lousã m, M. M. (2008). Effects of harrowing and fertilization on understory vegetation and timber production of a *Eucalyptus globules* Labill. Plantation in Central Portugal. *Forest Ecology and Management*, 255, 591–597.
- van den Driessche, R. (1984). Nutrient storage, retranslocation and relationships of stress to nutrition. In G. D. Bowen & N. EKS (Eds.), *Nutrition of plantation forest* (pp. 181–210). London: Academic Press.
- Ericsson, T. (1984). *Nutrient cycling in willow. IEA/ENFOR, Report 5* (p. 32). Ottawa: Canadian forestry service.
- FAO. (2011). Eucalyptus in east africa, socio-economic and environmental issues. In G. Dessie & T. Erkossa (Eds.), *Planted forests and trees working paper 46/E, forest management team, forest management division*. Rome: FAO.
- Fisher, R. F., & Binkley, D. (2000). *Ecology and management of forest soils* (3rd ed.). New York, NY: Wiley.
- Foelkel, C. (2005). *Minerais e nutrientes das árvores dos eucaliptos: Aspectos ambientais, fisiológicos, silviculturais e industriais acerca dos elementos inorgânicos presentes nas árvores. Eucalyptus Online Book & Newsletter*. Retrieved from http://www.eucalyptus.com.br/capitulos/capitulo_minerais.pdf.
- Forrester, D., Bauhus, J., & Cowie, A. L. (2005). Nutrient cycling in a mixed-species plantation of *Eucalyptus globulus* and *Acacia mearnsii*. *Canadian Journal of Forest Research*, 35, 2942–2950.
- George, M. (1984). Nutrients removal from eucalyptus plantations by harvesting wood. *Indian Forester*, 110, 61–67.
- Gómez, C. (2006). *Detección de limitantes nutritivos en Eucalyptus a través de ensayos en macetas*. Retrieved from Monografias.com. <http://www.monografias.com/trabajos38/limitantes-nutritivos/limitantesnutritivos2.shtml>.
- Gonçalves, J. L. M., Stape, J. L., Laclau, J. P., Smethurst, P., & Gava, J. L. (2004). Silvicultural effects on the productivity and wood quality of eucalypt plantations. *Forest Ecology and Management*, 193, 45–61.
- Grove, T. S., Thomson, B. D., & Malajczuk, N. (1996). Nutritional physiology of eucalypts: Uptake, distribution and utilization. In P. M. Attiwill & M. A. Adams (Eds.), *Nutrition of eucalypts* (pp. 77–108). Australia: CSIRO.
- Ingestad, T., & Agren, G. (1988). Nutrient uptake and allocation at steady-state nutrition. *Physiologia Plantarum*, 72, 450–459.
- Jagger, P., & Pender, J. (2003). The role of trees for sustainable management of less-favored lands: The case of *Eucalyptus* in Ethiopia. *Forest Policy and Economics*, 5, 83–95.
- Kirschbaum, M. U. F., Bellingham, D. W., & Cromer, R. N. (1992). Growth analysis of the effect of phosphorous nutrition on seedlings of *Eucalyptus grandis*. *Australian Journal of Plant Physiology*, 19, 55–66.
- Laclau, J. P., Bouillet, J. P., & Ranger, J. (2000). Dynamics of biomass and nutrient accumulation in a clonal plantation of eucalyptus in Congo. *Forest Ecology and Management*, 128, 181–196.
- Leite, F. P., Barros, N. F., Novais, R. F., & Fabres, A. S. (1998). Acúmulo e distribuição de nutrientes em *Eucalyptus grandis* sob diferentes densidades populacionais. *Revista Brasileira de Ciência do Solo*, 22, 419–426.
- Madeira, M., Fabiao, A., & Steen, E. (2002). Mass and chemical composition of roots in a *Eucalyptus globulus* plantation after one year under different water and plant nutrient regimes (in preparation).
- Miller, H. G. (1984). Dynamics of nutrient cycling in plantation ecosystems. In J. R. Aldous (Ed.), *Wood for energy: The implications for harvesting, utilization and marketing* (pp. 137–146). Edinburgh: Institute of chartered foresters.

- Nilsson, L. O., & Wiklund, K. (1994). Nitrogen uptake in a Norway spruce stand following ammonium sulphate application, fertigation, irrigation, drought and nitrogen-free-fertilization. *Plant and Soil*, 164, 221–229.
- Nilsson, L. O., & Wiklund, K. (1995). Nutrient balance and P, K, mg, S and B accumulation in a Norway spruce stand following ammonium sulphate application, fertigation, irrigation, drought and N-free fertilization. *Plant and Soil*, 168–169, 437–446.
- Ovington, J. D. (1965). Organic production, turnover and mineral cycling in woodlands. *Biological Reviews*, 40, 295–336.
- Pallardy, S. G. (2008). *Physiology of Woody plants* (3rd ed.p. 454). New York: Elsevier.
- Pereira, J. S., Linder, S., Araujo, M. C., Pereira, H., Ericsson, T., Borralho, N., & Leal, L. C. (1989). Optimization of biomass production in *Eucalyptus globulus* plantations. In J. S. Pereira & J. J. Landsberg (Eds.), *Biomass productivity by fast growing trees* (pp. 101–121). Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Qui, S., Bell, R. W., Hobbs, R. J., & Mc Comb, A. J. (2011). Estimating nutrient budgets for prescribed thinning in a regrowth eucalyptus forest in south-west Australia. *Forestry*, 85, 01–11.
- Reis, M. G. F., & Barros, N. F. (1990). Ciclagem de nutrientes em plantios de eucalipto. In N. F. Barros & R. F. Novais (Eds.), *Relação solo-eucalipto* (pp. 265–302). Viçosa, MG: Folha de Viçosa.
- Rudhe, J. (2014). Where has the fertilizer gone? Closing the nutrient budget for a eucalyptus fertilization experiment in Southern China. Master Thesis. Southern Swedish forest Research Centre, Swedish University of Agricultural Sciences.
- Rytter, L., & Ericsson, T. (1993). Leaf nutrient analysis in *Salix viminalis* (L.) energy forest stands growing on agricultural land. *Journal of Plant Nutrition and Soil Science*, 156, 349–356.
- Sands, P. J., Cromer, R. N., & Kirschbaum, M. U. F. (1992). A model of nutrient response in *Eucalyptus grandis* seedlings. *Australian Journal of Plant Physiology*, 19, 459–470.
- Schumacher, M. V., & Caldeira, M. V. W. (2001). Estimativa da biomassa e do conteúdo de nutrientes de um povoamento de *Eucalyptus globulus* (Labillardière) sub-espécie *maidenii*. *Ciência Florestal*, 11, 45–53.
- Snowdon, P., & Benson, M. L. (1992). Effects of combinations of irrigation and fertilization on the growth and above-ground biomass production of *Pinus radiata*. *Forest Ecology and Management*, 52, 87–116.
- Sugur, G. V. (1989). Litter production and nutrient cycling of different species under plantation conditions. *My Forest*, 25, 43–49.
- Switzer, G. L., & Nelson, L. E. (1972). Nutrient accumulation and cycling in loblolly pine (*Pinus taeda* L.) plantation ecosystems: The first twenty years. *Soil Science Society of America Proceedings*, 36, 143–147.
- Turner, J. (1981). Nutrient supply in relation to immobilization in biomass and nutrient removal in harvesting. In *Proceedings Australian Forest nutrition workshop. Productivity in perpetuity* (pp. 263–275). Canberra, Australia: Australian Forestry Council.
- Wright, T. W., & Will, G. M. (1958). The nutrient content of scots and Corsican pines growing on sand dunes. *Forestry*, 31, 13–25.
- Xu, D., Dell, B., Malajczuk, N., & Gong, M. (2002). Effects of P fertilisation on productivity and nutrient accumulation in a *Eucalyptus grandis* *E. urophylla* plantation in southern China. *Forest Ecology and Management*, 161, 89–100.

Essential Plant Nutrients

Uptake, Use Efficiency, and Management

Naeem, M.; Ansari, A.A.; Gill, S.S. (Eds.)

2017, XVI, 569 p. 52 illus., 29 illus. in color., Hardcover

ISBN: 978-3-319-58840-7