# SOIL FERTILITY EVALUATION FOR *EUCALYPTUS GLOBULUS* IN PORTUGAL: ESTABLISHMENT AND MAINTENANCE CRITICAL LEVELS OF PHOSPHORUS, POTASSIUM, CALCIUM AND MAGNESIUM

**A. S. Fabres; J. Rafael; N. Borralho; D. Ferreira and H. Barrocas**

RAIZ – Instituto de Investigação da Floresta e Papel, Quinta de S. Francisco, Ap. 15 3801-501 Eixo, Aveiro, Portugal, Telefone: 234 920 131(sfabres@raiz-iifp.pt)

## INTRODUCTION

The magnitude of plant phenotypic expression depends on environment factor levels, such as light, water and soil morphological, chemical, physical and biological properties. In each site condition, the availability of these factors and their interaction basically determine the forest productivity level, once they affect directly plant physiological process that controls growth. So, process-based models (mechanistic approach), that have been developed more recently (Stape 2002, Landsberg and Gower 1997 and Battaglia and Sands 1997), consider most of these variables and concretize undoubtedly a holistic approach. Even then, to better understand the relationship between soil fertility, plant nutrition and forest productivity, it could help both to improve the mechanistic simulation of growth and provide a useful management tool for fertilization practices. This issue is particularly important because on one hand most of forest soil has low natural fertility and on other hand the soil fertility is a variable that can be easily modified to improve site quality as compared with others. The knowledge of nutrient critical levels, for a given crop, is necessary to evaluate soil fertility (by interpretation of the soil analysis results). The soil nutrient critical level can be defined as the soil nutrient minimum concentration that provides the economic efficient maximum achievement, when other nutrients and production factors are near the optimum requirement by plants. The critical level allows practically to separate soil populations with high response probability to fertilization of those with low probability (Alvarez, 1996) and, this way, to do a much more precise recommendation of fertilization. For long term cycled vegetal species, like most forest species, the nutrient requirements vary with the plant age or growth phase, and thus different nutrient soil concentration are required for optimum growth in each phase. Generally, the critical level decreases with the stand age. That can basically be explained by three reasons: increase in the soil volume explored by roots, increase in the efficient mechanisms cycle biogeochemical and increasing uptake of nutrients fractions derived from minerals weathering, with the stand age. On the other hand, until the canopy closure, the nutrient relative accumulation is bigger than biomass relative accumulation due to high nutrient concentration in biomass components such as leaves and branches. After canopy closure, there is an increase of biomass allocation to trunk formation, which contains low nutrient concentrations, consequently decreasing the nutrient relative demand (Gonçalves *et al*., 1997). Additionally, the plant most mobile nutrients (N, P, K e Mg) are redistributed in the inner plant – biochemical cycling – and also the litterfall, mineralization and nutrients reuptake begins – geochemical cycling – resulting in a minor demand on the pool of soil mineral nutrients. Therefore, the concepts of establishment critical level (ECL) and maintenance critical level (MCL) acquire relevance to decide on eucalypt fertilizers application. So, Novais *et al.* (1986), based on empiric experimental evidences and some theoretical exercise, proposed values of critical levels of establishment and maintenance for eucalyptus cultivated in Brazil. In 2000, Barros *et al*. defined ECL as the soil nutrient concentration enough for the first months after the plantation and MCL as the soil nutrient concentration to maintain a given productivity during the rotation. Based on RAIZ' experimental results, critical levels of establishment and maintenance of P, K, Ca and Mg for *Eucalyptus globulus* plantation in Portuguese forest soil conditions were obtained, incorporating them on the concept of the NUTRIGLOBUS – program of fertilizers recommendation for Portugal's *Eucalyptus globulus* plantation (Fabres *et al.,* 2002).

In this work, it was intended to improve the concepts of critical levels, being suggested for ECL the soil nutrient concentration, in the neighborhood of plant roots, on time $t_0$ (beginning of plantation), necessary for eucalypts optimum growth until the time $t_1$ (1 to 2 years old, depending on site growth rate) and for MCL the soil nutrient concentration, considering all the soil mass for a given soil depth and stoniness, on time $t_1$, necessary to maintain eucalypt stand's optimum growth during the rotation. Based on these concepts, this work has as objectives i) to determine the soil critical levels of phosphorus, potassium, calcium and magnesium for establishment (ECL) and growth maintenance (MCL) for *Eucalyptus globulus* plantation in Portugal's soils forest conditions and ii) to compare these critical levels with the soil fertility of eight-forest soil group, based on soil morphological, physical and chemical properties.

## MATERIAL AND METHODS

For the determination of the critical levels of phosphorus, potassium, calcium and magnesium in the soil for the establishment (ECL) and maintenance (MCL) of *E. globulus* plantations, two different approaches were used. The first based on the methodology proposed by Novais *et al*. (1986), that consists on converting the mass of nutrients immobilized in the biomass, for a given forest productivity, in mass of labile nutrients in the soil, for a complete rotation or for each growth phase, that could be denominated of methodology of equivalence of masses. The second approach consists on the use of the correlation method and calibration of soil analysis, settling down regression equations for parameters of forest productivity as variables dependent on the soil nutrients concentration, in field conditions, according to methodology used by Viçosa's school (Alvarez V., 1996). In fact, this second methodology consists in an attempt of validation of the values obtained with the first approach.

**Equivalence of mass approaches.** How were the critical levels calculated (ECL and MCL)? A more precise estimative of eucalypt stand nutrients demand can be obtained by both the biomass accumulation curves and nutrients uptake curves as dependent variables of the stand age. Thus, based on RAIZ data (soil fertility and plant nutrition trials and nutritional evaluation of eucalypt commercial plantation), on one hand, starting from allometric equation and values of biomass nutrient critical concentration, for each component of the biomass (leaves, branches, wood and bark), along the cycle of growth of *E. globulus*, the nutrients uptake curves were obtained and, thus, known the amounts of P, K, Ca and Mg demanded for the maintenance of the optimum growth rates, for an expected productivity. On other hand, gradual coefficients of soil volume exploration by roots were considered with the stand age. By combination of them, MCL was obtained. The criteria used to estimate the ECL was that planting hole nutrient availability is enough to start up eucalypt growth and to keep optimum growth rates during at least one year.

**Field approach – validation of the establishment critical level (ECL) of phosphorus.** For the determination of ECL of P, two forest soils were chosen, one with sandy texture (Haplic Arenosol) and another with clay sand loamy texture (Leptic Cambisol) - characteristics presented in Table 1. Treatments consisted of five P levels, applied in the plantation hole (Table 2), immediately before the plantation of *E. globulus* clones. Monocalcic phosphate fertilizer was used as P source ($CaH_2PO_4.CaSO_4.7H_2O$ - 18% $P_2O_5$; 29% CaO and 27% $SO_3$). It was also done fertilization with 60 g of nitrogen per plant, applied in two fractions (20g/plant, one month old, and 40 g/plant, three and a half months old), which N source was the ammonium nitrate. Treatments were tested in design experimental of randomized blocks, with three replications. Four months after the plantation, in the whole zone (with approximately 18 $dm^3$) soil was sampled to measure the P available concentration by Mehlich3, Egner-Riehm and Olsen soil P tests. In each treatment, 20 sub samples were taken to compose one soil sample. The rate of recovery of P was determined, relating the concentration of available P in the soil by three extractants (Mehlich 3, Egner-Riehm and Olsen), as a function of P concentration in the planting hole (calculated from the dose of applied P and considering a constant volume of soil for hole of approximately 18 $dm^3$). The ECL of P was determined for the two places studied, according to the methodology used by Viçosa's school (Alvarez, 1996). According to this, regression equations were adjusted relating the plants height as variables dependent of the P doses applied. To obtain ECL accurately, it is necessary that the production equation has quadratic form ($Y = a + bX + cX^2$), or quadratic root ($Y = a + bX + cX^{1/2}$). The resolution of the 1st derived, allowed determining the dose corresponding to the maximum growth (X maximum), being the 2nd derived negative, which allowed to obtain the maximum production (Y maximum). The recommended dose (RD) was calculated for 90% of the maximum production (Figure 1, A), corresponding theoretically to the production of maximum economic efficiency (Y 90%). Still, equations of simple linear regression were adjusted, by relationship between soil available P for each extractant (P recovered by Mehlich 3, Egner-Riehm and Olsen) and P doses applied (Figure 1, B). The substitution of RD (or critical doses) of phosphate fertilizer in these equations allowed obtaining the establishment critical level of P in the soil. Actually, this procedure is only possible in sandy soil (Haplic Arenosol), because in clayest soil (Leptic Cambisol) the answer of the *E. globulus* plants to the application of the phosphate fertilizer is linear. So, in this case, the maximum dose (corresponding to the maximum production) is considered to obtain the critical level.

**Table 1. Soil characterization (0-40cm) of field experiments, including soil classification under FAO/UNESCO criteria (1998), pH, soil organic matter (%), clay content (%), phosphorus extracted by Olsen (mg/kg), phosphorus adsorption maximum capacity (PAMC, in mg/g) and exchangeable elements (K, Ca, Mg and Na extracted by $NH_4OAc$ (cmol/kg), effective cation exchange capacity (ECEC, in cmol/kg) and effective base saturation (V, in %)**

| Soil classification/Lithology FAO/UNESCO | $pH_{H2O}$ | Organic matter | Clay | P | PAMC | Exchange complex | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Na^{+}$ | ECEC | V |
| | | | | | | $NH_4OAc$ | | | | | |
| Eutric Haplic Arenosol (Meso-cenozoic sediments) | 5,37 | 0,88 | 2 | 0,41 | 0,15 | 0,19 | 0,06 | 0,03 | 0,01 | 0,33 | 81 |
| Rhodic Leptic Cambisol (Xyst) | 5,47 | 2,85 | 25 | 2,32 | 0,68 | 0,73 | 0,95 | 0,13 | 0,38 | 2,67 | 87 |

**Table 2. Doses of monocalcic phosphate ($CaH_2PO_4.CaSO_4.7H_2O$ – 18% $P_2O_5$; 29% CaO e 27% $SO_3$) applied and corresponding amount of $P_2O_5$, P and Ca**

| Treatment | P level | Monocalcic phosphate application | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Dose (g/plant) | | | | Dose (kg/ha) | | | |
| | | Fertilizer | $P_2O_5$ | P | Ca | Fertilizer | $P_2O_5$ | P | Ca |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 60 | 10,8 | 5,1 | 12,5 | 83 | 15 | 6,6 | 17 |
| 3 | 2 | 120 | 21,6 | 9,43 | 25,2 | 167 | 30 | 13,1 | 35 |
| 4 | 3 | 180 | 32,4 | 14,1 | 37,8 | 250 | 45 | 19,7 | 53 |
| 5 | 4 | 240 | 43,2 | 18,9 | 50,4 | 333 | 60 | 26,2 | 70 |

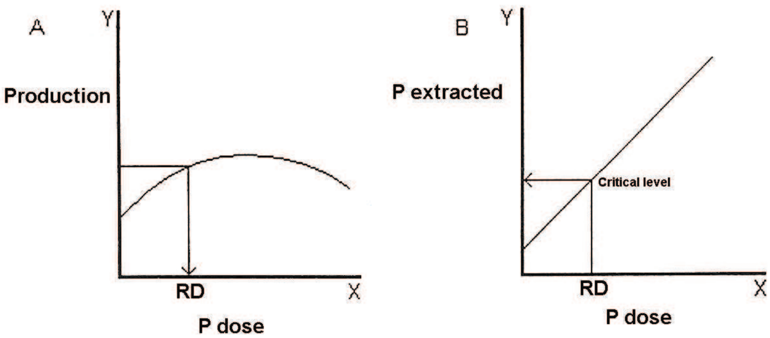
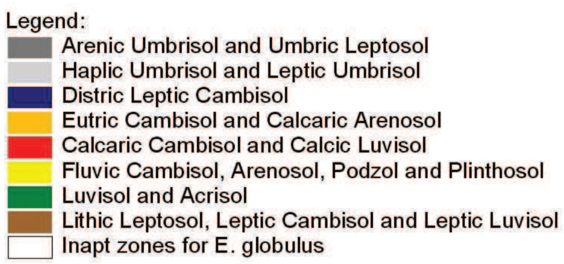



**Figure 1.** Illustration of both production equation, that allows to calculate the P fertilizer recommended dose (A), and P recuperated equation as function of P doses applied on soil, that becomes able to asses the critical level value, for a given extractant (B). Adapt from Alvarez V. (1996)

**Field approach – validation of maintenance critical level (MCL) values of phosphorus, potassium, calcium and magnesium for *Eucalyptus globulus* plantation.** For the validation of maintenance critical level of P, K, Ca and Mg, obtained with the approach (more theoretical) of the equivalence of masses, Portuguese forest soils were grouped into eight more or less homogeneous sets and were taken soil samples for chemical characterization (Table 3). In two of these environments (groups 2 and 6 – Table 3), 28 *E. globulus* stands were selected, with ages between four and six years old. In each stand, four plots of 400 $m^2$ were installed, trees height and diameters data were obtained, as well as soil samples were taken at 0 to 40 cm depth. In each plot, wood volume was estimated by the Leal's volumetric equations (1982). Two average trees were selected and cut down for rigorous cubage, weighting and sampling of biomass (leaves, branches, wood and bark). The samples were dried in hot-oven with forced ventilation at 65-70ºC until constant weight, triturated and analyzed at RAIZ laboratory of analysis of soils and plants. The analyzed biomass chemical parameters were the N concentration (Kjeldahl's method); P, K, Ca and Mg concentration (acid digestion and determination by colorimetric method – P and ICPS for the others).

**Table 3. Average eucalypt productivity ((MAI, in $m^3$/ha/year), classification (FAO, 1998) and characterization of eight soil groups, including pH, soil organic matter (%), clay content (%), phosphorus extracted by Egner-Riehm (mg/kg) and exchangeable elements (K, Ca, Mg and Na extrated by $NH_4OAc$ (cmol/kg), effective cation exchange capacity (ECEC, in cmol/kg) and effective base saturation (V, in %)**

| Soil classification/Lithology FAO/UNESCO | MAI | $pH_{H2O}$ | Organic matter | P | Exchange complex $NH_4OAc$ | | | | ECEC | V |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Na^{+}$ | | |
| 1. Arenic Umbrisol and Umbric Leptosol (Granite) | 29 | 4,78 | 5,36 | 13,5 | 0,99 | 0,33 | 0,08 | 0,07 | 4,09 | 36 |
| 2. Haplic Umbrisol and Leptic Umbrisol (Xyst) | 28 | 4,68 | 6,27 | 6,4 | 0,74 | 0,38 | 0,11 | 0,12 | 4,59 | 30 |
| 3. Distric Leptic Cambisol (Granite, Xyst and quartzite) | 18 | 4,91 | 1,74 | 13,4 | 0,47 | 0,55 | 0,21 | 0,1 | 3,28 | 41 |
| 4. Eutric Cambisol and Calcaric Arenosol (Granite, Xyst, quartzite and calcarium) | 17 | 5,11 | 1,37 | 6,3 | 0,88 | 0,66 | 0,16 | 0,12 | 3,1 | 63 |
| 5. Calcaric Cambisol and Calcic Luvisol (Calcarium) | 18 | 6,36 | 2,94 | 8,5 | 0,99 | 1,08 | 0,32 | 0,16 | 12,3 | 85 |
| 6. Fluvic Cambisol, Arenosol, Podzol and Plinthosol (Sediments meso-cenoizoic) | 17 | 5,09 | 1,52 | 5,3 | 0,61 | 0,49 | 0,12 | 0,11 | 3,17 | 54 |
| 7. Luvisol and Acrisol (Xyst, basalt and diorito) | 14 | 5,1 | 1,98 | 6,6 | 0,95 | 0,75 | 0,22 | 0,24 | 4,49 | 59 |
| 8. Lithic Leptosol, Leptic cambisol and Leptic Luvisol (Xyst) | 12 | 5,03 | 2,82 | 6,2 | 1,05 | 0,78 | 0,22 | 0,17 | 4,31 | 54 |



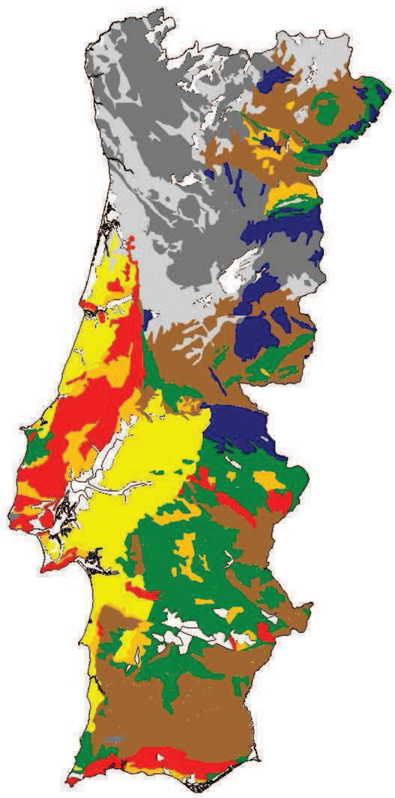



**Figure 2.** Portugal's soil map, by world reference base for soil resources criteria (FAO, 1998). Grouping in eight classes based on morphological, physical and chemical properties. Adapt from Rafael *et al.*, 2002

## RESULTS AND DISCUSSION

The soil critical levels of phosphorus, potassium, calcium and magnesium for establishment (ECL) and growth maintenance (MCL) for *Eucalyptus globulus* plantation in Portugal soil forest conditions are presented here under two different approaches, as described in the methodological part. Besides that, it was also made a comparison between these critical levels and the soil fertility of eight-forest soil group.

**Equivalence of mass approaches.** The results show that generally there is a quadratic relationship between forest productivity and soil nutrient critical levels, existing an opposite behavior between P and the remaining elements (Figures 3). While for P, the ECL is much higher than MCL, regardless the forest productivity level, for the remaining elements there is an increase in MCL with the increase of the productivity. This is explained due to the eucalyptus's high P metabolic demand on growth initial phase and, also, because in that phase the roots aren't sufficiently developed to explore larger soil volume. For the remaining nutrients, the eucalypt plants requirements increase with the age, although there are some compensation by gradual increase of the available nutrients amounts, as a result, mainly, of the increase in the soil volume explored by roots, improvement of the efficient mechanisms of cycle biogeochemical and nutrients uptake released probably from minerals weathering, with the stand age. Thus, for a forest productivity of 25 $m^3$/ha/year, for example, the ECL and MCL of P are approximately 100 and 10 mg/kg of soil, respectively, while for K the values are 0,10 and 0,15 cmol/kg, for Ca are 0,45 and 0,60 cmol/kg and for Mg are 0,10 and 0,15 cmol/kg, respectively for ECL and MCL. The soil test used were Olsen for P and $NH_4OAc$ for K, Ca and Mg.

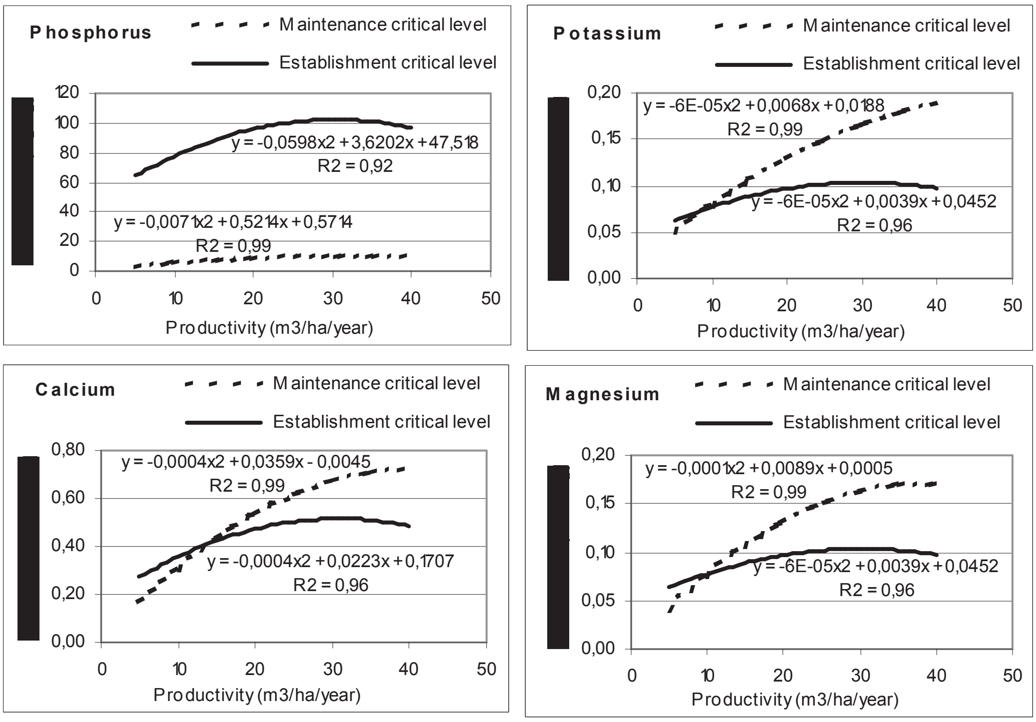



**Figure 3.** Soil critical levels of phosphorus, potassium, calcium and magnesium for establishment and growth maintenance of *Eucalyptus globulus* plantations in Portuguese forest soil conditions

**Field approach – establishment of critical levels of phosphorus for *E. globulus* plantation (ECL).** The phenomenon peculiarity of the P eucalypt nutrition, that can be expressed by the high P metabolic demand in the initial phase of eucalypt growth, and other the complexity of the soil P behavior – involving soil solution precipitation reactions, adsorption in the surface of oxy-hydroxy of iron and aluminum, presents in the soil fraction clay, and formation of complexes with the soil organic matter – made this element had a separate approach. The quadratic response obtained for sandy soil and linear response obtained for clayed soil (Table 4) was probably a consequence of soil characteristics related to the P buffer capacity (Table 1). So, the P recovery rates (P–extracted vs P–applied) were approximately 17% for Mehlich 3, 15% for Egner-Riehm and 7% for Olsen, for clayest soil, and of 22, 32 and 20%, respectively, for the sandy soil. Larger differences would be expected in the recovery rates among the two soils, if the method of P fertilizer application had not been placed at the plantation hole, strategy deliberately used to increase the phosphate fertilization efficiency (Novais and Smith, 1999; Ferreira *et al*., 2004). Thus, ECL of P determined in this work was 106 mg/kg by Mehlich 3, 157 mg/kg by Egner-Riehm and 92 mg/kg by Olsen, for the sandy soil. And for the clayest soil, the values were 187 mg/kg by Mehlich 3, 168 mg/kg by Egner-Riehm and 79 mg/kg by Olsen. The differences among extractants were probably due to the largest capacity of P–Ca chemical forms solubilization by extractants of a more acid composition (Egner-Riehm and Mehlich 3), leading eventually these extractants to overestimate the ECL. However, the values magnitude found here is very close to the estimated values by equivalence of masses approach in this work and those proposed by Novais *et al*. (1986) for establishment of eucalypts plantations in Brazil. These relatively ECL high values are explained, both for the high P plant metabolic demand and for the restricted soil volume explored by roots, in the initial phase of growth. Thus, for most of forest soils, the establishment phosphate fertilization is necessary to allow a good "start up" of the plants and guarantee adequate P supply during eucalypt first years, at least until the canopy closure. In this work, the optimum monocalcic phosphate doses (doses to provide 90% of the eucalypt maximum growth until to 12 months old) were equivalent to 16,9 and 43,2 g of $P_2O_5$/plant, respectively for the sandy soil and for the clayest one.

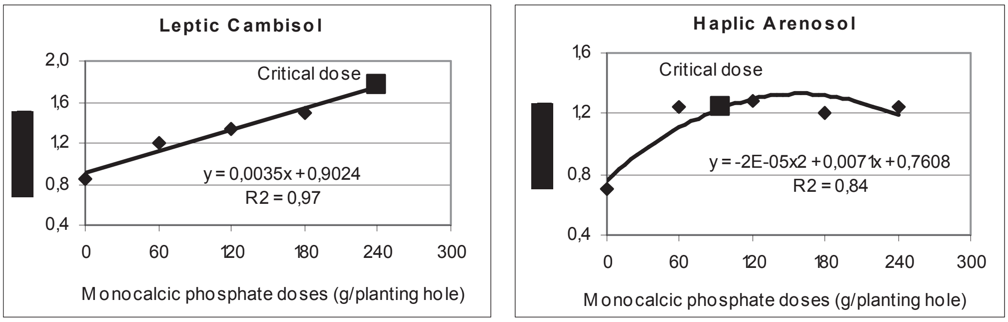



**Figure 4.** Regression equations relating height of E. *globulus* plants with 12 months old as dependent variable from doses of monocalcic phosphate applied in plantation hole immediately before planting, in both sand and silt clay loamy soil texture. Phosphate monocalcic critical dose for establishment of *Eucalyptus globulus* plantations in both sand and silt clay loamy soil texture.

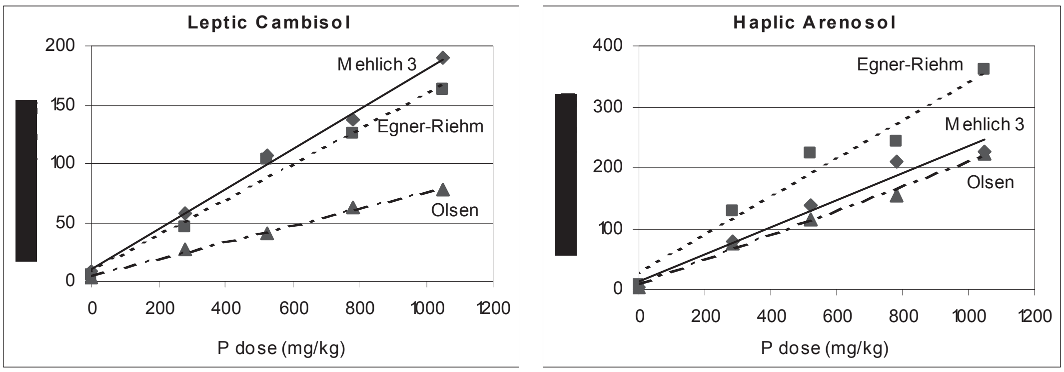



**Figure 5.** Regression equations relating P recuperated by Mehlich *3*, Egner-Riehm and Olsen extractants as a function of soil P concentration in plantation hole, in both sand and silt clay loamy soil texture. The soil samples were withdraw four months after monocalcic phosphate application and, for calculation of added P concentrations, it was considered a whole volume of 18 $dm^3$

**Field approach – maintenance critical level of phosphorus, potassium, calcium and magnesium (MCL).** Establishing significant correlation between forest productivity and soil nutrient concentrations is a challenging task, once the production depends on environmental factors such as water, land topography, soil physical factors (soil depth, texture, stoniness, porosity *vs*. compaction), besides atmospheric variables, such as light and temperature, that limit plant growth, as it can be seen at the following production-resource equation: Production = Supply. RCE . RUE, where Production is generally measured as aboveground net primary production (ANPP), Supply is the amount of resource available during the growth period, RCE is the resource-capture-efficiency (resource used-to-resource available ratio) and RUE is the resource-use-efficiency, representing the amount of production per unit of resource used, according to the approach presented by Stape, 2002. In this study, it was tried to set a correlation between forest productivity and soil nutrient concentrations for 28 plots distributed in two Portuguese regions, considering that variation for those characteristics, except soil fertility, weren't significant (Figure 6). Nevertheless, generally, the correlations obtained were weak, although the relationship between soil P level and forest productivity was reasonable, as well as for K. For Ca and Mg, weren't obtained significant correlations, probably because the soil fertility in these nutrients is high for most of soil conditions, often presenting superior values to each soil critical levels, as shows the soil fertility characterization done for eight groups of forest soil representatives of Portugal's different site conditions (Figure 7 e 8). In fact, soil fertility levels were often superior to respective MCL for almost cases.

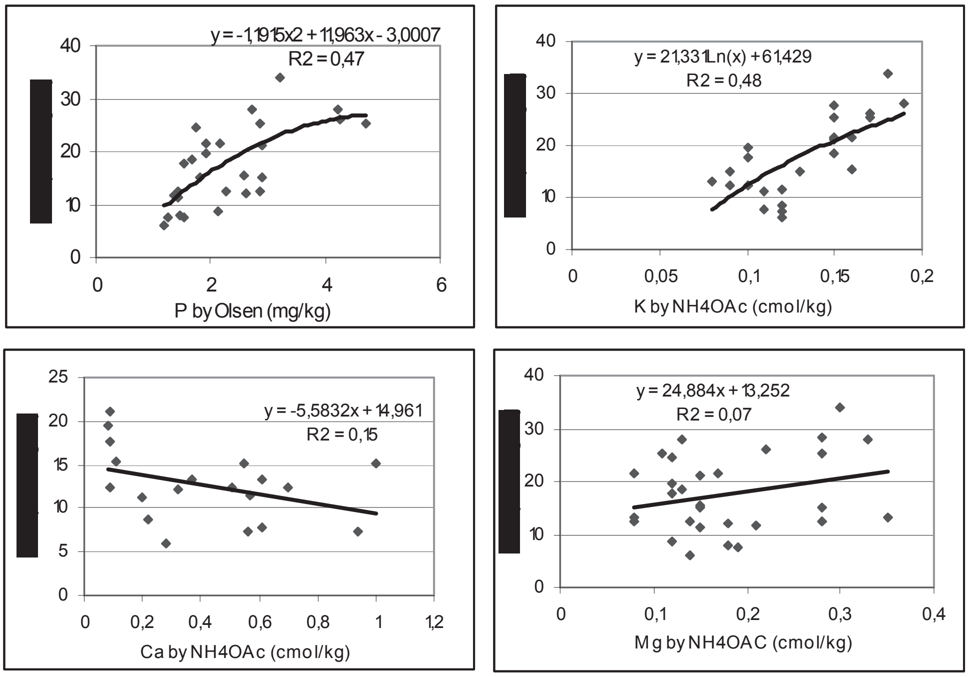



**Figure 6.** Relationship between *E. globulus* productivity and nutrients soil concentration for 28 plots distributed in two Portugal's forest soil conditions: soil group 2 – Haplic Umbrisol and Leptic Umbrisol (Xyst) and soil group 6 – Fluvic Cambisol, Arenosol, Podzol and Plinthosol (Sediments meso-cenozoic), as shown in Table 3

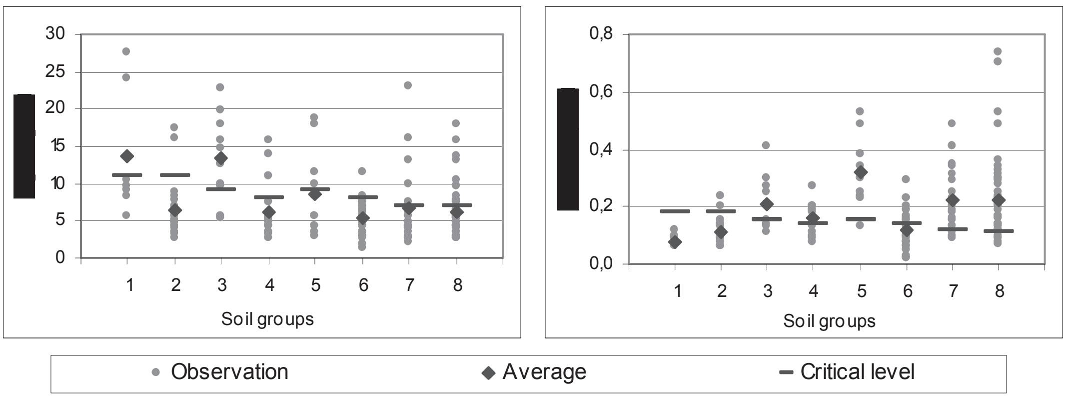



**Figure 7.** Soil fertility level and soil critical levels of phosphorus and potassium for growth maintenance of *Eucalyptus globulus* plantations in Portugal's eight forest soil conditions: 1 – Arenic Umbrisol and Umbric Leptosol; 2 – Haplic Umbrisol and Leptic Umbrisol, 3 – Dystric Leptic Cambisol; 4 – Eutric Cambisol and Calcaric Arenosol; 5 – Calcaric Cambisol and Calcic Luvisol; 6 – Fluvic Cambisol, Arenosol, Podzol and Plinthosol; 7 – Luvisol and Acrisol; 8 – Lithic Leptosol, Leptic Cambisol and Leptic Luvisol. In each soil group, the critical levels were estimated for the respective average eucalypt productivity, according to Table 3

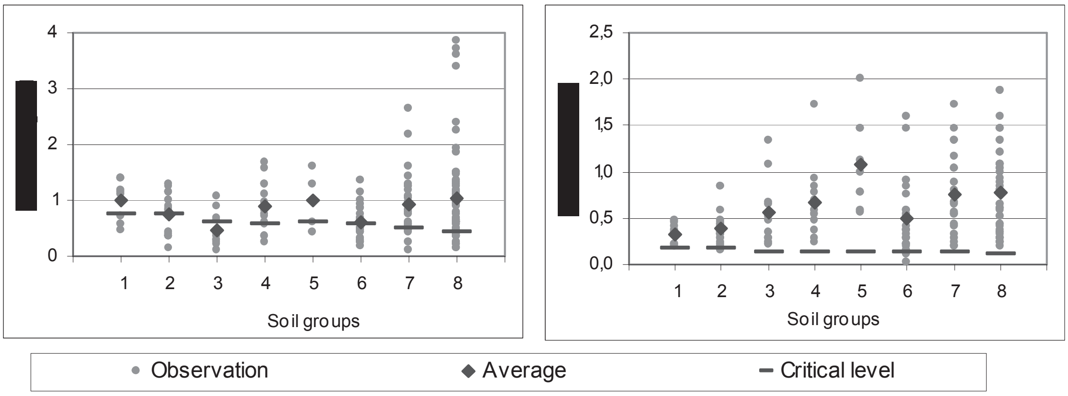



**Figure 8.** Soil fertility level and soil critical levels of calcium and magnesium for growth maintenance of *Eucalyptus globulus* plantations in Portugal's eight forest soil conditions: 1 – Arenic Umbrisol and Umbric Leptosol; 2 – Haplic Umbrisol and Leptic Umbrisol, 3 – Dystric Leptic Cambisol; 4 – Eutric Cambisol and Calcaric Arenosol; 5 – Calcaric Cambisol and Calcic Luvisol; 6 – Fluvic Cambisol, Arenosol, Podzol and Plinthosol; 7 – Luvisol and Acrisol; 8 – Lithic Leptosol, Leptic Cambisol and Leptic Luvisol. In each soil group, the critical levels were estimated for the respective average eucalypt productivity, according to Table 3

## CONCLUSION

Soil critical levels of phosphorus, potassium, calcium and magnesium for establishment (ECL) and growth maintenance (MCL) of *Eucalyptus globulus* plantations in Portugal's forest soil conditions, estimated by equivalence of mass approaches, have provided values which magnitudes are similar to the one's referred in literature. The results obtained in this work suggest that there is a quadratic relationship between forest productivity and soil nutrients critical levels, existing an opposite behavior between P and the remaining ones. For an eucalypt productivity of 25 $m^3$/ha/year, for example, the ECL and MCL of P were approximately 100 and 10 mg/kg of soil, respectively, while for K the values are 0,10 and 0,15 cmol/kg, for Ca are 0,45 and 0,60 cmol/kg and for Mg are 0,10 and 0,15 cmol/kg, respectively for ECL and MCL.

The quadratic response obtained for sandy soil and the linear response obtained for clayed soil was probably a consequence of soil characteristics related to the P buffer capacity. The optimum monocalcic phosphate doses (doses to provide 90% of the eucalypt maximum growth until 12 months old) were equivalent to 16,9 and 43,2 g of $P_2O_5$/plant, respectively for the sandy soil and for the clayest one. The P recovery rates (P–extracted *vs* P–applied) were approximately 17% for Mehlich 3, 15% for Egner-Riehm and 7% for Olsen, for clayest soil, and of 22, 32 and 20%, respectively, for the sandy soil. The ECL of P determined in this work was 106 mg/kg by Mehlich 3, 157 mg/kg by Egner-Riehm and 92 mg/kg by Olsen, for the sandy soil. For the clayest soil, the values were 187 mg/kg by Mehlich 3, 168 mg/kg by Egner-Riehm and 79 mg/kg by Olsen.

The soil fertility characterization done for eight Portugal forestry soil conditions showed that there is a significant variation between the different soil groups as well as within each one. However, for most of the observed cases, the MCL's of potassium, calcium and magnesium were often lesser than their respective soil levels. For phosphorus there was always the necessity to add phosphorus fertilizer to supply P eucalypts plant requirements for the initial growth (ECL is almost always higher than P soil levels), apparently, there is also some soil limitations for eucalyptus growth maintenance during the rotation for 50% at least of the soil population studied.

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