SCAP
SOCIEDADE DE CIÊNCIAS AGRÁRIAS DE PORTUGAL

Georeferenced soil database for running country-level forest growth simulations using the 3-PG process-based model

Base de dados de solos georreferenciados para execução de simulações de crescimento florestal a nível do país utilizando o modelo de base processual 3-PG

Jorge Delgado Nunes*, Jean Magalhães, Susana Barreiro & Margarida Tomé

Centro de Estudos Florestais, Laboratório Associado TERRA, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
*(*E-mail: jorgednunes@isa.ulisboa.pt)*
https://doi.org/10.19084/rca.38878

Received/recebido: 2024.08.31
Accepted/aceite: 2024.10.25

A B S T R A C T

In the current scenario of climate change, forest management faces new challenges, which has led to an increased interest in physiologically based forest growth models. One of the simplest and most versatile models, which has been used with different objectives namely to assess the impact of climate change on forest stands, is the 3-PG (Physiological Principles in Predicting Growth). This physiologically based model has been widely used and tested to predict the primary productivity of forest stands around the world. In this model, soil fertility is assigned through a fertility index, the so-called FR (fertility rating), that varies between 0 and 1. Another fundamental variable for site characterization is the maximum value of water available in the soil (MaxASW). The objective of this work was to create a database for public use, which indicates the values of FR and MaxASW for different geographical situations in Portugal. For this purpose, photopoints from the National Forest Inventory were layered with soil information from SNISolo and EPIC WebGIS Portugal. The FR and MaxASW were estimated for each pedological unit. Preliminary tests based on the comparison of observed data with results of 3-PG simulations showed the reliability of the information provided for FR and MaxASW.

Keywords: 3-PG, fertility rating, MaxASW, soil database, forest simulation.

R E S U M O

No atual cenário de alterações climáticas, a gestão florestal enfrenta novos desafios, o que leva a um aumento do interesse em modelos de crescimento florestal de base fisiológica. Um dos modelos mais simples e versáteis, que tem sido utilizado com diferentes objetivos, nomeadamente para avaliar o impacto das alterações climáticas na produção florestal, é o 3-PG (*Physiological Principles in Predicting Growth*). Este modelo de base fisiológica tem sido amplamente utilizado e testado para prever a produtividade primária dos povoamentos florestais em todo o mundo. Neste modelo, a fertilidade do solo resulta de um índice de fertilidade, o FR (*fertility rating*), que varia entre 0 e 1. Outra variável fundamental é o valor máximo da água disponível no solo (MaxASW). O objetivo deste trabalho foi criar uma base de dados para uso público, que indique os valores de FR e MaxASW para diferentes situações geográficas em Portugal. Assim, os fotopontos do Inventário Florestal Nacional foram sobrepostos com informação de solos do SNISolo e do EPIC WebGIS Portugal. O FR e o MaxASW foram estimados para cada unidade pedológica. Os testes preliminares de comparação de dados observados com os resultados estimados pelo 3-PG parecem indicar a fiabilidade da informação fornecida sobre o FR e a MaxASW.

Palavras-chave: 3-PG, *fertility rating*, MaxASW, base de dados de solo, simulações florestais.

INTRODUCTION

In recent years, physiologically based models have gained importance in forest management and especially in Portugal in eucalyptus stands (Nunes, 2023). Their application to other forest species with a high impact on the national economy, such as *Pinus pinaster* and *Quercus suber*, has led to a relevant research effort in the use of this type of models (Barreiro & Tomé, 2017). One of the simplest and most versatile, which has been used with different objectives, is the 3-PG (Physiological Principles in Predicting Growth). It treats a physiologically based model (Landsberg & Waring, 1997), widely used and tested to predict the productivity of primary forest stands around the world. In addition to being a tool for production prediction, 3-PG has also been used for carbon quantification (Amichev *et al*., 2011; Lonsdale *et al*., 2015), for studying the effects of forest pests (Meyer *et al*., 2017; Rua *et al*., 2020), and more recently for studying the effects of climate change on forest stands (Nölte *et al*., 2020; Palma *et al*., 2021; Wu *et al*., 2021).

The 3-PG model uses a very simple way to express soil fertility through a fertility index, the so-called FR (Fertility Rating), whose value varies between 0 and 1, empirically evaluated and depending on the soil characteristics of the site. The value 0 corresponds to very poor sites and the value 1 to sites where there is no nutritional limitation to growth. Landsberg *et al*. (2003) suggest the use of soil studies to estimate FR, but this methodology has significant implementation problems. It is difficult to characterize the fertility of a given site, and information on soil profiles is not always available.

With the aim of providing a simple access tool that allows obtaining FR and MaxASW data, for a use of 3-PG to a regional and national scale, without excluding its use at a more localized level with indicative intuits, has been created a georeferenced base of soils, whose characteristics are presented in the present work.

MATERIALS AND METHODS

Soil cartographic information was collected in digital format provided by the National Soil Information System (SNIS). To overcome the lack of soil information in areas not covered by the

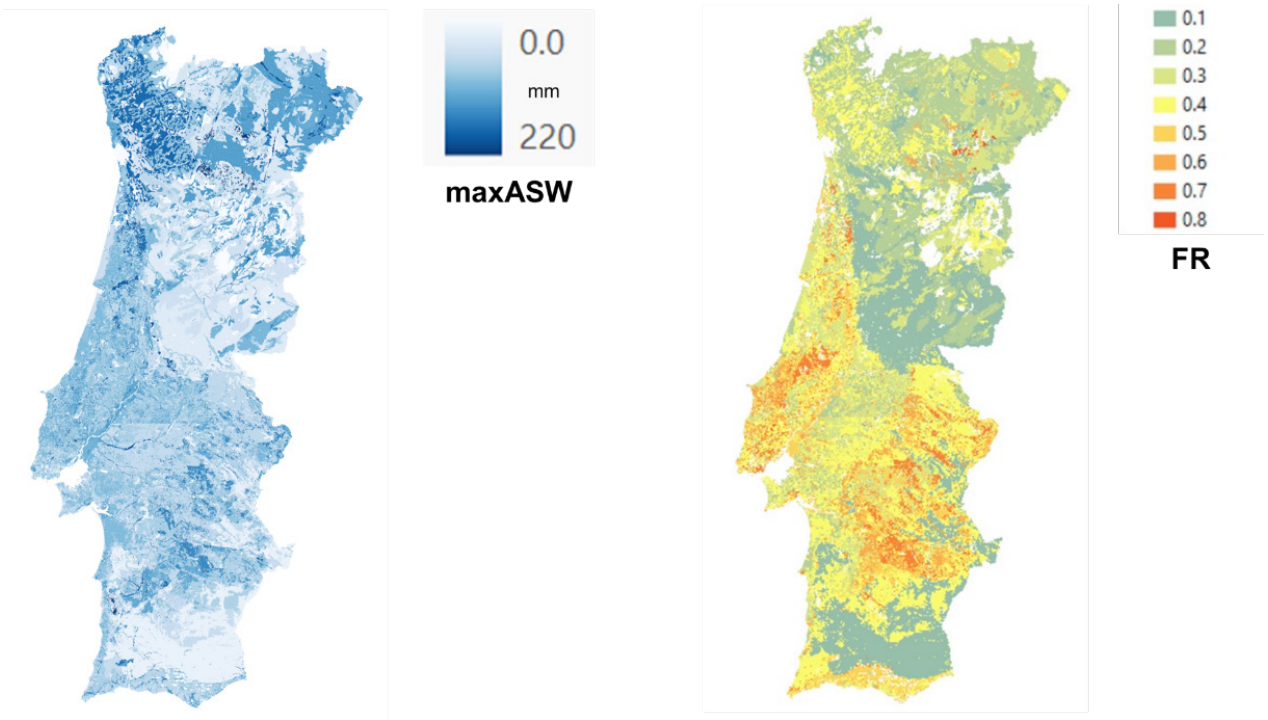

Figure 1 - MaxASW and FR values for the different locations of Portugal. Areas shown in white represent urban areas, water mirrors and watercourses, rocky outcrops or areas with insufficient information to calculate these parameters.

SNIS cartography, we used the digital cartography of the ecological value of the soil provided by EPIC WebGIS Portugal. Based on the morphological descriptions and analytical data of the different profiles available in Cardoso (1965), SROA (1973), Agroconsultores (1991, 1999) and Geometral (2004), a FR value is assigned to each of the soil pedological units. To calculate the maximum value of available water (MaxASW) of the pedological units, previous analytical data was used, using the equations of Saxton & Rawls (2006), after converting the soil texture from the IUSS system to the USDA system.

The National Forest Inventory (IFN) photopoint grid was overlaid with the digital soil map. For each photopoint one or more FR and/or MaxASW values were assigned, depending on the characteristics of the corresponding cartographic unit, regarding the dominant and subdominant soil types.

RESULTS AND DISCUSSION

For the maximum available soil water (MaxASW) and the fertility rating (FR), we developed digital maps, based on the best soil maps for each region, that provide this information to the user (Figure 1). By entering the coordinates of a given location, the user receives as output one or more values for each of these two parameters, depending on the complexity of the soil cartographic unit.

The FR and MaxASW values obtained from the database are then introduced into the 3-PG model, duly calibrated for the different Portuguese forest species, in order to obtain an estimate of the different stand variables of interest to the user.

The simulations carried out for different Eucalyptus and Maritime pine plots, for which biometric

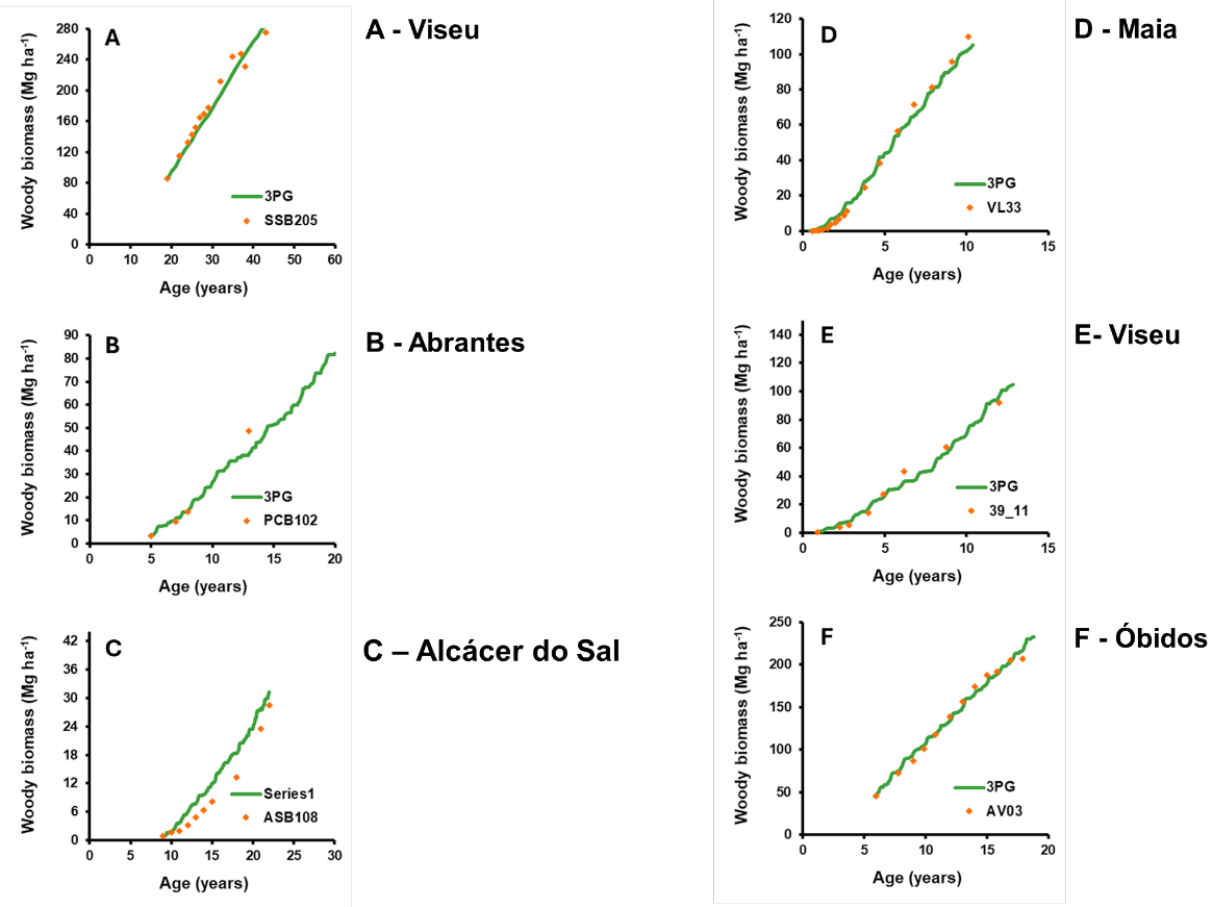

Figure 2 - Woody biomass growth simulations performed for maritime pine (left) and eucalyptus (right).

data obtained over several years were available, showed a fairly close fit between the observed and estimated values (Figure 2). These results seem to indicate that the FR and MaxASW values accessible through this database allow us to carry out forest production forecasts analogous to those obtained through more demanding methods from an analytical point of view (Nunes, 2023).

The existence of a georeferenced soil database, such as the one presented in this work, can play a relevant role in validating the applicability of the 3-PG process-based model for the whole country (Barreiro & Tomé, 2017), one of the ongoing tasks at the Centro de Estudos Florestais.

CONCLUSIONS

The simulations carried out seem to indicate a good adequacy of the values of FR and MaxASW for the field of application considered (national simulations).

To make the FR and MaxASW estimates more reliable, it is necessary to complete/improve the soil information for some regions of the country. The database is still being tested and work will continue to address the lack of properly validated cartography for the coastal central part of the country and to revise the FR and MaxASW estimates as soon as georeferenced pedological information becomes available.

BIBLIOGRAPHIC REFERENCES

Agroconsultores (1991) - *Carta dos solos, carta do uso actual da terra e carta da aptidão da terra do Nordeste de Portugal*. Universidade de Trás-os-Montes e Alto Douro, Vila Real, 114 p.

Agroconsultores (1999) - *Carta de solos e carta de aptidão da terra para a agricultura (1:25.000) em Entre Douro e Minho*. Direcção Regional de Agricultura de Entre Douro e Minho, Ministério da Agricultura, Pescas e Florestas, Braga, 99 p.

Amichev, B.Y.; Hangs, R.D. & van Rees, K.C.J. (2011) - A novel approach to simulate growth of multi-stem willow in bioenergy production systems with a simple process-based model (3PG). *Biomass Bioenergy*, vol. 35, n. 1, p. 473–488. https://doi.org/10.1016/j.biombioe.2010.09.007

Barreiro, S. & Tomé, M. (2017) - Portugal. *In:* Barreiro, S.; Schelhaas, M.J.; McRoberts, R. & Kändler, G. (Eds.) - *Forest Inventory-based Projection Systems for Wood and Biomass Availability. Managing Forest Ecosystems*. Springer, Cham, vol. 29, p. 259–272. https://doi.org/10.1007/978-3-319-56201-8_22

Cardoso, J.C. (1965) - *Os solos de Portugal; sua classificação, caracterização e génese, 1 - A sul do Tejo*. 1.ª ed., Direcção-Geral dos Serviços Agrícolas, 310 p.

Geometral (2004) - Elaboração da carta de solos e de aptidão das terras da Zona Interior Centro. Instituto de Desenvolvimento Rural e Hidráulica, Ministério da Agricultura, Pescas e Florestas, Lisboa, 289 p.

Landsberg, J.J. & Waring, R.H. (1997) - A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning, *Forest Ecology and Management*, vol. 95, n. 3, p. 209-228. https://doi.org/10.1016/S0378-1127(97)00026-1

Landsberg, J.J.; Waring, R.H. & Coops, N.C. (2003) - Performance of the forest productivity model 3-PG applied to a wide range of forest types. *Forest Ecology and Management*, vol. 172, n. 2-3, p. 199-214. https://doi.org/10.1016/S0378-1127(01)00804-0

Lonsdale, J.; Xenakis, G.; Mencuccini, M. & Perks, M. (2015) - A comparison of models for quantifying growth and standing carbon in UK Scots pine forests. *IForest*, vol. 8, p. 596–605. https://doi.org/10.3832/ifor1403-008

Meyer, G.; Black, T.A.; Jassal, R.S.; Nesic, Z.; Grant, N.J.; Spittlehouse, D.L.; Fredeen, A.L.; Christen, A.; Coops, N.C.; Foord, V.N. & Bowler, R. (2017) - Measurements and simulations using the 3-PG model of the water balance and water use efficiency of a lodgepole pine stand following mountain pine beetle attack. *Forest Ecology and Management*, vol. 393, p. 89–104. https://doi.org/10.1016/j.foreco.2017.03.019

Nölte, A.; Yousefpour, R. & Hanewinkel, M. (2020) - Changes in sessile oak (*Quercus petraea*) productivity under climate change by improved leaf phenology in the 3-PG model. *Ecological Modelling*, vol. 438, art. 109285. https://doi.org/10.1016/J.ECOLMODEL.2020.109285

Nunes, J.M.S.D.N. (2023) - *Análise da capacidade do modelo 3PG para apoiar as decisões sobre a necessidade de aplicação de fertilizantes em plantações de eucalipto em Portugal*. Dissertação de Mestrado. Lisboa, Universidade de Lisboa – Instituto Superior de Agronomia. 82 p.

Palma, J.H.N.; Hakamada, R.; Moreira, G.G.; Nobre, S. & Rodriguez, L.C.E. (2021) - Using 3PG to assess climate change impacts on management plan optimization of Eucalyptus plantations. A case study in Southern Brazil. *Scientific Reports*, vol. 11, art. 2708. https://doi.org/10.1038/s41598-021-81907-z

Rua, J.C.P.; Barreiro, S., Branco, M. & Tomé, M. (2020) - Estimating defoliation impact of *Gonipterus platensis* on *Eucalyptus globulus* stands productivity using a forest simulator based on 3-PG. *Forest Ecology and Management*, vol. 478, art. 118495. https://doi.org/10.1016/j.foreco.2020.118495

Saxton, K.E. & Rawls, W.J. (2006) – Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Science Society of America Journal*, vol. 70, n. 5, p. 1569-1578. https://doi.org/10.2136/sssaj2005.0117

SROA (1973) - *Carta de solos de Portugal. Classificação e caracterização dos solos de Portugal. II Volume. Dados analíticos das unidades pedológicas*. Boletim 16. Serviço de Reconhecimento e Ordenamento Agrário, Secretaria de Estado da Agricultura, Ministério da Economia, Lisboa, 252 p.

Wu, C.; Chen, D.; Shen, J.; Sun, X. & Zhang, S. (2021) - Estimating the distribution and productivity characters of *Larix kaempferi* in response to climate change. *Journal of Environmental Management*, vol. 280, art. 111633. https://doi.org/10.1016/J.JENVMAN.2020.111633