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Efectos del fuego sobre propiedades químicas del suelo en bosque natural de Pinuscubensis
Fire effects on soil chemical properties in natural Pinuscubensis forest

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Resumen
La investigación se realizó en un bosque de *Pinuscubensis* perteneciente a la Unidad Empresarial de Base de Yateras, con el objetivo de evaluar los efectos de la quema prescrita sobre algunas propiedades químicas del suelo. Se determinó la cantidad de material combustible, comportamiento del fuego y sus efectos sobre propiedades químicas del suelo, se obtuvo como resultado en retroceso la reducción del 58,5%del material combustible y en avance, el 43,7%. Para ambos casos, la intensidad de quema no sobrepasó las 165 $kcal.m^{-1}.s^{-1}$. En cuanto a las propiedades químicas del suelo, no se encontraron diferencias entre las técnicas.

Palabras clave: Fuego; Suelo; Material combustible; Quemas prescritas.

Abstract
The research was carried out in a Pinuscubensis forest belonging to the Yateras Base Business Unit, with the objective of evaluating the effects of prescribed burning on some chemical properties of the soil. The amount of fuel material, fire behavior and its effects on soil chemical properties were determined, resulting in a reduction of 58.5% of the fuel material in backward burning and 43.7% in forward burning. In both cases, the burning intensity did not exceed 165 $kcal.m^{-1}.s^{-1}$. As for the chemical properties of the soil, no differences were found between the techniques.

Keywords: Fire; Soil; Fuel material; Prescribed burning.

Introduction

According to Agee, (1998) "Fire has been the cause of several adaptations present in the genus Pinus and its wide distribution in its native habitat in the Northern Hemisphere and the high expansive range as an exotic species in the Southern Hemisphere" (p.193). In this regard, Urrutia (2012), states:

In order to sustainably use the goods and services provided by forest resources, man has had to know the effects of fire on the different elements of forest ecosystems. This has led several countries, such as the United States, Brazil and Spain, to have sufficient information on the subject, even to the point of legislating the way to evaluate the environmental impact of forest fires. (p.103.)

Durán, (2014a), states that the implementation of the integrated concept in forest resource management has implied the search for versatile and economical alternatives for its implementation. One of these is prescribed burning, although in Cuba there is little background on the subject, it is implemented in several countries as a tool to support their integrated forest management plans.

In correspondence with the above, it is considered that the implementation of prescribed burning in Cuba should be paid attention to argue its medium and long term effects on the different elements that make up the pine forests, among which are the chemical properties of the soil.

Knowledge of the effects of fire on the chemical properties of the soil, generated by the implementation of prescribed burns in pine forests, is important if one takes into account that the existence of this type of forest in Cuba exceeds 250,000 ha.

The prescribed burns in Cuba have been applied at an experimental level, only some of them describe the effects of burns on the chemical properties of the soil in Pinuscaribaeae.

There are studies on the effects of prescribed burning in a Pinuscubensis forest in Guantanamo province. These are focused on the variations of fungal communities and natural regeneration before and after applying prescribed burns, therefore, it is necessary to evaluate the fire on chemical properties of the soil in a natural forest of Pinuscubensis in Yateras municipality in Guantanamo province.

Development

The research was carried out in a fragment of natural forest of Pinuscubensis belonging to the Forestry Base Business Unit (UEB) of the Guantanamo Integral Forestry Enterprise in Monte Llano, Yateras municipality, Guantanamo Province, in lot 11 stand 22; coordinates X 677.263 and Y187.263.

A randomized design was used, evaluating the load of combustible material, fire behavior, some soil characteristics and effects of fire on certain chemical properties of the soil. Because of this, it was necessary to combine different types of plots in the same place, applying prescribed burns in six rectangular plots of 20 X 50 m, three in advance and three in retreat. The dry weight of the combustible material before and after the burns was determined for evaluation, and the fire behavior was evaluated. For the chemical analysis of the soil, six samples of 0-10 and 10-20 cm depth were taken for each 20 x 50 m plot. The determination of the available combustible material load was carried out one week before and one week after the burns were applied in the six burned plots, according to Ramos (2010), and used by Pérez (2012), Urrutia (2012) and Durán (2014), which consists of estimating the weight of all available combustible material deposited in a 1 m2 plot.

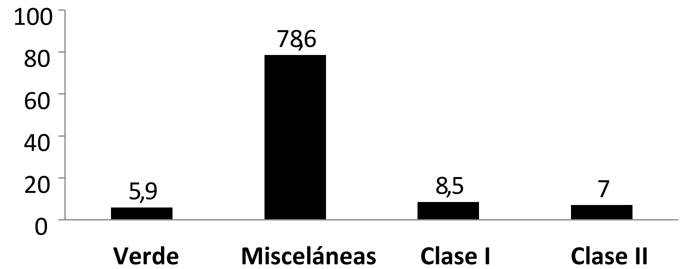
Fire behavior parameters were evaluated: fire intensity according to Byram (1959), heat released per unit area, flame height, according to the formula described by Batista (1990), and fire propagation speed was determined according to Ramos (2010), "locating several points and calculating the time it took for the fire to arrive, expressing the result in meters per second" (p. 213).

For the evaluation of the effects of fire on some chemical properties of the soil, the results of pH, Mg2+, K+, Ca2+, Na+ and Organic Matter were analyzed. The analysis was carried out at the Guantanamo Provincial Soil Laboratory, belonging to the Ministry of Agriculture. For this purpose, six random samples were taken per plot of 1,000 m2, from 0 to 10 cm and 10 to 20 cm depth, seven days before applying the two prescribed burning techniques and 15, 30, 45, 60, 75, 90, 105, 120, 135 days, 6 and 12 months after the burns. The methodology used by Martínez (2006), Pérez (2012), Durán (2014a) and Durán (2015) was taken into account.

En el gráfico 1 se observa el porcentaje de material combustible por tipo antes del fuego en avance, donde las misceláneas es la que más aparecen.

With these results, Batista (1995) and Grodzki (2000), when they calculated the amount of combustible material to burn in Pinus pinaster with the objective of reducing the fuel load to avoid the occurrence and propagation of forest fires, reported that the greatest amount of combustible material corresponds to miscellaneous.

Betancourt (1990) points out that "the high quantities of miscellaneous material influence the speed of burning, since it is a fine material and has the property of gaining or losing humidity in a short time according to meteorological conditions" (p. 46).



Graph 1. Percentage by type of material.

Self made

The percentage by type of fuel material before the fire in the plots where the prescribed back burning technique was applied with 100% cover.

Using the words of Wright, et al. (1979), cited by Anderson, et al. (2007):

Green material, Miscellaneous, Class I and Class II, there is a minimum fine, dry 1,235 and scattered fuel material type in an area so that a surface fire can spread across the forest floor and even on occasion, when it is very intense and flames exceed 2 meters it can become a crown fire. (p. 482.)

Soares (1985) and Kauffman and Martin (1989), analyzing the fuel material in coniferous forests in three areas of California, found that class I fuel materials represented less than 1% of the total weight of fuels in all locations, class II and III contributed less than 4% and needle litter contributed between 62 and 84% of the total weight. In determinations of the available fuel material in P. radiata, approximately 70-85% of the total amount of fuel with a diameter of less than 2.5 cm corresponds to the available fuel material.

In relation to the reductions of combustible material, when applying forward fire, green material was reduced by 100%, miscellaneous by 66.6%, class I by 78.04% and class II by 82.83%.

It is necessary to know the amount of fuels on the forest floor before and after burning to determine the percentage of reduction in each of the classes of fuel material in the diagnosis carried out.

Percentage reduction of fuel materials after the advancing fire

Immediately after the backfires, the greatest reduction was obtained in the green fuel material class, product of the dehydration of the leaves caused by the hot gases and high temperatures, followed by the miscellaneous because it is the finest material, which can be easily consumed by fire, by 21.9 % in class I and 17.17 % in class II.

Similar results are explained by Ramos (2010), reporting that "a pine forest accumulates combustible material between 200 - 1 500t.ha-^{1}, which can experience a reduction of 5 to 25 %, depending on the intensity of the fire" (p. 213).

Table 1 shows the variations in total mulch depth (cm) before and after fire for each of the prescribed burning techniques applied.

Fire in progress before and after	**Fire in backward movement before and after**
P1-8,7 3,4	**P4-**9,4 2,7
P2-12,6 2,4	**P5 -**12,9 1,8
P3-13,2 2,9	**P6 -**14,9 2,1

Table 1. Total depth of mulch (cm) before and after burns.

Source: Own elaboration

The percentage of mulch depth reduction after the fire where prescribed burning was applied in advance was reduced by 72.7% on average, indicating that the fire did not directly affect the mineral soil in most of the area. Therefore, this mulch reduction influences the mineral soil not to be affected.

According to Urrutia (2010), who states:

> Similarly, in a mixed natural forest of Pinustropicalis and Pinuscaribaeae, when applying prescribed burns in advance, mulch thickness experienced a reduction of 7.2 to 4.23cm in depth, on average after the burns. On the other hand, the percentage of mulch depth reduction after the fire where prescribed back burning was applied, with an average reduction of 81.06 %. (p. 103.)

Fire behavior parameters

The burns were maintained within the ranges reported by Nájera (2000) and The Nature Conservancy (2005), and the prescribed burn days were also maintained within the established ranges as shown in Table 2.

Wade and Lunsford (1989) state that in order to plan and execute burns it is necessary to have a general understanding of the separate and combined effect of the elements of climate and fire behavior. Other researchers, such as Brown and Davis (1973), applied prescribed burns in a natural forest of P. oocarp with an interval of one to four days without rainfall and north winds between 4.8 and 16 km.h-^{1}, which allowed the fulfillment of the planned objectives.

Weather conditions	**Established**	**Burning Day**
Vv (km.hora^{-1})	6 – 12	7,4
Dv	NE	NE
Hr (%)	50–70	59
Hc (%)	15 - 25	15-25
T (°C)	< 30	27
Dsll	2 – 5	4

Table 2. Relationship between established meteorological conditions and those of the day of the burns.

Source: Own elaboration.

Legend: Vv: Wind speed; Dv: Wind direction; Hr: Relative humidity; Hc: Fuel humidity; T: Temperature; Dsll: Days without rain.

According to Urrutia (2012), Pérez (2012) and Durán et al. (2014), climatic conditions are important factors for prescribed burning and they define the success of the application.

Table 3 shows that the average clean stem height, which is one of the relative characteristics of the stand to be burned, is the clean stem height with 15.35 meters as average, favoring the application of prescribed burns, being an element that should not be overlooked at the time of planning, if they are not sufficient, the flames could move to the top of the trees and become a crown fire, making it impossible to comply with the planned objectives.

	N	**Minimal**	**Max**	**Media**	**Desv. típ.**	**Variance**
Altura	109	11	24	15,35	3,18	10,089

Table 3. Height of the clean stem of the Pinuscubensis species in the area proposed to be burned (m).

Source: Own elaboration.

One of the aspects to take into account is the height of the clean stem, since prescribed burning under the trees in coniferous stands can be one of the methods of eliminating fuel to avoid, firstly, the ignition of ground fires and, secondly, that these can become crown fires according to Jurado (2006), Vélez (2000) and Heikkilä, et al. (2010).

Fire behavior in prescribed burns in progress

In plots 1, 2 and 3, where there was more miscellaneous, the fire spread rapidly with gusts of wind at some times during the forward burn influenced the length of the flames reaching results of 1.38 m in height. Studies conducted by Flores and Benavides (1994), cited by Urrutia (2010), reached flame height results of 0.5 m for backward burns and up to 5 m for forward burns in pine forests in Jalisco; however, in none of the cases did the fire reach the tree canopy. With the analysis of the results obtained from the forward burning, it was possible to determine that the fire intensity results are within the limits, ranging between 128.24 and 159.64 Kcal/m/s^{-1} with 145.04 Kcal/m/s^{-1} as average, coinciding with Rodríguez, et al.(2010), who state that the intensity is medium when it is between 101 and 500 kcalm-1s-1. The results corresponding to fire behavior are shown in Table 4.

Plots	**I(Kcal/m/s^{-1})**	**r (m/s^{-1})**	**Ha(kcal.m^{-2})**	**L (m)**
Plot 1	147,24	0,018	15900	1,33
Plot 2	159,64	0,011	16800	1,29
Plot 3	128,24	0,040	14800	1,53
Media	**145,04**	**0,023**	**15833,3**	**1,38**

Table 4. Parameters of forward fire behavior.

Source: Own elaboration

Legend: *I = linear intensity of fire, r= rate of spread, Ha = heat released per unit area and L = length of flames.*

Fire behavior in prescribed burns in backward burns

Table 5 shows the parameters of fire behavior in backward burning, where the intensity results obtained in plots 4, 5 and 6 are 139.44, 148.64 and 128.24 Kcal.m.s^{-1} respectively, with 138.77 Kcal.m.s^{-1} as average. This result is lower than the intensity result obtained in the forward burns. However, the percentage of available combustible material in the 6 plots was similar, and the wind speed contributed greatly to the fact that in plots 4, 5 and 6, the fire intensity values were lower, with the propagation speed ranging from 0.0078 to 0.0097m. S^{-1} with 0.0088 m.s1 on average, reaching flame heights of 1.10 m. The heat released per unit area on average in plots 4, 5 and 6 was relatively low compared to plots 1, 2 and 3 where forward burning was applied. According to Batista (1995), the heat released directly influences the amount of fuel material available and the intensity of the fire.

Plots	**I(Kcal.m.s^{-1})**	**r (m.s^{-1})**	**Ha(kcal.m^{-1})**	**L (m)**
Plots4	139,44	0,0078	13800	1,07
Plot 5	148,64	0,0097	15600	1,09
Plot 6	128,24	0,0088	14000	1,13

Media	138,77	**0,0088**	**14467**	**1,10**

Table 5.Parameters of backward fire behavior.

Source: Own elaboration

Legend: *I = linear fire intensity, r = rate of spread, Ha = heat released per unit area and L = flame length.*

Similar results were obtained by Urrutia, et al. (2010), in the application of prescribed back burning in Pinuscaribaeae, with a propagation speed of 0.007m.s-¹ and flame height of 0.60m. According to Flores, et al. (2007), in studies conducted in the Sierra de Mamantean Biosphere Reserve, they determined results of fire propagation speeds of 0.30 m/min with flame heights that ranged from 0.25m to 3.5m.

Behavior of some chemical properties of the soil

In relation to pH, where backward burning was applied at fifteen days, an increase was observed from 0-10cm depth, reaching its maximum value at 135 days, experiencing a slight decrease until 12 months and from 10-20cm had a slight decrease at 105 days, followed by an increase between 120 and 135 days, decreasing slightly between 6 and 12 months, but in both depths it did not reach the initial values.

Where forward burning was applied, pH increased at 15 days after burning, with a gradual increase up to 135 days with its maximum values, from 0-10cm, higher values than from 10-20cm depth and a slight decrease in both pH (0-10cm) depths between 6 and 12 months after fire.

The pH presented a variation from 5.14 to 5.62, in the case of Amanita muscaria, it was observed that it develops between 4.9 and 5.62, this indicates that it has a high plasticity as stated by Perez, et al. (2010), who describe this genus in a pH range between 4.2 and 6.4; Daza, et al. (2007), observed the development of the genus Amanita in acid soils (pH 6.2).

It is established at pH 4.5 to 7.5 according to Guerin, et al. (2003), a result that indicates that this genus can develop in a wide pH range, so it could persist in sites affected by fire where variations in pH occur after this phenomenon.

According to Vega, et al. (2000) and Martín (2010), pH tends to increase in soils burned by prescribed fire due to the contribution of cations from the ashes, although depending on the intensity of the burn and other edaphic characteristics, there may not be appreciable changes.

As can be seen, where prescribed back burning was applied, the percentage of organic matter from 0 to 10 cm depth showed an increase fifteen days after the prescribed burns and a decrease 6 to 12 months later, but without reaching the initial results. From 10 to 20 cm there was a slight increase until 15 days after the prescribed burns.

In the plots where prescribed burns were applied in advance, the percentage of organic matter from 0 to 10 cm depth showed an increase 15 days after the prescribed burns, from 3.32 to 4.47%, and a decrease 12 months later, but without reaching the initial results. From 10 to 20 cm there was a slight increase up to 15 days after the prescribed burns, from 2.98 to 3.3%, decreasing up to 12 months, to results very close to the initial values.

This slight increase in the values of organic matter from 0 to 10 cm depth after the application of the 5,000 burns may be attributed to the 4,000 decomposition and more rapid incorporation of the 3,000 organic fragments on the 2,000 burned surfaces.

MO (0-10cm) 1,000 immediately after 0,000 burns, the percentage of organic matter does not decrease, but after 12 months of burning, the results decrease for both depths.

When prescribed burns were applied in forests dominated by Pinustropicalis and Pinuscaribaeae, it was observed that the results of the percentage of organic matter suffered statistically significant alterations after the prescribed burn was applied. Flores (2010), found a slight increase after applying prescribed burns and observed after a fire, a significant increase in the percentage of organic matter, when comparing the unburned area with burned area, five months after the fire from 0.85 % to 2.21 %, which means that this increase was due to the fire.

The sample, the effect of fire on calcium, sodium, potassium and magnesium at depths of 0 to 10 cm, where prescribed burns were applied in setback. Magnesium showed a slight increase in its results up to 135 days after the burns, from 0.32 to 0.40, decreasing to 0.34, values very close to the initial values at 12 months. On the other hand, Arocena and Opio (2003) observed an increase in Mg^{2+} content after the application of prescribed burns.

Calcium (Ca^{2+}) and sodium (Na^{+}) increased until 15 days after the burns, and then remained stable until 135 days after the burns, when they decreased to results very close to the initial values at 12 months. Potassium (K^{+}) had a slight decrease 15 days after the burns, reaching values at 105 days, reaching its maximum result at 120 days, gradually decreasing at 12 months.

The sodium (Na^{+}), calcium (Ca^{2+}) and potassium (K^{+}) content of the soil before and after the fire showed a significant increase in calcium up to 15 days after the fire, although it decreased up to 12 months without reaching the initial results. For its part, sodium showed an increase at all times, at 15 days after it remained stable, but an increase was observed 12 months after the burns.

Potassium showed no significant differences before the prescribed burns and fifteen days later, but there was a significant increase at 135 days, decreasing later at 12 months.

Magnesium showed a slight increase in its results up to 120 days after the prescribed burns, up to 0.38; decreasing to 0.34 at 135 days, with values very close to the initial values at 12 months.

According to MINAG (1984), nutrient contents are classified as low before and after burning.

Martínez (2006) found that when prescribed burns were applied in Pinustropicalis forests, nutrients were deficient before and after burning. He found significant increases in Na+ and K+ over time. In Ca2+ and Mg2+, lower, non-significant results were observed. Likewise, Chávez, et al. (2010), found increases in Ca2+ and Mg2+ after the application of burns in P. oocarpa.

The application of prescribed burning is undoubtedly the most practical and cheapest method to reduce accumulations of combustible material, especially when considering the prevention of forest fires through these works in the field, taking into account that pine formations are 5% dependent on fire and natural regeneration is almost null, Therefore, by applying prescribed burning, all the existing combustible material on the forest floor is eliminated and allows natural regeneration, which in turn economizes in terms of a new plantation to preserve these species and provides cover for the forest to be preserved naturally. On the other hand, it is clear that fire can have negative consequences for flora and fauna when it occurs in the wrong place at the wrong time. Certainly, fires can kill animals, but mortality among most species has been found to be low and fire generally does not pose a significant threat to wild populations.

Several factors influence the degree of wildlife mortality caused by fire, including wind speed, fuel loads, vegetation moisture content, time of year, and fire size, among others.

Uncontrolled fires can advance more rapidly and burn at higher temperatures than prescribed burns, posing a much greater risk to both wildlife and humans. However, during prescribed burns a higher level of control is exercised over these factors by selecting environmental conditions that minimize risks.

Recalling that one of the objectives of prescribed burning is to manage the soil and eliminate flammable vegetation to reduce the risk of uncontrolled wildfires that threaten the habitat of these species.

Conclusions

Prescribed burns in Pinuscubensis forests reduce the amount of combustible material in greater proportion when applied in backward than in forward burns.

The intensity, heat released per unit area, flame height and fire propagation speed were maintained in the appropriate ranges for the application of prescribed burns.

Variations in soil chemical properties did not reach significant results outside the normal ranges for this site when medium intensity prescribed burns were applied in Pinuscubensis forests.

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