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Producción de oxígeno en *Pinus teocote* Schl. et Cham. y *Pinus oocarpa Schiede*. En la región Montaña del estado de Guerrero, México

Oxygen production of Pinus teocote Schl. et Cham. and Pinus oocarpa Schiede. From the Mountain of Guerrero, Mexico

Produção de oxigênio em Pinus teocote Schl. et Cham. e Pinus oocarpa Schiede. Na região montanhosa do estado de Guerrero, no México

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Resumen

El objetivo de este estudio fue cuantificar la producción de oxígeno de las especies *Pinus teocote* Schl. et Cham. y *Pinus oocarpa* Schiede. ubicadas en las áreas forestales de la región de Montaña del estado de Guerrero (México). Para ello, se empleó la ecuación de Schumacher $yi = exp(b0 + b1/x)$, la cual permitió estimar el punto óptimo de producción de oxígeno mediante el cruce del incremento corriente anual (ICA) y el incremento medio anual (IMA). Los resultados muestran que los aumentos en la emisión de oxígeno se pueden predecir adecuadamente a través de la edad, pues se obtuvieron valores de R^2 de 0.99 para *Pinus teocote* Schl. et Cham. y de 0.98 para *Pinus oocarpa* Schiede. En concreto, se puede indicar que *Pinus oocarpa* Schiede. produjo 1856 kg O_2 arbol^{-1} a los 71 años, mientras que *Pinus teocote* Schl. et Cham. solamente emitió 952 kg O_2 arbol^{-1} a los 76 años. Por tal motivo, se puede concluir que la primera especie generó más del doble de oxígeno que la segunda, de ahí que se recomiende su empleo para las plantaciones forestales o reforestaciones de servicios ambientales.

Palabras clave: modelos de crecimiento, oxígeno, *Pinus oocarpa* Schiede., *Pinus teocote* Schl. *et* Cham., servicios ambientales.

Abstract

The objective of this study was to quantify the oxygen production of the species *Pinus teocote* Schl. *et* Cham. and *Pinus oocarpa* Schiede. located in the forest areas of the Mountain region of the state of Guerrero (Mexico). For this, the Schumacher equation$yi = exp(b0 + b1/x)$was used, which allowed us to estimate the optimal point of oxygen production by crossing the annual current increase (ICA) and the annual average increase (IMA). The results show that increases in oxygen emission can be predicted adequately through age, since R^2 values of 0.99 were obtained for *Pinus teocote* Schl. *et* Cham. and from 0.98 for Pinus oocarpa Schiede. In particular, it can be indicated that *Pinus oocarpa* Schiede. produced 1856 kg O2 tree^{-1} at age 71, while *Pinus teocote* Schl. *et* Cham. only issued 952 kg O2 tree^{-1} at age 76. For this reason, it can be concluded that the first species generated more than twice as much oxygen as the second, which is why its use is recommended for forest plantations or reforestation of environmental services.

Keywords: growth models, oxygen, *Pinus oocarpa* Schiede., *Pinus teocote* Schl. *et* Cham., environmental services.

Resumo

O objectivo deste estudo foi quantificar a produção de espécies de oxigénio pinus teocote Schl. et Cham. e Pinus oocarpa Schiede. localizado nas áreas de floresta da região montanhosa do estado de Guerrero (México). Por isso, foi usada a equação que permitiu Schumacher estimar a produção óptima de oxigénio através do cruzamento do incremento corrente anual (ICA) e o aumento médio anual (IMA). Os resultados mostram que os aumentos na emissão de oxigénio pode ser adequadamente previsto através dos valores antigos para R^2 de 0,99 para pinus teocote Schl foram obtidos. et Cham. e de 0,98 para Pinus oocarpa Schiede. Em particular, pode ser indicado que Pinus oocarpa Schiede. produziu 1856 kg O_2 arbol^{-1} aos 71 anos, enquanto Pinus teocote Schl. et Cham. emitiu apenas 952 kg de O_2 arbol^{-1} aos 76 anos. Portanto, pode-se concluir que a primeira espécie gerado mais de duas vezes o segundo oxigênio, daí o uso de plantações florestais ou reflorestamento de serviços ambientais recomendadas.

Palavras-chave: modelos de crescimento, oxigênio, oocarpa Schiede Pinus, pinus teocote Schl . et Cham., serviços ambientais.

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Introduction

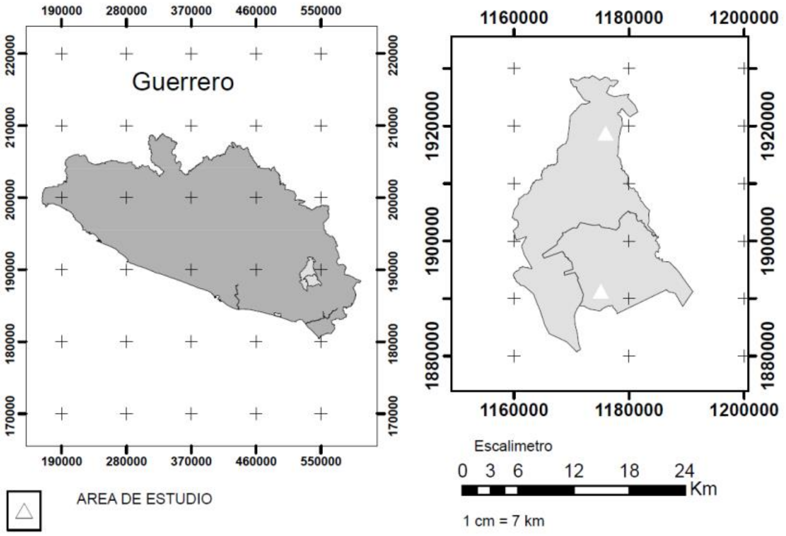
Forests are ecosystems consisting mainly of trees, which are determinant for the conservation of life on our planet, since through the chemical process of photosynthesis they generate one of the essential ingredients for subsistence: oxygen (Cabudivo, 2017; From Lima, Rojas, Méndez, Salazar and Salmerón, 2017, Pérez-Urria, 2009). However, in the final stage of maturity of these ecosystems, the net emission of oxygen decreases because the trees are only able to produce the amount they require for their own breathing (Azcón, Fleck, Aranda and Gómez, 2008). Therefore, it is crucial to know what is the true capacity of forests to generate this element during all stages of their life, a task that can be concretized by analyzing carbon concentrations at different ages (Medina 2010) and by adjusting models of growth in various forest species (Carillo, 2008).

For this reason, the purpose of this research was to evaluate the oxygen production capacity of two of the most abundant species in the Montaña region of the state of Guerrero (Mexico): Pinus teocote Schl. et Cham. and Pinus oocarpa Schiede. (Álvarez, Balboa, Merino and Rodríguez, 2005, Gernandt and Pérez de la Rosa, 2014). The null hypothesis (Ho) raised was the following: there are differences between these two species in terms of oxygen generation, which could be used as an argument to plan reforestation programs that contribute to the production of this element and the valuation of services environmental

Materials and methods

The study area of the present investigation is located between the following geographic coordinates: 98 ° 39 '24 "LW and 17 ° 19' 30" LN (figure 1) at an average altitude of 2100 m s. n. m. (National Institute of Geographic Statistics and Information Technology [Inegi, 2016]), and is constituted by the municipalities of Iliatenco and Malinaltepec, where the aforementioned pine species grow naturally. In addition, it has a semi-warm temperate climate, with intense rains in the months of July and August. The temperature ranges between -3 ° C and 26 ° C, while the soil type is mostly regosol, abundant in organic matter (Inegi, 2008; Inegi, 2014).

Figura 1. Localización geográfica del área de estudio



Fuente: Inegi (2016)

Delimitation of the study area

Before the sampling, field trips were made to locate the forest areas where the Pinus teocote Schl species grow naturally. et Cham. and Pinus oocarpa Schiede. In total, stratified and representative areas were selected with presence of mature forests of the mentioned species, which cover a total of 105 hectares. The criterion for the election of these was its wide distribution in the Mountain region of the state of Guerrero, Mexico.

Selection and felling of trees

To estimate the production of oxygen, sample trees were chosen, for which the proposal by Méndez, Luckie, Capó and Nájera (2011) was considered, who describe the criteria, number and trees to be extracted. Subsequently, 40 trees (free of pests and diseases) of Pinus teocote Schl were selected. et Cham. and Pinus oocarpa Schiede., which had all the diameter and height categories of the study area. The sample of trees was felled during two sessions in a period no longer than three months to avoid variations in foliage and moisture content.

Each tree was located and marked for easy identification. Then, before being knocked down, it was measured on foot to determine the normal diameter (DN) at 1.30 m with a diametric tape, the total height in meters (m) and the height of clean shaft (AFL) with a Haglof electronic clinometer. This information was recorded in the previously prepared field formats (Gayoso, Guerra and Alarcón, 2002, Soriano, Ángeles, Martínez, Plascencia and Razo, 2015). To avoid damage to the adjacent trees, the directional felling method was used, for which a Stihl MS 382 24 "chain saw was used. Likewise, and to avoid the loss of plant components, a canvas was placed on the ground where the tree fell for later sectioning.

Obtaining green weight

The tree was torn down, immediately separated into two components: leaves-branches and shaft. The first one was placed in sacks and weighed with a TecNova-300 kilogram digital hanging scale, which has an accuracy of up to 100 grams. At the same time, a representative sample of 5% leaf-branches was weighed and packed in paper bags for transfer to the laboratory. The stem component was divided into logs: the first two at commercial length (2.5 m), and the later ones at each meter until reaching the section of tips of the tree, which facilitated the weighing in the field.

From each loaf slices were obtained at different cutting heights, which were weighed in green and the average diameter of each side of the logs was obtained with a Forestry Suppliers Diameter Tape FOI0-0106. The total slices of each tree were labeled and packaged in bags for transfer to the laboratory. To obtain the aerial green weight of each tree, the following equation was applied:

$$PVA = PCHR + PF + PR$$

As

PVA = peso verde aéreo árbol (kg)

$PCHR$ = peso verde de componente hojas-ramas (kg)

PF = peso verde fuste (kg)

PR = peso verde rodajas (kg).

Secado y análisis de muestras

In the laboratory, the leaves-branches and slices samples were introduced in a drying oven (Felisa brand FE-293 of conventional type) at an average temperature of 100 ° C ± 5 ° C until reaching anhydrous weight, for which purpose it was monitored the weight of each sample every third day with a high precision scale. The samples were dried, sanded and growth rings were counted along the entire shaft by the trunk analysis procedure. Based on the above, different ages, diameters and heights were obtained during the life of the tree. Subsequently, it was captured in Excel 97-2003 spreadsheet.

Quantification of aerial biomass

The biomass area of each component was obtained by extrapolating the total aerial green weight of the field with the green weight of samples and dry weight of samples of each component. To obtain it, the equations proposed by Schelegel, Gayoso and Guerra (2000) modified:

$$BAC = \frac{(PVm) * (PVA)}{PVc}$$

As

BAC = biomasa área total árbol^{-1} (kg)

PVm = peso verde muestra de componente (kg)

PVA = peso verde aéreo árbol (kg)

PVc = peso seco muestra de componente (kg).

Obtaining stored carbon

The carbon (C) stored (kg) of each species was obtained through the product of aerial biomass by the standardized carbon fraction as 50% of the tree biomass (Gayoso et al., 2002, Intergovernmental Panel on Climate Change [IPCC], 2010; Schelegel et al., 2000).

Estimation of oxygen production

The production of oxygen is directly linked to the accumulation of carbon (C), so Nowak et al. (2007) indicate that the oxygen (O2) produced during photosynthesis and consumed during respiration can be estimated with the ratio of atomic weights of the CO2 molecule to the weight of the carbon atom (C) and oxygen (O2) that they make up, in this way:

$O = C * F$

As:

O = producción neta de O_2 (kg)

C = carbono almacenado en la biomasa (kg)

F = factor de conversión a oxígeno tomando como base los pesos atómicos de las moléculas de carbono y oxígeno (32/12).

In this sense, the model widely used in Schumacher forest growth studies was adjusted (López et al., 2017, Murillo et al., 2017, Pacheco, Juárez, Martínez and Ortiz, 2016), which is expressed as follows shape:

$$y = exp(b0 + b1/x)$$

As

y = oxígeno producido en kg

x = edad del árbol en años

exp = exponencial

b0 y b1 = parámetros del modelo.

To estimate the absolute shift (maximum oxygen production) the annual current increase (ICA) and the average annual increase (IMA) were obtained in each species studied, according to the following equation:

$$ICA = diferencia \quad incremento/diferencia\, tiempo$$

$IMA = incremento/edad$

Subsequently, with the adjusted model, the increases in ICA and IMA were derived, and with x, and with a, according to the following formulas:

$ICA = Dy/Dx = -a/x^2\, exp(\, a + b/x)$

$IMA = Dy/Da = -1/x \quad exp(\, a + b/x)$

The average values were estimated using the Proc Means function of the statistical program Statistical Analysis Software System (SAS, 2002), and the allometric adjustment was made with the least squares method, using the nonlinear Proc Nlin Model procedure of the same program.

Results and Discussion

Pacheco *et al.*, (2016) adjusted regression models to estimate the increment in a sample of 20 Pinus montezumae Lamb trees, dominant in Oaxaca forests. Likewise, Marroquín, Méndez, Jiménez, Aguirre and Yerena (2018) used a sample of 50 trees to estimate biomass and carbon in 22-year-old young plantations of Pinus halepensis and Pinus cembroides in Saltillo, Coahuila (Mexico).

In the present study, however, 20 trees of Pinus teocote Schl were used to estimate oxygen production. et Cham. and Pinus oocarpa Schiede. This number was considered adequate because it is natural forests where different diametric categories can be found, which would have implied, if the sample size had been increased, higher costs in sampling, labor and time.

However, the minimum values for the normal diameter of the felled trees were 5.6 cm for Pinus teocote Schl. et Cham. and 4.7 cm for Pinus oocarpa Schiede., with maximum values of 58.3 cm and 38.6 cm, respectively. Regarding the total height (m), the interval was between 6 m and 23 m for Pinus teocote Schl. et Cham., while in Pinus oocarpa Schiede. the values oscillated between 5 m and 25 m. The average age was slightly higher in Pinus teocote Schl. et Cham., aged 9 years with respect to Pinus oocarpa Schiede .; however, the oxygen concentration differed between species, associated with the growth rate of the species reflected in diameter, basal area and volume (table 1).

Tabla 1. Parámetros estadísticos descriptivos de *Pinus teocote* Schl. *et* Cham. y *Pinus oocarpa* Schiede. para la región Montaña del estado de Guerrero

Estadísticos (*Pinus teocote* Schl. *et* Cham.)	**DN (cm)**	**HT (m)**	**E (años)**	**O (kg)**
N.° de observaciones	20	20	20	20
Mínimo	5.60	6.17	7	5.88
Máximo	58.3	23	55	610
Media	28.86	17.06	30.35	248.91
Desviación estándar	15.34	5.59	13.39	205.68
Coeficiente de variación (%)	53.15	32.76	44.11	82.63
Varianza	235.31	31.24	179.29	42 304.26

Estadísticos (*Pinus oocarpa* Schiede.)	**DN (cm)**	**HT (cm)**	**E(años)**	**O(kg)**
N.° de observaciones	20	20	20	20
Mínimo	3.5	5	4	3.49
Máximo	38.6	25	40	880.63
Media	20.46	15.85	21.45	288.23
Desviación estándar	10.84	5.44	10.53	287.24
Coeficiente de variación (%)	52.98	34.32	49.09	99.65
Varianza	117.50	29.5936	110.8809	82506.81

Nota: DN = diámetro normal (cm); HT = altura total (m); O = oxígeno producido.

Fuente: Elaboración propia

Oxygen production estimation

The Schumacher forestry growth model in its form y = exp (a + b / x) presented very good adjustments for the prediction of oxygen production. A coefficient of determination (R2) of 0.99 was obtained for Pinus teocote Schl. et Cham. and 0.98 for Pinus oocarpa Schiede., with standard error values (Syx) of 0.80 and 1.76, respectively; likewise, both allometric models are highly significant (p <0.0001), so it can be said that the model adequately predicts the production of oxygen at any age of the trees, that is, juvenile or mature stages of the forest (table 2).

Tabla 2. Estadísticos obtenidos para la predicción de la producción de oxígeno (kg) para *Pinus teocote* Schl. *et* Cham. y *Pinus oocarpa* Schiede. en la región Montaña del estado de Guerrero

Especie		**Coeficiente**	**E. E.**	**Valor de *p***	**R^2**	**Sxy**	**C. V.**
P. teocote	*b0*	7.8370	0.14	< 0.0001	0.99	0.80	11.46
	b1	-74.3134	2.45	< 0.0001			
P. oocarpa	*b0*	8.5001	0.10	< 0.0001	0.98	1.76	19.67
	b1	-68.1942	1.80	< 0.0001			

Nota: E. E. = error estándar del coeficiente de regresión; R^2 = coeficiente de determinación; Sxy = error estándar del modelo de regresión; C. V. = coeficiente de variación; b0, b1 = parámetros de la regresión.

Fuente: Elaboración propia

The exponential model obtained for the production of oxygen in Pinus teocote Schl. et Cham. It was the following:

$$O = exp(7.837 + (74.3134/E)$$

As

O = producción de oxígeno (kg)

E = edad (años).

Also, for Pinus oocarpa Schiede. the allometric model was the following: $O = exp(8.5001 + (-68.19/E)$

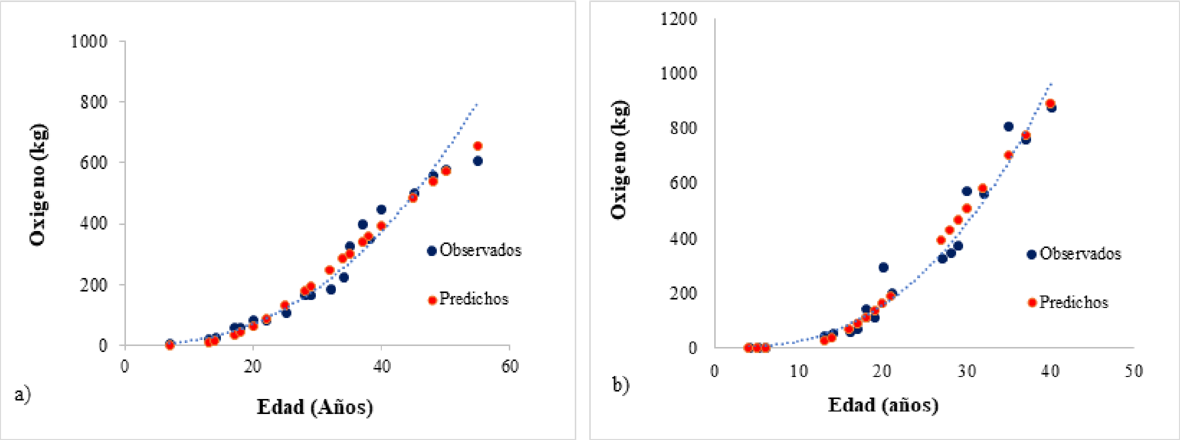
As

O = producción de oxígeno (kg)

E = edad (años).

In Figure 2 you can see the observed and predicted values of the model to estimate oxygen production in *Pinus teocote* Schl. *et* Cham. *and Pinus oocarpa* Schiede.

Figura 2. Comportamiento de observados y predichos del modelo para predicción de oxígeno: a) *Pinus teocote* Schl. *et* Cham., b) *Pinus oocarpa* Schiede. en la región Montaña del estado de Guerrero (México)



Fuente: Elaboración propia

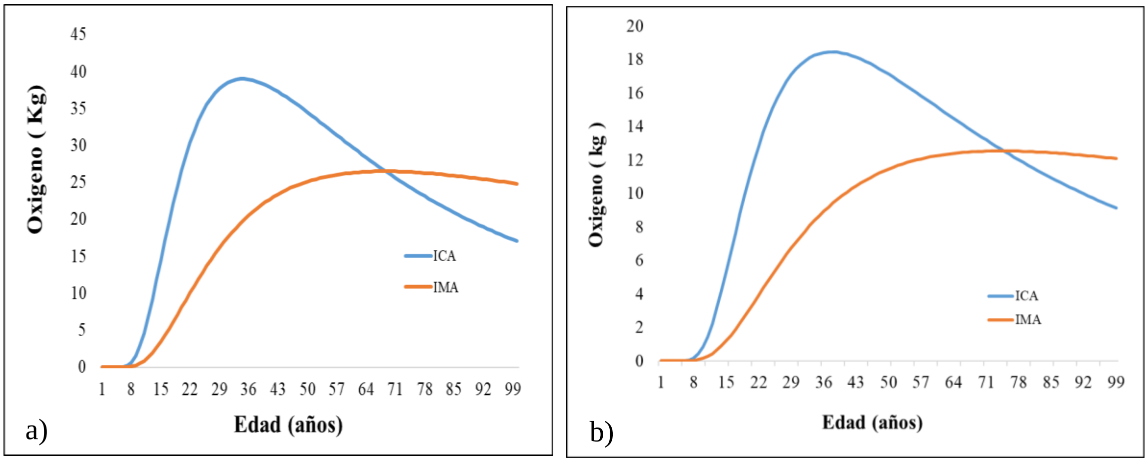
In this sense, Guerrero (2013) adjusted the Schumacher model in its exponential form to estimate the oxygen production of Pinus cembroides in forest plantations in southeastern Coahuila (Mexico), which allowed it to achieve values of R2 of 0.82 and Syx of 0.96. Similar results were found in the present investigation, where age was a good predictor of oxygen for Pinus teocote Schl. et Cham. and Pinus oocarpa Schiede. in the Mountain region of the state of Guerrero. Similarly, Hernández et al. (2015) adjusted height-age growth models for Pinus teocote Schl. et Cham. in the state of Hidalgo, where the Schumacher model presented the best adjustments with values of R2 of 0.97 and Syx of 3.34.

On the other hand, it must be indicated that the statistical parameters of the model differ with that reported by Pacheco et al. (2016), who recorded increases in height for site indices of Pinus montezumae Lamb., Based on the age of the trees, the best model fitting that of Champan-Richards an R2 adj of 0.94, Sxy of 1517.5 and CME of 12.33; However, for studies of biomass, carbon and, in this case, oxygen production, it has been corroborated that Schumacher's exponential model has achieved better adjustments (López, Méndez, Zermeño, Cerano and García, 2017; Murillo, Domínguez, Martínez , Lagunes and Aldrete, 2017; Pacheco et al 2016).

Oxygen production and increments

The crossing of ICA and IMA (absolute shift of maximum oxygen production) occurred at age 76 for Pinus teocote Schl. et Cham. with a maximum oxygen generation of 11 kg tree-1; while for Pinus oocarpa Schiede. the maximum production was given at 70 years with 26 kg per tree-1 (figure 3).

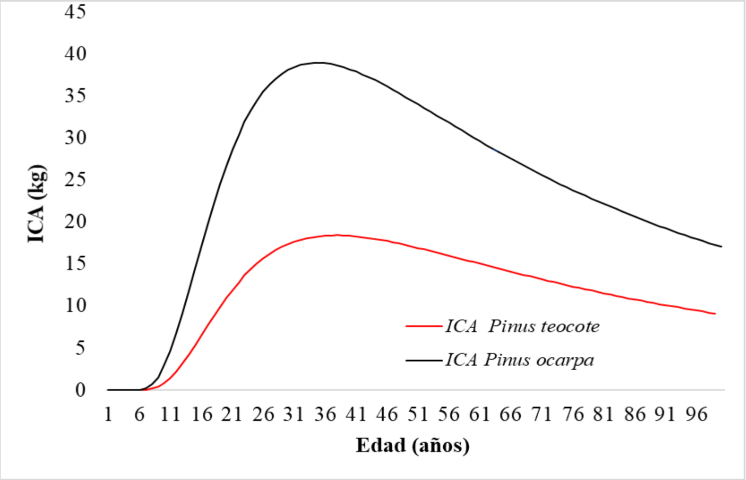
Figura 3. Producción de oxígeno para a) *Pinus oocarpa Schiede.* y b) *Pinus teocote* Schl. *et* Cham. en la región Montaña del estado de Guerrero



Fuente: Elaboración propia

The maximum ICA obtained for Pinus teocote Schl. et Cham. was 18.4 kg of O2 year-1 at the age of 38 years, while Pinus oocarpa Schiede. produced 39 kg of O2 year-1 at the age of 35 years. Likewise, it should be noted that Pinus teocote Schl. et Cham. presented the same increases in oxygen until seven years of age, while later the growth rate was higher in Pinus oocarpa Schiede. with marked marked differences in oxygen production with respect to Pinus teocote Schl. et Cham. (figure 4).

Figura 4. Incremento corriente anual (ICA) de la producción de oxígeno para *Pinus teocote* Schl. *et* Cham. y *Pinus oocarpa Schiede.* en la región Montaña del estado de Guerrero

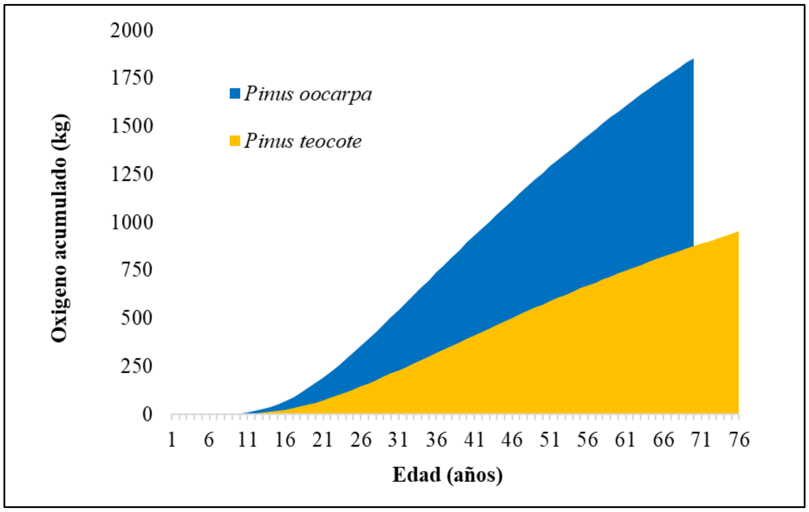


Fuente: Elaboración propia

Accumulated oxygen production

Considering the absolute shift, maximum production of oxygen accumulated during the whole life of the tree, Pinus oocarpa Schiede. produced 1856 kg O2 tree-1 at age 71, while Pinus teocote Schl. et Cham. only issued 952 kg O2 tree-1 at 76 years (figure 5).

Figura 5. Producción acumulada de oxígeno en *Pinus oocarpa* Schiede. y *Pinus teocote* Schl. *et* Cham. en la región Montaña, Guerrero (México)



Fuente: Elaboración propia

According to Perry and LeVan (2003), a person consumes an average of 0.84 kg of oxygen per day, which means that from the results obtained, 12 70-year-old Pinus oocarpa Schiede trees are required. and 25 trees of Pinus teocote Schl. et Cham. to produce the daily oxygen that a person requires (table 3).

Tabla 3. Aportación diaria y por persona de oxígeno en *Pinus teocote* Schl. *et* Cham. y *Pinus oocarpa* Schiede. en la región Montaña del estado de Guerrero

Especie	Turno absoluto	Oxígeno acumulado (kg)	Oxígeno anual (kg)	Oxígeno diario (kg)	Arboles necesarios /persona/día
Pinus oocarpa Schiede.	70	1,855.58	26.50	0.072	11.57
Pinus teocote Schl. *et* Cham.	75	940.25	12.53	0.034	24.46

Fuente: Elaboración propia

Finally, Canfield (2014) indicates that the amount of oxygen needed per person is higher when the altitude is higher than sea level (~ 40% more at altitudes higher than 3000 m asl), which is due to the difference in the atmospheric pressure. This means that more oxygen concentrations in the atmosphere would be required to supply the daily demands per person.

Conclusions

According to the data reported, it can be concluded that the adjusted growth model adequately predicts oxygen (kg) based on the age of the trees studied, since R2 values of 0.99 were found for Pinus teocote Schl. et Cham. and from 0.98 for Pinus oocarpa Schiede.

It was also found that Pinus oocarpa Schiede. produces more than twice as much oxygen as Pinus teocote Schl. et Cham., so it can be recommended for payments projects for environmental services in the Mountain region of the state of Guerrero or in similar habitats for growth of this species.

Finally, the care of forest resources should be promoted, since -as it has been confirmed- a considerable number of the species studied is needed to provide the daily oxygen requirements of a person.

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