Journal of Stress Physiology & Biochemistry, Vol. 15, No. 4, 2019, pp. 5-14 ISSN 1997-0838

ORIGINAL ARTICLE

OPEN ACCESS

Nutrient Use Efficiency in Eucalyptus clones

S. Saravanan

Silviculture, Forest Management and Agroforestry division Tropical Forest Research Institute (Indian Council of Forestry Research and Education) RFRC (PO), Mandla Road, Jabalpur – 482021. Madhya Pradesh, India

*E-Mail: saravanans@icfre.org and ifgtbsara9@gmail.com

Received September 13, 2019

The Institute of Forest Genetics and Tree Breeding (IFGTB), Coimbatore, India functioning under the Indian Council of Forestry Research and Education (ICFRE), Dehara Dun, India, has a long term systematic tree improvement programme in *Eucalyptus* spp. aimed to enhancing productivity and screening of clones for site specific. In the process, twenty four clones of *Eucalyptus* spp. were studied for the nutrient use efficiency (NUE) from the established clonal trials. It also provides valuable information for establishing plantations at different geographic locations. Considerable variations were observed when the selected 24 clones of Eucalyptus spp. were subjected to NUE studies. The clones of C-188, C-10, C-14, C-19, C-123 and C-186 are falls in one cluster and the NUE for production of biomass and the commercial wood, the Eucalyptus clones of are registered lower consumption of available nutrients for production of biomass and commercial wood compared to ruling clones and the seed origin seedlings. Further, the clonal variations in NUE are discussed in detail in this article and clones suitable for large scale planting with higher productivity and NUE.

Key words: Clonal trial, Nutrient use efficiency, Eucalyptus clones, Productivity

Frequent nutrient removals accompanying wood and crop harvests from rotational woodlot systems may contribute to declining site productivity and sustainability because of soil nutrient depletion. However, selecting for nutrient-efficient tree species may well sustain productivity under this system. The FAO report of 2010 points to an expected population growth of about 34% by 2050, because of this, the demand for food and for products of plant origin will tend to increase. For example, to meet the demand for food, it is estimated that agricultural production should grow 70% by the middle of this century. This will also happen with the demand for forest products, such as wood for the production of energy and pulp. Therefore, in addition to an increase in productivity, new areas should be included for wood production, especially in Asia.

Short-rotation forests, associated with the high use of local resources, have raised questions related to the ecological impact of plantations and the sustainability of timber production by the forest (Stape *et al.,* 2004), which, among other factors, is determined by the nutrient balance of the soil-plant system (Santana, 2008).

Eucalypts are among the most widely cultivated forest trees in the world. The major Eucalyptus growing countries are China, India and Brazil. Growth rates that routinely exceed 35 m^3 ha^{-1} $year^{-1}$. These fast-growing plantations can be grown under a range of different climates for products that include pulp and paper, charcoal, fuel wood, and solid wood products such as poles, furniture, and timber construction. The pulp and paper industry is one of the key industrial sectors contributing to the Indian economy. There are 759 paper mills in India with an operating capacity of 12.7 million tonnes and consumption at 11 million tonnes with 9.3 kg per capita consumption of paper. Commercial forest plantations can relieve pressure on primary forests and meet timber supply needs, support local economies and stimulate biomass and soil carbon sequestration.

The increasing demand for wood products and the benefits of sequestering carbon dioxide are important aspects of forests plantation, however, more information is needed on soil resource demands and environmental impacts from fast-growing forest species. This information is especially needed to plant trees on marginal lands such as degraded agricultural and pasture and to ensure sustainable forest production practices.

Many pulp and paper and other wood based industries are now establishing clonal forestry programme after the promulgation of 1988 National Forest Policy of India. The policy also indicated that small and marginal farmers have to be encouraged to grow wood species required in forest based industries in their marginal and sub-marginal lands. Over 5 million hectares of eucalyptus plantations have been established throughout India. As a fast growing, remunerative and consistently demanded industrial wood, Eucalyptus has witnessed an unfettered support in India. Eucalyptus clonal planting has been said to have advantages includes quick provision of benefits associated with fast growth, short rotation for production of pulp wood (about 70 MT ha^{-1}), ready marketing and other reasons. It is an important industrial species and now popularized among the farmers due to varies reasons especially climatic vagaries (erratic and shortage of total rainfall, variation in the distribution, etc.) and shortage of irrigation to agriculture.

The clonal plantations are the one among the best option to meet out the ever increasing demand for paper and pulp wood. But there is a continuous depletion of the natural resources especially various nutrients from the soil due to its repeated rotation and fast growth in nature. Information on consumption of natural resources mainly water and nutrients for production of biomass and stem wood are not well documented especially in Eucalyptus clones. The clonal evaluation for better nutrient use efficiency study will help to overcome the natural calamities and proper management and optimum utilization of nutrients for wood production.

Eucalyptus is the most planted genus in tropical regions, but the sustainability of these plantations is a major concern of researchers, since these forests are usually established in soils of low fertility, with a large export of nutrients occurring every 6-7 years with the removal of biomass through forest harvesting (Laclau *et al.,* 2010). Therefore, the use of inputs is increasing in the forestry sector to balance the output of nutrients when harvesting.

Increasing the efficiency of using nutrients to produce new biomass may be an important competitive strategy for plants adapted to infertile environments. Nutrient-use efficiency has commonly been defined as the amount of production per unit nutrient used. In short-lived plants this value is simply the inverse of tissue concentration, but in perennial plants it is most appropriately defined as total net primary production (above- and belowground) per unit nutrient absorbed annually. Increased nutrient-use efficiency with decreasing nutrient availability has been demonstrated in both single species and mixed communities. Nutrient use efficiency, defined as the ratio of biomass production to nutrient uptake, has been proposed as a criterion for selecting tree species for this purpose. This ratio describes differential abilities of tree species to use soil nutrients for growth. It also provides a basis for comparing nutrient ''costs'' of biomass production and the potential of plant species to grow well under conditions of limited soil nutrient supply. The role of nutrient use efficiency in sustaining productivity of short-rotation tropical plantations by minimizing nutrient loss from harvesting. The general consensus is that nutrient-efficient tree species reduce nutrient export at harvests because of low nutrient content per unit biomass.

Therefore the present study was undertaken to assess nutrient use efficiency of *Eucalyptus* clones along with the commercial clones available in the market at present and the seed origin seedlings for comparison purpose. The findings of the study will help in screening the clones for higher nutrient use efficiency and also adds value for the particular clone at the time of commercial release.

MATERIALS AND METHODS

To carry out the nutrient use efficiency study, *Eucalyptus* clones are selected as the experimental material. This includes 24 clones and two seed origin seedlings. Among the 24 clones, 16 clones are shortlisted by IFGTB and these clones are numbered from C-7 to C-196. For comparison purpose, 8 clones (6 ITC clones and 2 TNPL clones) and two seed origin seedlings (each one from Tamil Nadu Forest Plantation Corporation and IFGTB) are selected and named as check clone 1 to 10. The biomass components like leaf, branch, wood, root, etc. of the different clones of *Eucalyptus* were analyzed for various nutrients like nitrogen, phosphorus, potassium, calcium and magnesium and the nutrient content presents in the different biomass components along with the nutrient concentrations were analyzed as per the standard procedures *viz.* Nitrogen (Alkaline potassium permanganate method by Subbiah and Asija, 1956), Phosphorus (Olsen's method by Olsen *et al*., 1954), Potassium (Flame photometer by Hanway and Heidal, 1952) and Calcium and Magnesium (Versenate method by Jackson, 1962). Observations from 25 ramets per clone in 3 replications were recorded for all the nutritional parameters in the *Eucalyptus* clonal trials established in 4 locations to study the NUE. The data obtained on nutrient contents in various biomass components were used to perform correlation, regression and other statistical analysis using SPSS® 21.0 version and Microsoft® Excel 2007 (Panse and Sukhatme, 1985).

Nutrient content in the biomass components including the concentrations

The biomass components like leaf, branch, wood, root, etc. of the different clones of Eucalyptus were analysed for various nutrients like nitrogen, phosphorus, potassium, calcium and magnesium and the nutrient content presents in the different biomass components along with the nutrient concentrations.

Nutrient Use Efficiency for production of biomass

Data collected on various nutrients were analyzed statistically by using the software GENSTAT version 3.2.0 and SPSS version 21. The results showed that, there is a significant difference among the clones and the results are presented.

RESULTS

Nitrogen use efficiency

The nutrients that most frequently limit forest growth is nitrogen. Nutrient availability can alter growth rate through changes in dry mass partitioning, specific leaf area or in the assimilation rate per unit leaf area. In the case of nitrogen use efficiency (required to produce the biomass of one kilogram), clone C-188 recorded the lowest level of nitrogen consumption (0.181, 0.179 and 0.162 g) for production of biomass (kg). Check clone 5 registered the highest amount of nitrogen consumption (0.252 g) in the 1st year, check clone 2 recorded an amount of 0.256 g and 0.240 g in the 2nd year and 3rd year, with the mean of 0.209, 0.207 and 0.190 g during 1st, 2nd and 3rd year respectively, for production of biomass (kg).

Phosphorus use efficiency

Globally, phosphorus (P) limits productivity of trees in many forests and plantations. Many experiments with Eucalyptus seedlings showed that responses to nitrogen applications depend on phosphorus availability, and that growth can be reduced by nitrogen fertilization if phosphorus is limiting. In the case of phosphorus uptake of various clones for production biomass, clone C-188 registered the lowest uptake of 1.187, 0.938 and 0.481 mg of phosphorus for production of biomass (kg). On the other hand, Clone C-100 consumes maximum quantity of phosphorus (2.181 mg) for production of biomass during the first year and C-63 consumes 1.757 mg and C-124 consumes 1.285 mg of phosphorus with the mean of 1.73, 1.471 and 1.02 g, during 1st, 2nd and 3rd year respectively, for production of biomass.

Potassium use efficiency

The nutrient Potassium is involved in essentially all cellular functions. Potassium is an essential macronutrient in higher plants. Potassium is essential for osmotic regulation, cell expansion, stomatal movements and enzyme activation in respiration and photosynthesis. The demand for potassium can be substantial, especially in Eucalyptus. Clone C-188 absorbs less quantity of potassium (6.162, 5.687 and 5.236 mg) for production of biomass (kg). The clone of C-100 recorded the highest consumption of 10.32 mg, check clone 5 consumes 8.44 mg and check clone 10 consumes 7.793 mg with the mean of 7.63, 7.12 and 6.69 mg during 1st, 2nd and in the 3rd year respectively.

Calcium use efficiency

Calcium is an essential for tree metabolism and various physiological processes related to growth. In recent years, special interest was therefore accorded to the effect of both cations on cambial activity and xylem development. Various studies revealed a distinct correlation between calcium nutrition and wood formation. Calcium, this mineral element appears to play an important role in the synthesis of cell walls particularly in the middle lamella where pectin chains are linked together via calcium. It is also required during cell division and as a second messenger for numerous responses to environmental and hormonal signals. Additionally, intracellular calcium acts as a membrane stabilizer, having also a protective effect against passive ion influx. In the case of calcium use efficiency for production of biomass, C-188 (6.578, 5.758 and 4.866 mg) recorded the lowest required amount of Calcium. The clone C-100 registered the highest consumption of calcium during the first year (9.887 mg), C-63 recorded highest in 2nd year (8.039 mg) and check clone 8 recorded higher amount of calcium consumption in the third year (7.325 mg) with the mean of 7.98, 7.14 and 6.24 mg in the 1st, 2nd and 3rd year respectively, for production of biomass.

Magnesium use efficiency

Magnesium (Mg), apart from being a central chlorophyll constituent, is also involved in chlorophyll biosynthesis, activation and bridging of enzymes, formation and utilization of energy transport molecules, photo-assimilates partitioning and utilization and more. It has a great impact on plant growth and productivity. Magnesium has an active role in the action of some enzymes and in maintaining the integrity of plant ribosomes. In addition, it is a key constituent of chlorophyll. Clone C-188 recorded the lowest consumption of magnesium for the 1st, 2nd and 3rd year with the amount of 1.25, 1.499 and 1.247 mg for production of biomass. On the other hand, clone C-124 recorded the highest consumption of magnesium level of 2.572 mg and 2.575 mg during the 1st and 3rd year and check clone 1 recorded higher in the 2nd year (2.808 mg) with the mean of 2.13, 2.37 and 2.12 mg. in 1st, 2nd and 3rd year respectively for production of biomass.

Correlation analysis on nutrient use efficiency of different clones of *Eucalyptus*

With reference to the presence of the various nutrient contents in the biomass all are negatively correlated with the production of total biomass in different clones of *Eucalyptus*. The presence of the leaf potassium (r = 0.839) is strongly correlated with the total biomass (Table-4).

Table 1. Nutrient use efficiency of Nitrogen (in g) for production of biomass (kg) in different clones of *Eucalyptus* during 1st year

Clone no	Nutrients				
	N	P	K	Ca	Mg
C 7	0.186^{a-b}	1.759^{a-b-c}	7.603^{b-c}	7.708^{a-b}	2.431^{d}
C 9	0.22^{c-d}	1.757^{a-b-c}	7.917^{b-c}	8.601^{d}	2.250^{b-c}
C 10	0.211^{a-b-c}	1.601^{a-b}	6.506^{a-b}	7.472^{a-b}	1.881^{a-b}
C 14	0.211^{a-b-c}	1.663^{a-b}	6.638^{a-b}	7.475^{a-b}	2.082^{a-b-c}
C 19	0.208^{a-b}	1.643^{a-b}	6.623^{a-b}	6.802^{a}	2.090^{a-b}
C 63	0.221^{b-c-d}	1.986^{b-c-d}	8.554^{b-c-d}	8.853^{c-d}	2.46^{c-d}
C 66	0.200^{a-b}	1.780^{b-c-d}	7.036^{b}	8.321^{c-d}	2.075^{a-b-c}
C 100	0.206^{a-b}	2.181^{e}	10.320^{d}	9.887^{d}	2.520^{c-d}
C 111	0.202^{a-b}	1.708^{a-b-c}	8.186^{b-c-d}	7.614^{a-b-c}	1.858^{a-b}
C 115	0.201^{a-b}	1.790^{b-c-d}	8.463^{c-d}	8.443^{c-d}	2.175^{b-c}
C 123	0.202^{a-b}	1.419^{a-b}	6.395^{a-b}	6.288^{a}	1.564^{a}
C 124	0.240^{d}	1.982^{c-d}	7.878^{b-c-d}	8.235^{c-d}	2.572^{d}
C 186	0.197^{a-b}	1.408^{a-b}	6.175^{a}	6.414^{a}	1.441^{a}
C 187	0.188^{a}	1.386^{a-b}	6.544^{a-b}	7.971^{a-b}	1.865^{a-b}
C 188	0.181^{a}	1.187^{a}	6.162^{a}	6.178^{a}	1.250^{a}
C 196	0.209^{a-b}	1.723^{a-b-c}	6.981^{b}	7.757^{a-b}	1.810^{a-b}
Check 1	0.214^{a-b-c}	1.751^{a-b-c}	7.411^{b-c}	8.172^{c-d}	2.552^{d}
Check 2	0.261^{d}	1.760^{a-b-c}	7.936^{b-c-d}	8.816^{d}	2.341^{c-d}
Check 3	0.224^{c-d}	1.776^{a-b-c}	7.563^{b-c}	8.043^{c-d}	2.232^{c-d}
Check 4	0.187^{a}	1.694^{a-b-c}	8.278^{c-d}	8.166^{c-d}	2.458^{d}
Check 5	0.252^{d}	1.797^{c-d}	8.898^{c-d}	8.557^{d}	2.444^{d}
Check 6	0.238^{c-d}	1.814^{d}	7.886^{b-c}	7.945^{b-c}	2.261^{c-d}
Check 7	0.239^{c-d}	1.763^{b-c-d}	8.024^{c-d}	8.118^{b-c}	2.330^{c-d}
Check 8	0.235^{c-d}	1.929^{c-d}	7.408^{b-c}	8.235^{c-d}	2.118^{b-c}
Check 9	0.215^{b-c}	1.845^{c-d}	8.364^{c-d}	8.457^{c-d}	2.121^{b-c}
Check 10	0.199^{a-b-c}	1.755^{b-c-d}	8.705^{c-d}	8.603^{d}	2.125^{b-c}
Mean	**0.209**	**1.73**	**7.63**	**7.98**	**2.13**

Table 2. Nutrient use efficiency of Nitrogen (in g) for production of biomass (kg) in different clones of *Eucalyptus* during 2nd year

Clone no	Nutrients				
	N	P	K	Ca	Mg
C 7	0.186^{a-b}	1.511^{a-b-c}	7.138^{b-c}	6.900^{a-b}	2.682^{d}
C 9	0.224^{c-d}	1.516^{a-b-c}	7.475^{b-c}	7.821^{c-d}	2.509^{b-c}
C 10	0.211^{a-b-c}	1.354^{a-b}	6.045^{a-b}	6.664^{a-b}	2.132^{a-b}
C 14	0.209^{a-b-c}	1.417^{a-b-c}	6.181^{a-b}	6.673^{a-b}	2.336^{a-b-c}
C 19	0.206^{a-b}	1.396^{a-b}	6.158^{a-b}	5.996^{a}	2.341^{a-b}
C 63	0.221^{b-c-d}	1.737^{d}	8.085^{d}	8.039^{d}	2.717^{c-d}
C 66	0.201^{a-b}	1.539^{b-c-d}	6.597^{b-c}	7.540^{b-c-d}	2.333^{a-b-c}
C 100	0.216^{a-b}	1.493^{e}	7.693^{d}	7.172^{d}	2.260^{c-d}
C 111	0.200^{a-b}	1.465^{a-b-c}	7.743^{d}	6.828^{a-b-c}	2.115^{a-b}
C 115	0.203^{a-b}	1.546^{b-c-d}	8.010^{d}	7.651^{c-d}	2.431^{b-c}
C 123	0.202^{a-b-c}	1.436^{a-b}	6.909^{c-d}	6.659^{a}	2.110^{a}
C 124	0.236^{d}	1.721^{d}	7.352^{b-c-d}	7.374^{c-d}	2.798^{d}
C 186	0.195^{a-b-c}	1.168^{a-b}	5.726^{a}	5.636^{a}	1.700^{a}
C 187	0.185^{a-b}	1.136^{a-b}	6.066^{a-b}	7.144^{a-b-c}	2.113^{a-b}
C 188	0.179^{a}	0.938^{a}	5.687^{a}	5.758^{a}	1.499^{a}
C 196	0.208^{a-b}	1.477$^{a-b-c-d}$	6.520^{b}	6.953^{a-b}	2.062^{a-b}
Check 1	0.208^{a-b-c}	1.506^{a-b-c}	6.958^{b-c}	7.375^{c-d}	2.808^{d}
Check 2	0.256^{d}	1.519^{a-b-c}	7.502^{b-c-d}	8.044^{d}	2.601^{c-d}
Check 3	0.221^{c-d}	1.530^{a-b-c}	7.107^{b-c}	7.238^{b-c-d}	2.486^{c-d}
Check 4	0.185^{a}	1.444^{a-b-c}	7.797^{c-d}	7.344^{c-d}	2.703^{d}
Check 5	0.250^{c}	1.552^{c-d}	8.442^{d}	7.757^{d}	2.698^{d}
Check 6	0.237^{c-d}	1.568^{d}	7.432^{b-c}	7.146^{b-c}	2.515^{c-d}
Check 7	0.237^{c-d}	1.517^{b-c-d}	7.567^{c-d}	7.320^{b-c-d}	2.584^{c-d}
Check 8	0.235^{c-d}	1.638^{c-d}	6.673^{b-c}	7.171^{b-c}	2.236^{b-c}
Check 9	0.213^{b-c}	1.599^{c-d}	7.907^{c-d}	7.658^{c-d}	2.375^{b-c}
Check 10	0.197^{a-b-c}	1.510^{b-c-d}	8.254^{d}	7.802^{d}	2.378^{b-c}
Mean	**0.207**	**1.47**	**7.12**	**7.14**	**2.37**

Table 3. Nutrient use efficiency of Nitrogen (in g) for production of biomass (kg) in different clones of *Eucalyptus* during 3rd year

Clone no	Nutrients				
	N	P	K	Ca	Mg
C 7	0.167^{a-b}	1.055^{a-b-c}	6.691^{b-c}	6.008^{a-b}	2.430^{d}
C 9	0.206^{c-d}	1.057^{a-b-c}	7.010^{b-c}	6.913^{b-c-d}	2.252^{b-c}
C 10	0.199^{a-b-c}	0.920^{a-b}	5.739^{a-b}	5.919^{a-b}	1.929^{a-b}
C 14	0.191^{a-b-c}	0.958^{a-b-c}	5.721^{a-b}	5.768^{a-b}	2.080^{a-b-c}
C 19	0.190^{a-b}	0.939^{a-b}	5.713^{a-b}	5.107^{a-b}	2.091^{a-b}
C 63	0.20^{b-c-d}	1.281^{d}	7.642^{b-c-d}	7.151^{c-d}	2.468^{c-d}
C 66	0.183^{a-b}	1.089^{b-c-d}	6.191^{b-c}	6.693^{b-c-d}	2.095^{a-b-c}
C 100	0.211^{a-b}	1.048^{e}	7.311^{d}	6.338^{b-c-d}	2.027^{c-d}
C 111	0.182^{a-b}	1.006^{a-b-c}	7.287^{d}	5.928^{a-b-c}	1.861^{a-b}
C 115	0.184^{a-b}	1.091^{b-c-d}	7.564^{d}	6.765^{c-d}	2.181^{b-c}
C 123	0.185^{a-b}	0.981^{a-b}	6.475^{b-c-d}	5.778^{a-b}	1.862^{a}
C 124	0.222^{d}	1.285^{d}	6.976^{b-c-d}	6.554^{c-d}	2.575^{d}
C 186	0.178^{a}	0.712^{a-b}	5.284^{a}	4.750^{a}	1.450^{a}
C 187	0.167^{a-b}	0.678^{a-b}	5.61^{a-b}	6.243^{a-b}	1.858^{a-b}
C 188	0.162^{a}	0.481^{a}	5.236^{a}	4.866^{a}	1.247^{a}
C 196	0.191^{a-b}	1.022^{a-b-c}	6.081^{b-c-d}	6.072^{a-bb}	1.813^{a-b}
Check 1	0.193^{a-b-c}	1.051^{a-b-c}	6.516^{b-c}	6.491^{c-d}	2.559^{d}
Check 2	0.241^{d}	1.061^{a-b-c}	7.043^{b-c-d}	7.141^{d}	2.347^{c-d}
Check 3	0.205^{c-d}	1.071^{a-b-c}	6.651^{b-c}	6.343^{b-c-d}	2.232^{c-d}
Check 4	0.168^{a}	0.994^{a-b}	7.382^{d}	6.482^{c-d}	2.465^{d}
Check 5	0.208^{b-c}	0.983^{a-b}	7.175^{c-d}	6.162^{b-c}	2.197^{d}
Check 6	0.219^{c-d}	1.110^{c-d}	6.975^{b-c-d}	6.246^{b-c}	2.261^{c-d}
Check 7	0.221^{c-d}	1.057^{b-c-d}	7.100^{c-d}	6.411^{b-c-d}	2.326^{c-d}
Check 8	0.219^{c-d}	1.388^{c-d}	7.211^{c-d}	7.325^{d}	2.332^{b-c}
Check 9	0.196^{b-c}	1.141^{c-d}	7.450^{d}	6.758^{c-d}	2.121^{b-c}
Check 10	0.182^{a-b}	1.051^{b-c-d}	7.793^{d}	6.901^{d}	2.125^{b-c}
Mean	**0.190**	**1.02**	**6.69**	**6.27**	**2.12**

Table 4. Correlation coefficients of nutrient use efficiency among different clones of *Eucalyptus*.

	Biomass N	*Biomass P*	*Biomass K*	*Biomass Ca*	*Biomass Mg*	*Total Biomass*
B-N	1					
B-P	0.540**	1.000				
B-K	0.288	0.724**	1.000			
B-Ca	0.222	0.768**	0.767**	1.000		
B-Mg	0.331	0.790**	0.642**	0.717**	1.000	
Total Biomass	-0.326	-0.552**	-0.702**	-0.670**	-0.636**	1

* Significant at 0.05% level
** Significant at 0.01% level

DISCUSSION

From the above study, Clones C-188, C-10, C-14, C-19, C-123 and C-186 showed high nutrient use efficiency (lower quantity of nutrients) for production of stem wood biomass.

Anthony A. Kimaro *et al*., (2007) studied the above ground use efficiency for N ($P = 0.0035$), P ($P < 0.0001$), K ($P < 0.0001$), Ca ($P = 0.001$), and Mg ($P = 0.0081$) varied significantly among the tree species. In general, *A. crassicarpa* was the most efficient for all nutrients except for N and Mg, exemplifying that this species produced the highest above ground biomass at lowest nutrient ‘‘costs’’. Its K-use efficiency was four times higher than that of *G. sepium* while P-use efficiency was three times as high as that of *A. nilotica*. Similar results were also observed for nutrient use efficiency based on wood production. Overall, nutrient use efficiency of wood was consistently higher than that of whole-tree biomass except for K, Ca, and Mg in *A. polyacantha*, and for P and Ca in *A. nilotica*.

Jose Luiz Stape *et al*., (2010) studied the N-use-efficiency in clonal *E. grandis x urophylla* and resulted that, the efficiency was observed by 1.6 fold (248 to 415 kg yr^{-1}). Across all sites, ANPP did not correlate with supply (r^2 = 0.01, P = 0.71) but did correlate with N uptake (r^2 = 0.95, P < 0.001) and marginally with N-capture-efficiency (r^2 = 0.25, P = 0.07). N-capture-efficiency increased with water supply (r^2 = 0.57, P = 0.03). N-use-efficiency increased with N use (r^2 = 0.56, P = 0.03).

The variation in nutrient use efficiency among species may be attributed to several reasons related to uptake, transport, and utilization within plants (Marschner, 1995; Schroth *et al*., 2003). For example, extensive root systems and abundant mycorrhizal associations are characteristics that increase P-use efficiency of plants (Schroth *et al*., 2003). Higher rates of nutrient re-translocation during either vegetative or reproductive growth also increase nutrient use efficiency due to better utilization of organically bound nutrients for growth (Marschner, 1995). These mechanisms probably accounted for the observed species variability in nutrient use efficiency, since Australian Acacia species usually form mycorrhizal associations and have low litter nutrient concentrations (Doran *et al*., 1997; Jamaludheen and Kumar, 1999) that may reflect high nutrient re-translocation rates.

Jean Paul Laclau *et al*., (2003) studied the annual requirement of nutrients for biomass production in Eucalyptus and reported that, 64.4 kg ha^{-1} yr^{-1} of N, 8.2 kg ha^{-1} $yr^{-1}$of P, 29.7 kg ha^{-1} yr^{-1} of K, 25.3 kg ha^{-1} yr^{-1} of Ca and 24.7 kg ha^{-1} yr^{-1} of Mg required for production of biomass during 1st year and 117.2, 15.6, 37.3, 34.8 and 27.3 kg ha^{-1} yr^{-1} and 235, 47, 59, 68 and 49 kg ha^{-1} yr^{-1} of N, P, K, Ca and Mg nutrients required for production of biomass in the 5th and 7th year respectively in the *Eucalyptus* clonal stands in Congo.

Phosphorus application significantly increased tree growth, biomass production, N, P and K uptake, and decreased understorey biomass and litter dry weight. Application of 208 kg P ha^{-1} was adequate for tree growth. The proportion of stem-wood was increased and the proportion of root biomass was decreased as the quantity of phosphorus applied increased. The application of P also increased the proportion of tree biomass, total biomass of tree, understorey and litter. The N and K use efficiencies for tree biomass and stem-wood production increased with P supply. The P use efficiency was highest in the 13 kg P ha^{-1} treatment, and decreased at higher rates of P. The P recovery by tree uptake was between 7.6 and 25.3% and decreased as the quantity of P applied increased (Xu *et al*., 2002).

Most nutrient fluxes were driven by crown establishment the two first years after planting and total biomass production thereafter. These forests were characterized by huge nutrient requirements: 155, 10, 52, 55 and 23 kg ha^{-1} of N, P, K, Ca and Mg the first year after planting at the Brazilian study site, respectively. High growth rates the first months after planting were essential to take advantage of the large amounts of nutrients released into the soil solutions by organic matter mineralization after harvesting. This study highlighted the predominant role of biological and biochemical cycles over the geochemical cycle of nutrients in tropical *Eucalyptus* plantations and indicated the prime importance of carefully managing organic matter in these soils (Jean Paul Laclau *et al*., 2003).

There are several other investigations of the impact of harvesting regimes on soil nutrient pools for *Eucalyptus* and other tree species (Hopmans *et al*., 1993; Merino *et al*., 2005). For instance, Merino *et al*., (2005) reported the impact of different harvesting intensities in fast growing forest plantations in Southern Europe. They found high ratios between nutrients exported by harvesting and those available in soil stores, indicating limitations for P, Ca and Mg over the long term basis which is consistent with frequently observed deficiencies in the tropical regions.

Mohan Kumar *et al*., (1998) studied the rate of biomass accumulation and nutrient accumulation was highest for *Acacia* and the least for *Leucaena*. Allometric relationships linking above ground biomass with DBH and/or total height gave reasonable predictions. A comparison between species and among tissue types within species indicated that nutrient use efficiency for N, P and K varied widely.

Accumulation of nutrients in the above-ground biomass varied significantly between species and ranged from 24 to 41 g m^{-2} for N, 2.6 to 5.9 g m^{-2} for P, 0.5 to 9.2 g m^{-2} for Na, 12 to 27 g m^{-2} for K, 7 to 52 g m^{-2} for Ca and 3.1 to 7.9 g m^{-2} for Mg. Nutrient accumulation was generally greater in species with a comparatively large crown biomass relative to stem size such as *C. cunninghamiana* and *E. camadulensis*. Average nutrient accumulation by trees as a percentage of input from effluent was estimated at 19% for N, 9% for P, 1% for Na, 14% for K, 52% for Ca and 32% for Mg (Hopemans *et al*., 1990).

According to Zaia and Gama-Rodrigues (2004), levels of N, P, K, Ca and Mg in E. grandis at 6 years of age were 1.66, 0.09, 0.88, 0.7 and 0.25 respectively. For Gonçalves, *et al,* (1997), the levels of N, P, K, Ca and Mg in adult plants is considered adequate when between 1.3 and 1.8, 0.09 and 0.13, 0.9 and 1.3, 0.6 and 1.0, and 0.35 and 0.50% respectively. The differences in nutrient use efficiency between species, origin, progeny and clone in the *Eucalypt*, besides being inherent to a capacity for the absorption, translocation and conversion of the nutrients into the biomass of each genotype, are products of the interaction of genotype with the environment.

Thus, nutrient use efficiency makes it possible to recognize genotypes and management practices that may contribute to sustainability of the forests, since when the efficiency in the use of a nutrient and the expectations for biomass production are known, it becomes possible to estimate the amount of nutrients necessary for a proper nutritional balance during the following cycle (Saidelles et al., 2010).

Studying the origins of E. grandis and *E. saligna* at 6.5 years of age, Santana et al, (2002) found differences in nutrient use efficiency in the production of trunk biomass, this also varying with the site. Those authors observed that use efficiency decreased in the following order: P>Mg>K>N>Ca, being the same tendency seen by *Faria et al.* (2008). Significant differences for phosphorus use efficiency (PUE) between clones of *E. urophylla* at eight months of age under field conditions were seen by Godoy and Rosado (2011).

The harvest and removal from the site of only the commercial parts of the plant is recommended as a way of reducing the export of nutrients from the system, thereby maintaining the quality and productivity of the soil. Thus, with the production of coal and pulp, and for other uses, it is recommended to debark the trunk and leave the bark in the forest, reducing the removal of nutrients, especially of Ca, which by not being internally remobilized by the eucalypt, tends to concentrate in greater quantities in the bark (Arias *et al.,* 2011). This is also true for Mg and to a lesser extent for the remaining nutrients, which due to displaying greater mobility in the plant are found in greater percentages and amounts in other components, such as leaves and branches.

In terms of nutrient content, the wood has the lowest associated values, but being the most abundant component of the tree, it is responsible for the largest export of nutrients from the system. In this respect, Santana *et al.* (2008) found that with an increase in age, nutrients allocated to the canopy tend to reduce and nutrients allocated to the trunk tend to increase.

CONCLUSION

In view of the above, the use of genotypes efficient in the use of nutrients is essential for sustainability of the forest ecosystem, reducing the export of nutrients in proportion to the biomass produced. This becomes more important depending on the use of some forests, such as those intended for pellet production, where the complete tree is harvested, including the bark and the canopy. Also, the recommendation of genotypes which are efficient in the use of nutrients for sites of poor soil fertility can optimize productivity in these locations, without requiring major applications of fertilizer.

REFERENCES

Anthony A. Kimaro, Vic R. Timmer, Ancelm G. Mugasha, Shaban A. O. Chamshama, Deborah A. Kimaro. (2007). Nutrient use efficiency and biomass production of tree species for rotational woodlot systems in semi-arid Morogoro, Tanzania. *Agroforestry System*, DOI 10.1007/s10457-007-9061-x.

Arias, D. Calvo-Alvarado, J. Richter, D. de B. Dohrenbusch, A. (2011). Productivity, aboveground biomass, nutrient uptake and carbon content in fast-growing tree plantations of native and introduced species in the Southern Region of Costa Rica. *Biomass and bioenergy*, **35**: 1779-1788.

Doran, J.C., Turnbull, J.W., Martensz, P. N., Thomson, L.A.J, and Hall, N. (1997). Introduction to the species' digests. In Doran, J.C., Turnbull, J.W. (*Eds)* Australian trees and shrubs: species for land rehabilitation and farm planting in the tropics. ACIAR Monograph No. 24, viii, pp 89–384.

Fábio Luiz Fleig Saidelles, Marcos Vinicius Winckler Caldeira, Mauro Valdir Schumacher, Rafaelo Balbinot and Waldir Nagel Schirmer. (2010). Determinação do ponto de amostragem para a quantificação de macronutrientes EM *Acacia mearnsii* DE WILD. *FLORESTA*, **40 (1)**: 49-62.

Geraldo Erli de Faria, Nairam Félix de Barros, Vanderley Luiz Paranaíba Cunha, Ildeu Soares Martins and Rosana de Carvalho Cristo Martins. (2008). Evaluation of the productivity, content and nutrient use efficiency in genotypes of eucalyptus spp. in Jequitinhonha valley, MG. *Ciência Florestal*, **18(3)**: 363-373.

Godoy, T. G.; Rosado, C. S. (2011) Efficiency of phosphorus use in young plants of *Eucalyptus urophylla* S.T. Blake. *Revista Cerne*, **17 (3)**: 303-308.

Gonçalves, J.L.M., Raij, B.V., Gonçalves, J.Q. (1997) Florestas. In: Raij, B. V. et al. Recomendações de adubação e calagem para o Estado de São Paulo. 2 ed. Campinas: Instituto Agronômico: Fundação IAC,. p. 247-259.

Hanway, J.J. and Heidal, H. (1952). Soil analysis methods as used in Iowa State College, Soil Testing Laboratory, *Iowa State College Agric. Bull*, **57**: 1-13.

Hopmans, P. Stewart, H.T.L. and Flinn, D.W., (1993.) Impacts of harvesting on nutrients in a eucalypt ecosystems in southeastern Australia. *Forest Ecology and Management*, **59**: 29-51.

Hopmans, P., Stewart, H. T. L., Flinn, D. W. and Hillman, T. J. (1990). Growth, biomass production and nutrient accumulation by seven tree species irrigated with municipal effluent at Wodonga, Australia. *Forest Ecology and Management*, **30(1–4)**: 203–211.

Jackson, M.L. (1962). Soil Chemical Analysis. Prentice-Hall, Englowood Cliffs, N.J.

Jamaludheen, V. and Kumar, B.M. (1999). Litter of multipurpose trees in Kerala, India: variations in the amount, quality, decay rates and release of nutrients. *Forest Ecology and Management*., **115:** 1–11.

Jose Luiz Stape, J.L., Binkley, D., Ryan, M.G., Fonseca, S., Loos, R.A., Taka-hashi, E.N., Silva, C.R., Silva, S.R., Hakamada, R.E., de Ferreira, J.M.A., Lima, A.M.N., Gava, J.L., Leite, F.P., Andrade, H.B., Alves, J.M., Silva., G.G.C. and Azevedo, M.R. (2010). The Brazil *Eucalyptus* potential productivity project: Influence of water, nutrients and stand uniformity on wood production. *Forest Ecology and Management*, **259**: 1684-1694.

Laclau, J-P.R., Gonçalves J., Maquere J., Krusche V.V., M'Bou A.T., Nouvellon A., Saint-Andre Y., Laurent J.-P., de Cassia Piccolo B., Marisa Deleporte P.. (2010). Biogeochemical cycles of nutrients in tropical Eucalyptus plantations: Main features shown by intensive monitoring in Congo and Brazil. *Forest Ecology and Management,* **259**. 1771-1785.

Marschner, H. (1995). Mineral nutrition of higher plants, 2nd edn. Academic Press, NY, 889 p.

Merino, A., Balboa, M.A., Soalleiro, R.R. and Gonzalez, J.G.A. (2005). Nutrient export under different harvesting regimes in fast-growing forest plantations in southern Europe. *Forest Ecology and Management*, **207**: 325-339.

Mohan Kumar, B, Suman J.G., Jamaludheen, V. and Suresh, T.K. (1998). Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in woodlot and silvopastoral experiments in Kerala, India. *Forest Ecology and Management,* **112(1-2)**:145–163.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. Circ. 939. U.S. Govt. Printing Office, Washington DC.

Panse, V.G. and Sukhatme, P.V. (1985). Statistical methods for agricultural workers, 4th Edition, ICAR, New Delhi.

Santana, R.C., de Barros N.F., Novais R.F., Leite H.G. and Comerford N.B. (2008). Nutrient allocation in eucalypt plantations in Brazil. *R. Bras. Ci. Solo*, **32**: 2723-2733.

Santana, R.C., Barros, N.F., Neves, J.C.L. (2002). Eficiência de utilização de nutrientes e sustentabilidade da produção em procedências de Eucalyptus grandis e Eucalyptus saligna em sítios florestais do estado de São Paulo. *Revista Árvore*, **26(4)**: 447-457.

Santana, R. C., Barros, N. F., Novais, R. F., Leite, H. G. and Comerford, N. B. (2008). Alocação de nutrientes em plantios de eucalipto no Brasil. *Revista Brasileira de Ciência do Solo*, **Número especial**. p. 2724-2734.

Schroth G, Lehmann J, and Barrios, E. (2003). Soil nutrient availability and acidity. In: Schroth G, Sinclair FL (eds) Trees, crops and soil fertility: concepts and research methods. CABI publishing, Wallingford, UK, pp 93–130.

Stape, J.L., Binkley, D. and Ryan, M.G. (2004). Eucalyptus production and the supply, use and efficiency of use of water, light and nitrogen across a geographic gradient in Brazil. *Forest Ecology and Management*, **193**, 17-31.

Subbiah, B.V. and Asija, C.L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Sciences*, **25**: 259-260.

Xu, D., Dell, B., Malajczuk, N. and 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 (1-3)**: 89-100.

Zaia, F.C., Gama-Rodrigues, A.C. (2004) Ciclagem e balanço de nutrientes em povoamentos de eucalipto na região Norte Fluminense. *Revista Brasileira de Ciências do Solo*, **28**, 843-852,.