DOI: https://doi.org/10.29298/rmcf.v10i51.147

Article

Influencia de la fertilización mineral sobre la retención de carbono en una plantación de pino

Influence of mineral fertilization on carbon retention in a pine plantation

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Resumen:

Con el objetivo de estimar el efecto que ejerce la fertilización mineral sobre la retención de carbono aplicada de forma fraccionada en los primeros cinco años de establecida la plantación el trabajo consistió en la evaluación de 288 árboles de diferentes edades durante los primeros 41 años de edad en una plantación de *Pinus caribaea*, establecida en la Estación Experimental Forestal de Viñales en Pinar del Río, Cuba. A partir de un diseño de bloques al azar, se establecieron siete tratamientos diferenciados por las dosis de NPK y regímenes de aplicación, más un tratamiento testigo sin la aplicación de fertilizante químico. Se realizaron mediciones de altura y diámetro y se calculó el volumen a diferentes edades. El análisis evidenció que las dosis de 600 g árbol^{-1}, 800 g árbol^{-1} y 1 000 g árbol^{-1} favorecen la retención de carbono de *P. caribaea.* Con la aplicación de una dosis única de 300 g árbol^{-1} se obtienen valores inferiores a los del tratamiento testigo.

Palabras claves: Carbono, fertilización mineral, dosis, pinares, retención, tiempo.

Abstract:

The work was carried out with measurements taken on the same trees during the first 41 years of age of a *Pinus caribaea* plantation, established in the Experimental Station of Viñales Forest in Pinar del Río, Cuba, from a random block design where, Seven different treatments were established by the NPK doses and application regimes, plus a control treatment without the application of chemical fertilizer. Measurements were made at different ages to 288 trees with follow-up for 41 years. To estimate the effect of fertilization on carbon retention, height and diameter and the volume was calculated measurements were performed at different ages. The objective of this research was to study carbon sequestration in response to mineral fertilization applied fractionally in the first five years after the establishment of the plantation during the entire time studied. The analysis was used as a result to assert that the doses of 600 g tree^{-1}, 800 g tree^{-1} and 1 000 g tree^{-1} favor the carbon retention of the planted species, with the application of a single dose of 300 g tree^{-1} lower values are obtained than those obtained by the control treatment.

Key words: Carbon, mineral fertilization, dose, pinewood, retention, time.

Fecha de recepción/Reception date: 11 de enero de 2018
Fecha de aceptación/Acceptance date: 29 de noviembre de 2018

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Introduction

The beneficial effects of fertilizers on the biology of plants are well known. However, when applied incorrectly —whether in excess or in deficit—, they may have negative consequences.

Pinus caribaea Morelet *var*. *caribaea* Barret and Golfari is a native conifer of *Cuba*. Due to its high ecological plasticity and its rapid growth compared to other native pine species of Cuba, it is widely used in reforestation plans across the Cuban archipielago (Herrero *et al.*, 1990).

Forests absorb CO_2 from the atmosphere and store it as carbon, not only in the biomass, but also in the subsoil, thereby contributing to reduce the amount of CO_2 present in the air. Forests cover approximately 29 % of the continents and contain 60 % of the carbon of the terrestrial vegetation. It is therefore suggested that an increase in the forest surface area may help mitigate the effect of the global warming and the potential climate change, at least in the medium and long term (Sedjo and Solomon, 1989; Adams *et al.*, 1993; Van Kooten *et al*., 1995; IPCC, 1996; Adams *et al*., 1999; IPCC, 2000).

The possibility of using the growth of forest masses as a form of carbon storage has received growing attention by public administrators as a way of facing a potential climate change (Bruce *et al.*, 1996). Carbon absorption may be utilized to meet the goals of reducing greenhouse gas emissions (Mogas and Riera, 2004).

The possibility of reducing greenhouse gas emissions through forest activity and its potential for augmenting carbon sequestration increases the importance of the forest sector and its participation in actions aiming to mitigate the effects of the climate change as established by the Kyoto Protocol (Makundi and Razali, 1998), since carbon fixation through forest activity depends on the biomass accumulation and storage; therefore, any forest management practice that modifies the amount of biomass existing in a particular area impacts its ability to store or fix carbon (Moura, 2001).

Forests and forest soils are the main terrestrial reserve areas of atmospheric carbon. Monocultures or single species plantations emerge as the most efficient way of consolidating the ability to capture this element because they are easy to establish and manage, although, due to their homogeneity, they may be more susceptible to fire and to pests.

Likewise, the selection of species has a direct impact on the potential for carbon storage: species with a rapid growth accumulate more biomass and carbon than those that develop slowly.

Conifers are ascribed a greater ability to accumulate carbon than broadleaves because their organic matter decay process are slower. Thus, eucalyptus varieties offer high carbon uptake rates within a broad interval of conditions.

Nevertheless, although the ability to retain carbon is not always expressed under natural conditions due to water and nutrient limitations, it can manifest in a well-managed plantation (Prado, 2015).

In a large number of sites, eucalyptus varieties have invasive tendencies; however, in Cuba, they have not been rated as exotic species.

Thus, the following hypothesis was proposed: the fractioned application of mineral fertilizers in *Pinus caribaea* plantations established in Alitic soils with low clayey activity contributes to increase carbon retention by the species. The objective was to study carbon retention in response to the fractioned application of mineral fertilizers in the first five years of establishment of the plantation across the study period.

Materials and Methods

The experiment was established at *Estación Experimental Forestal de Viñales* (Viñales Forest Experimental Station) in *Pinar del Río, Cuba.* located at 22º37´ N and 83º41´ W, at an altitude of 150 m.

At the beginning of the planting, the temperature values corresponded to those of the closes weather station in the city of *Pinar del Río*, according to which the mean annual temperature was 24.7 ^{0}C; the daily maximum temperature was 28.7 ^{0}C; the minimum daily temperature, 20.4 ^{0}C, and the absolute minimum temperature, 16.2 ^{0}C (Awan and Frías, 1970).

Experimental design

The experimental design was that of León *et al.* (2016); the experiment gives continuity to a series of measurements carried out in the same trees established in 1971, to a mineral fertilization assay with a randomized block design consisting of four blocks and eight treatments; in these, NPK was applied fractionally with the formula 8-10-10, which indicates no changes in the proportion of NPK, but only in the amount administered to each tree (Table 1).

Table 1. Experimental treatments.

Treatment	**Total NPK Dose**		**Applications by age (g tree^{-1})**				
	g tree^{-1}	**kg ha^{-1}**	**Age (years)**				
			1	**2**	**3**	**4**	**5**
T1(control)	0	0	0	0	0	0	0
T2	300	333	300	0	0	0	0
T3	600	667	200	400	0	0	0
T4	600	667	200	0	400	0	0
T5	800	889	200	200	400	0	0
T6	800	889	200	0	200	0	400
T7	1000	1111	200	200	400	200	0
T8	1000	1111	200	0	400	0	400

The fertilizer is made up of ammonium nitrate, mono ammonium phosphate and potassium sulfate, whose characteristics are the following: 35 % ammonium nitrate, with a solubility of 1 700 g L^{-1}, an electric conductivity of 850 μS cm^{-1}, and an acid reaction; mono ammonium phosphate, with 11 %, 48 % phosphorus, a solubility of 200 g L^{-1}, an electric conductivity of 455 μS cm^{-1}, and an acid reaction; potassium sulfate with 50 % richness, a solubility of 110 g L^{-1}, an electric conductivity of 880 μS cm^{-1}, and a neutral reaction.

The provenance of the seeds was the *Marbajitas* seed orchard, located in the municipality of *La Palma*, at a distance of 50 km from the place where the trees were planted. The planting frame was 3 × 3 m. The size of the plots was 225 m^2, with a total of 25 trees, and nine in the useful plot, whose individuals were labeled and followed up throughout the duration of the assay.

The experiment was established in 1971 at the *Viñales* Forest Experimental Station. The planting hole method was utilized; the fertilizer was applied to the furrows in a half-moon shape and covered with earth, at the start of the rainy season, in July, and during the first five years after the establishment of the plantation.

Mensuration data taken at the assay

In order to assess the response of the species to fertilization, the number of living trees ha^{-1} was estimated, and the height and the diameter at 1.30 m above the ground of the trees of the useful plot were measured, using a Blume-Leiss-1969 hypsometer and a caliper (Varsi-1970), respectively).

The data were recorded from 1977 (at six years of age) to 2012 (at 41 years of age). The number of living trees per hectare was estimated considering only those present in the useful plot.

The content of retained carbon was determined, in (Mg ha^{-1}), based on the height, the number of living trees ha^{-1}, the diameter and the volume of the timber with bark at 6, 18, 15, 33, 35 and 41 years of age of the plantation.

Height (h) was measured using a calibrated ruler up to two years after the planting, and a Blume–Leiss hypsometer after five m.

The volumes of timber corresponding to each of the plots were estimated by adding the volumes of the surviving trees, so that the estimated values reflected the changes in the number of trees ha^{-1} (Table 2).

Table 2. Tons of carbon (Mg ha^{-1}) retained by the plantations, by treatment and by age.

Treatment	Age of the plantation (years)					
	6	**8**	**15**	**33**	**35**	**41**
T-1	4.53 b	7.40 c	26.08 c	76.73 ab	88.28 b	106.25 b
T-2	5.13 b	9.00 bc	29.03 bc	61.55 b	83.40 b	102.03 b
T-3	6.88 ab	11.20 abc	40.93 abc	81.80 ab	105.50 ab	139.83 ab
T-4	7.05 ab	12.58 abc	37.03 abc	91.68 a	111.58 ab	154.43 a
T-5	7.38 ab	12.60 abc	44.25 ab	90.25 a	103.70 ab	137.28 ab
T-6	6.75 ab	13.28 ab	45.40 ab	96.13 a	124.53 a	156.68 a
T-7	8.43 a	15.00 a	48.85 a	99.13 a	122.80 a	151.48 a
T-8	7.33 ab	12.33 abc	46.08 ab	93.93 a	120.00 a	146.58 a
EE	0.900	1.613	5.406	6.993	9.577	12.749
CV	20.74	31.36	31.17	19.77	20.78	22.08

Means with different letters indicate significant differences (Duncan, $P < 0.05$ %).

Estimations were made from the age of six years, based on the number of living trees per hectare, using Hubert's formula:

$$V = \frac{\pi}{4} \times 10^{-4} \times d^2 \times h \times C_f$$

Where:

V = Volume of timber per tree, m^3 .tree^{-1}

d = Diameter at 1.30 m from the ground (cm)

h = Height (m)

C_f = Morphic coefficient (0.5 for *Pinus caribaea)*

Retained carbon

Carbon retention was calculated at 6, 8, 15, 33, 35 and 41 years of age of the plantation, using the methodology to establish the carbon retention baseline (Mercadet and Álvarez, 2009), which considers the variables species, age (years, surface area (ha), height, m, diameter (cm), diameter (m), volume (m^3), stem biomass (t) aerial biomass, root biomass, total biomass (t) and carbon biomass (t).

Economic analysis

The economic benefit was calculated considering carbon at the age of 41 years after panting (Table 2), the cost of the fertilizers expressed in UPC ($ 2 800.00 MXN), the cost of applying the fertilizer ($ 81.60 UPC), and the value of the ton of carbon (€ 10.01), annual mean for 2018 (https://www.sendeco2.com/es/precios-co2).

It was calculated using the formula:

$$EB = (T_C n - T_0) * CT_c - (C_{fer} + C_{apfer})$$

Where:

EB = Economic benefit

$T_c n$ = Tons of carbon for a treatment *n*

T_0 = Tons of carbon for control

CT_c = Cost of the ton of carbon (UPC)

C_{fer} = Cost of fertilizers (UPC)

C_{apfer} = Cost of fertilizers application

The Value/Cost ratio (V/C) was calculated using the following expression:

$$V/C = \{EB\} / (C_{fer} + C_{apfer})$$

The price of the ton of carbon in Euros was converted into UPC according to the current exchange rate of 1.23245 UPC, and this value was multiplied by $ 25.00 MXN at the current exchange rate for the Cuban peso, in order to unify the currency.

Statistical analysis

The amount of retained carbon was subjected to multivariate variance analyses and to Duncan's mean comparison tests. The data were processed by means of a variance analysis, with a significance level of 0.05 %. Univariance analysis were carried out separately for the different ages. Compliance with the normality assumptions was verified, using the Shapiro-Wilk test, and the variance homogeneity, using Levene's test.

Result and Discussion

Effect of fertilization on carbon retention

Controlled fertilization in forest plantations favors carbon storage in the trees. Table 2 shows that the treatments with the highest doses of fertilizers produced the largest carbon reserves and exceeded those of the control by an average of 41.8 Mg ha^{-1} at the age of 41 years. Treatment T2, with the lowest dose, obtained lower values than the control, in agreement with the thesis of Reyes *et al.* (2014), that the application of less than the appropriate dose of fertilizer produces nutritional imbalances and, therefore, less growth.

Statistical differences were registered in treatment T1 for the ages of 6, 8 and 15 years, as well as for higher ages; this was influenced by height, which exhibited significant differences among treatments only in the first years, after which stability was attained, and then lost at the age of 17 years (Jiménez and Herrero, 1994); at the end of the period, only the treatment in which 300 g of NPK were applied per tree turned out to be statistically different, with a lower estimated value, which proves that height is an indicator of the quality of the site (Reyes, 2016).

The results for the different treatments in which doses of mineral fertilizer equal to or above 600 g tree^{-1} were applied exhibited larger volumes of timber, which resulted in a larger amount of carbon retained by the plant, as timber is one of the main variables that influence carbon retention in the species. There were no significant differences between treatment T1 at the age of 33 years and treatments T3 to T8. However, its numerical value is lower than the one attained by these other treatments, which ratifies the importance of applying mineral fertilizers, not only in order to increase the outputs in timber volume as the main economic benefit, but also as means to mitigate the effects of climate change through carbon sequestration and retention.

Bruce *et al*. (1996), cited by Mogas and Riera (2004), suggested the possibility of using forest mass growth as a form of carbon storage for addressing the potential climate change and increasing the sequestration of this element by forest plantations.

Considering that the application of 800 to 1 000 g tree^{-1} of chemical fertilizer contributes to increase carbon retention by an average of 41.8 Mt ha^{-1}, it may be said that the fractioned application of mineral fertilizer in the first five years after the establishment of the plantation favors carbon retention by the cultivated species.

The sustainability of forest plantations requires consideration of both economic and environmental factors. Field experiments prove that the use of large amounts of fertilizers increases tree growth (Muller da Silva *et al.*, 2013).

Fertilization with nitrogen has the ability to significantly alter the edaphic environment of forests and can increase carbon storage (Smaill *et al.*, 2008). According to Shryock *et al.* (2014), fertilization with nitrogen significantly increased the sequestered carbon by each tree compared to unfertilized plots.

In studies conducted by BBC WORLD (2003) and FAO (2011), in general, forests provide a unique environmental service by eliminating carbon dioxide from the atmosphere and storing it in the biomass, the soil, and the products; furthermore, they offer a sustainable alternative to fossile fuels. In particular, rapidly growing forest plantations (pine and eucalyptus) have a beneficial impact on the environment, as they contribute to the reduction of the greenhouse effect.

Eucalyptus plantations in *Cuba* exhibit no adverse results in terms of species displacement, as they are mainly used as low-size timber for assuring tobacco crops, as poles for the production of covered tobacco, and as sticks ("*cujes*") for stringing the tobacco leaves.

There is evidence that soil conditions such as the porous space occupied by water, the temperature, and the availability of soluble carbon (C) have a dominant impact on N_2O emissions. Crop management and the source of fertilizer to be used are factors that can affect N_2O emissions, but, due to the interactions with soil factors, general conclusions are hard to reach.

Mismanagement of the correct dose, the source, the time, or the location of the fertilizer (N), and a lack of appropriate balance with other essential nutrients may increase the total loss of N, as well as the N_2O emissions. When N is applied in larger doses than the optimal economic dose, or if the N available in the soil (especially in forms of NO_3-) exceeds its absorption by the crop, the risk of increasing N_2O emissions increases (Leyva, 2015).

Forest plantation can play an important role in carbon retention and in supporting global efforts to solve greenhouse effect and climate change issues (Salleh, 1997).

The amount of carbon fixated per planted hectare varies according to the species, the design of the plantation, the management, and the soils, among other factors; however, the increase in the volume of accumulated biomass in the entire reforested area increases the number of tons of mitigated carbon (Arguedas-Marín, 2012,).

The graphic representation of the tons of carbon registered for the various treatments at the different ages reflects this (Figure 1). The treatments with doses of fertilizer of over 300 g tree^{-1} are observed to produce the largest carbon retentions, significantly higher than the other treatments. Treatment T2, with the lowest dose, resulted in lower values than those of the control treatment; this ratifies the results obtained by Vásquez (2001) and Reyes *et al.* (2014).

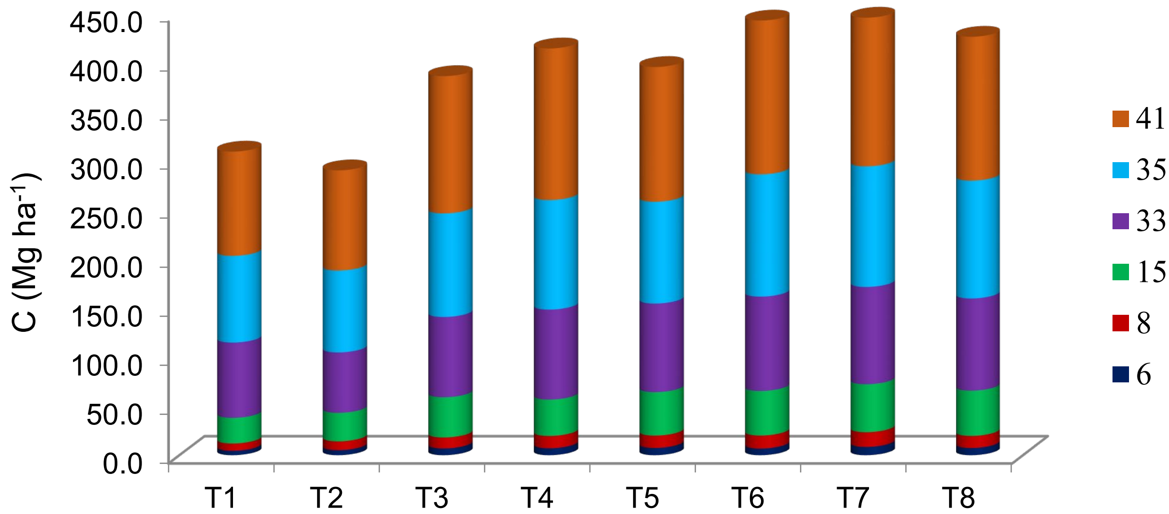
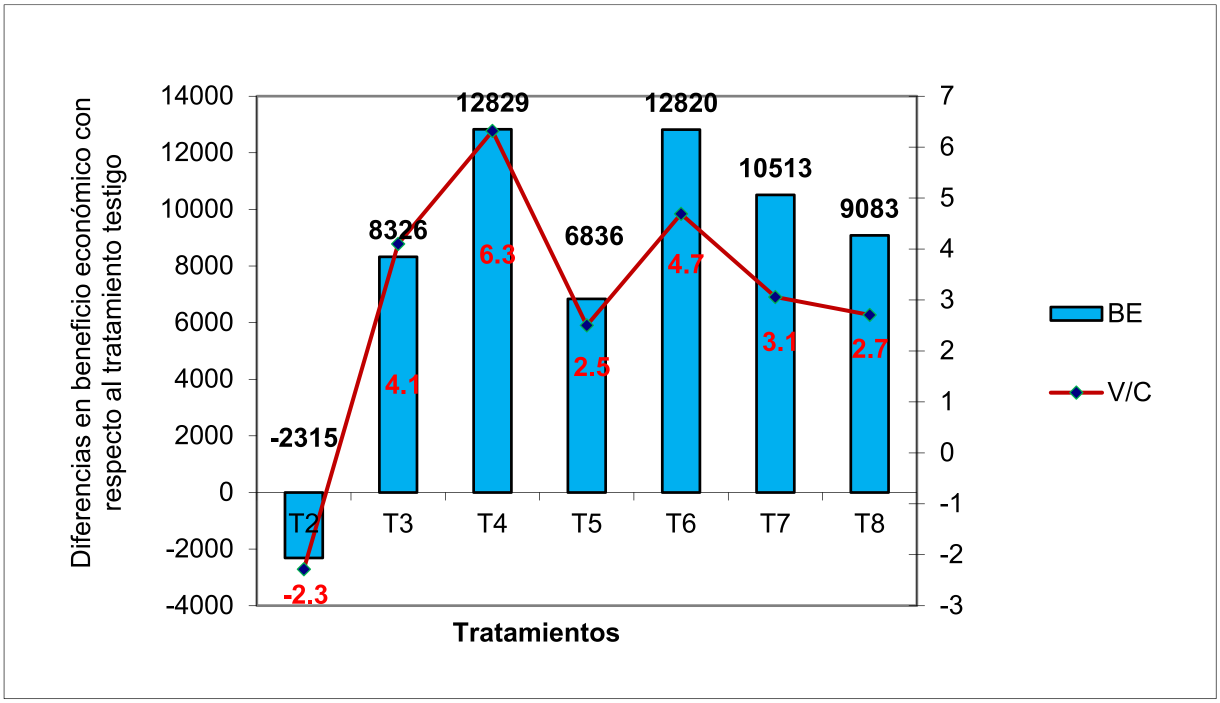


Figure 1. Retained carbon by age and by treatment.

The orthogonal contrasts did not exhibit significant differences between the alternate and the continuous regimes as to the amount of carbon retained in any of the years, with values of P_{1977} =0.462; P_{1979}= 0.881; P_{1986}=0.693; P_{2004} = 0.550; P_{2006}= 0.337; P_{2012}= 0.362.

Economic analysis

The treatments T3, T4, T5, T6, T7 and T8 registered positive economic effects, except for treatment T2, in which a minimum dose of 300 g árbol^{-1} was applied. Figure 2 shows the differences in economic benefit and the value/cost ratio of the treatments, compared with the control. The profits for treatments T3 to T8 are above $ 6 000 ha^{-1}; treatments T4 and T6 obtained the highest profits, above $ 12 000 ha^{-1}. The losses of treatment T2 were below $ 2 300 ha^{-1}, at 41 years of age of the plantation, and the V/C ratios for treatments T3, T4, T5, T6, T7 and T8 were above 2, an acceptable value for investment in fertilization, considering the volumes of timber obtained per hectare (FAO, 1986).



Trataminetos = Treatments; *Diferencias en beneficio económico con respecto al tratamiento testigo* = Differences in economic benefit with respect to the control treatment.

Figure 2. Economic analysis of the experiment on the application of mineral fertilizers in an Alitic soil with low clayey activity.

In general, treatments T3, T4, T6, T7 and T8 had the best results, notably T4 and T6, with an economic benefit above $ 12 000 ha^{-1} and a value/cost ratio above four. It is important to highlight that treatment T7 behaved as the most stable in all the assessed variables (Reyes, 2016). In the economic analysis it obtained a value/cost ratio of 3.1, which is lower than that of other treatments; however, its economic benefit exceeds $ 10 000 ha^{-1}. Either of these variants represents an attractive option for forest management, in terms of the available fertilizer and the use given to the timber, in order to obtain the maximum carbon retention, the highest profits and the best value/cost ratio.

Conclusion

Assessment of the carbon retention by the planted species shows that fertilization as a silvicultural activity has a positive impact which is sustained through time and continues to increase 41 years after the establishment of the plantation, with the highest doses resulting in the highest values.

Conflict of interests

The authors declare that no conflict of interests.

Contribution by author

Jorge Luis Reyes Pozo: field work, drafting of the abstract, introduction, results, discussion, and conclusions of the mansucript; Maria Amparo León Sánchez: drafting of the abstract, the results, discussion, and conclusions of the manuscript, design of the tables and figures, and statistical analysis; Grisel Herrero Echeverría: general revision and editing, support in the results and discussion sections of the manuscript, revision of the manuscript, and suggestions in relation to the results, discussion, and conclusions.

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