Growth and increase of a *Pinuspatula* plantation with fertilization and thinning treatments.

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Abstract— *Thinning and fertilization of forest plantations are forestry practices that are necessary to obtain an increase in the annual volume growth, mean increment and periodic increment (AMI and API) which allow shortening the commercial shift maintaining the same volumes at the time of harvest. In this study, the effect of thinning and fertilization on the growth and increase in Pinuspatula plantations was evaluated, which were established in 1998 in Huayacocotla, Veracruz, Mexico. A 2^2 factorial experiment was set up in the plantation in order to evaluate the thinning and fertilization factors with two levels each. The experimental unit was a 10x10 m plot. Three repetitions were established per treatment. An residual basal area of 21m^2 $ha^{-1}$was obtained in the thinned plots of the plantation. The average basal area in the unthinned plots was 42 m^2 ha^{-1}. The fertilization doses were: 1.4; 0.4; 8.34 kg of urea, calcium triple superphosphate and potassium sulfate, respectively. Fertilization (treatment 3) increased the volume and the AMI 2012, 2013 and 2014. Thinning (treatment 2) tended to increase the API slightly.*

Keywords— ***Annual Mean Increase (AMI), Annual Periodic Increase (API), basal area (BA), intensities of thinning, forestry practice, Volume.***

I. INTRODUCTION

Growth is defined as the integral and gradual increase in biomass, product of the individual's biological activity. The growth of a tree is influenced by its genetic constitution and the environment that it develops in. The genetic information determines the tree's response to the different environments, controlling its manifestations. The environment provides nutrients, water and illumination, and therefore, the tree's growth is the response to the joint action of its genetic information and the environmental factors (Hocker, 1984).

Thinning is forestry tool that when applied selectively favors the best trees, and it is useful in old and young stands. After thinning, the remnant (residual) trees react by increasing their growth rate and reducing the length of their tracheids, they also acquire tolerance to bark beetles (*Dendroctonusadjunctus*) and more resistance to fires, decrease the level of leaf infestation caused by fungi, and also change the biomass distribution between foliage and stem(Gajardo-Caviedes, 2005).

The objective of thinning applied to a forest mass is to produce a higher commercial wood volume per surface unit. This is achieved because when reducing the density of the plantation, the residual trees obtain greater growth space and can grow more in diameter, with which the proportion of timber-yielding products with sawmill and plywood quality of large dimensions extracted, can be increased (Rodríguez *et al.*, 2011).

Fertilization is another forestry practice, which, according to Lázaro *et al.* (2012), has the objective of attaining high yields in harvesting wood of good quality. Its action consists in improving the soil as nutritional substrate as well as complementing the natural supply of nutritional elements, in some cases deficient, and restoring the nutritional elements that have been extracted by the crop itself or that have disappeared because of other reasons.

The same authors indicate that the application of fertilizers is necessary for the survival of many tropical and temperate plantations, since the fertilizers increase the diameter of the tree more than the height and therefore increase the tapering of the lumber, reducing the shape factor. They also reduce the variability of the diameter of trees in plantations.

The combination of thinning and fertilization in forest plantations improves the properties and quality of the wood. Based on this, the objective of this study is to evaluate growth in two *Pinuspatula* plantations treated with thinning and fertilization.

II. MATERIALS AND METHODS

2.1 Description of the study area

The *P. patula* plantation analyzed in this study is located in the *ejido*of Palo Bendito, municipality of Huayacocotla, in the northern zone of the state of Veracruz, at 20º 27´N and 98º 29´ W with an altitude of 2,460 masl. The climate is temperate sub-humid, with summer rains and frequent mists, with a mean annual temperature on the coldest month (January) of between 3 and 8 °C and the warmest month (May) higher than 16 °C. The mean annual rainfall ranges from 633.9 to 1,385.1 mm (Domínguez*et al*., 1997). The plantation under study was established during the rainy season, in the month of July 1998 with spacing of 2.5 m between trees.

The soils were originated from sedimentary rocks, primarily lutites and sandstone, presenting a general loam–clay texture. The drainage is superficial fast and slow inside, as a result of high quantities of humus with predominant sandy texture. The main soils are phaeozemluvic, with a rich layer of organic matter and nutrients, and vertisolpelic of clay type, with fine and impermeable texture. The average slopes are 30 % (Domínguez*et al.*, 1997).

2.2 Experimental design

In the P. patula plantation, a factorial experiment with two factors (fertilization and thinning) was performed, and two levels for each factor. The levels of the fertilization factor were: 1) without fertilization and 2) application of N-P-K; those of the thinning factor were: 1) without thinning and 2) with thinning. Four treatments were obtained: a) without fertilization and without thinning; b) without fertilization and with thinning; c) with fertilization and without thinning; and d) with fertilization and with thinning. Each treatment had three repetitions and the experimental unit was a plot of 100 m^2 distributed according to a completely random experimental design.

The chemical fertilization treatments were applied on September 10^{th}, 2011, and consisted in the contribution, randomly, of 1.4, 0.4 and 8.34 kg $plot^{-1}$of urea, calcium triple superphosphate and potassium sulfate, respectively, for the plantation.

The thinning treatments were performed on September 10^{th}, 2011, and they consisted in the elimination of trees in the plots that corresponded to this treatment, until achieving an approximate residual basal area of 21 m^2 ha^{-1}. During the selection of the trees to be felled, in addition to the residual basal area, obtaining an adequate distribution of trees within the plot and the felling of suppressed trees was considered.

2.3 Variables evaluated

2.3.1 Diameter at breast height (DBH)

It was measured with measuring tape, and this measurement was carried out each year to obtain the increments of trees in the plantation and thus evaluate the growth in diameter. This variable was used in the models by Castellanos *et al.*(1996) to obtain the increments.

2.3.2 Height

This variable was evaluated through an equation generated with the *Pinuspatula* data from Hernández *et al.* (2013) to be able to obtain the increments in height. The equation is the following:

$$Height = \alpha_0(1 - exp^{\alpha_1 * Dn})$$

Where:

α_0= 30.47

α_1=0.0536

Dn= Normal diameter

2.3.3 Volume

It was evaluated through a model for *Pinuspatula* volume in Zacualtipán, Hidalgo, Mexico, proposed by Hernández *et al.*(2013).The equation is presented next.

$$V_c = e^{\alpha_0} D^{\alpha_1} H^{\alpha_2}$$

Where:

α_0= -10.47

α_1=1.704

α_2=1.375

D= diameter

H= height

2.3.4 Annual mean increment (AMI)

It was estimated by dividing the current value by the time passed or age.

$$AMI_{(volume)} = Volume/age$$

2.3.5 Annual periodic increment (API)

It was calculated in the following way:

$API_{(volume)}$= $Volume_{(period\ 2)}$- $Volume_{(period\ 1)}$/ $Year_{(period\ 2)}$- $Year_{(period\ 1)}$

2.3.6 Statistical Analysis

The variance analysis was performed with the data in agreement with the completely random experimental design with factorial arrangement. The Tukey test ($p \leq 0.05$) was carried out to compare the treatment means. To process data, the SAS package (SAS Institute, 2004) was used.

III. RESULTS

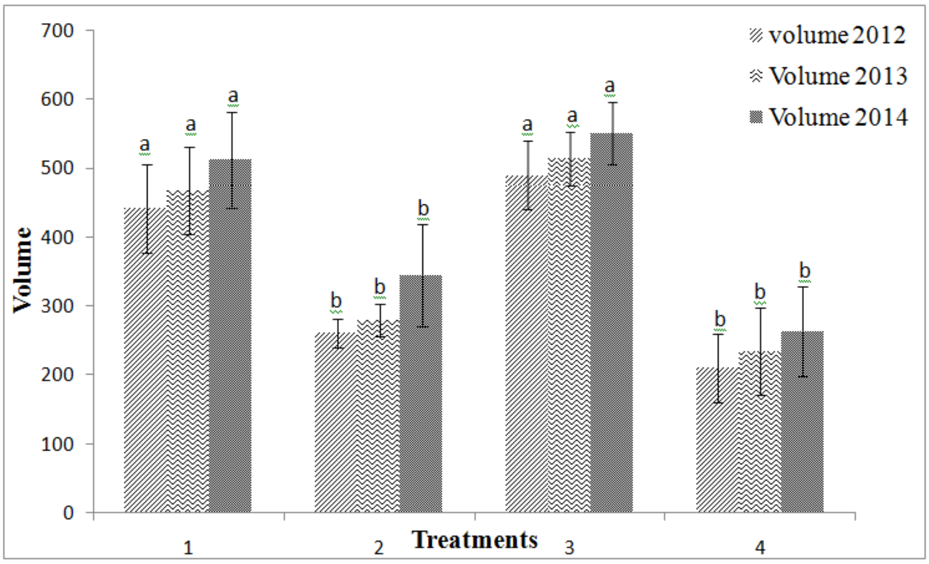
In the plantation, treatment 3 (with fertilization and without thinning) had a significant effect on the variables: volume 2012, 2013, 2014, and on the annual mean increment (AMI) 2012, 2013 and 2014, but not on the annual periodic increment (API) (Table 1). However, treatments 1 (without fertilization and without thinning), 2 (without fertilization and with thinning), and 4 (with fertilization and with thinning), did not affect significantly the variables under study.

TABLE 1
LEVELS OF PROBABILITY THAT CORRESPOND TO THE VARIANCE ANALYSIS OF THE FERTILIZATION AND THINNING EXPERIMENT IN THE *P. PATULA* PLANTATION, PALO BENDITO, HUAYACOCOTLA, VERACRUZ.

Source of variation	GL	Level of significance						
		vol12	vol13	vol14	IMA12	IMA13	IMA14	IPA
Treatment	3	0.0003	0.0003	0.0018	0.0003	0.0003	0.0018	0.7059

GL: Degrees of freedom; Vol 12: Volume of the year 2012; Vol13: Volume of the year 2013; Vol14. Volume of the year 2014; IMA12: Annual mean increment in 2102; IMA13: IMA in 2013. IMA14: IMA in 2014. IPA: Annual periodic increment.

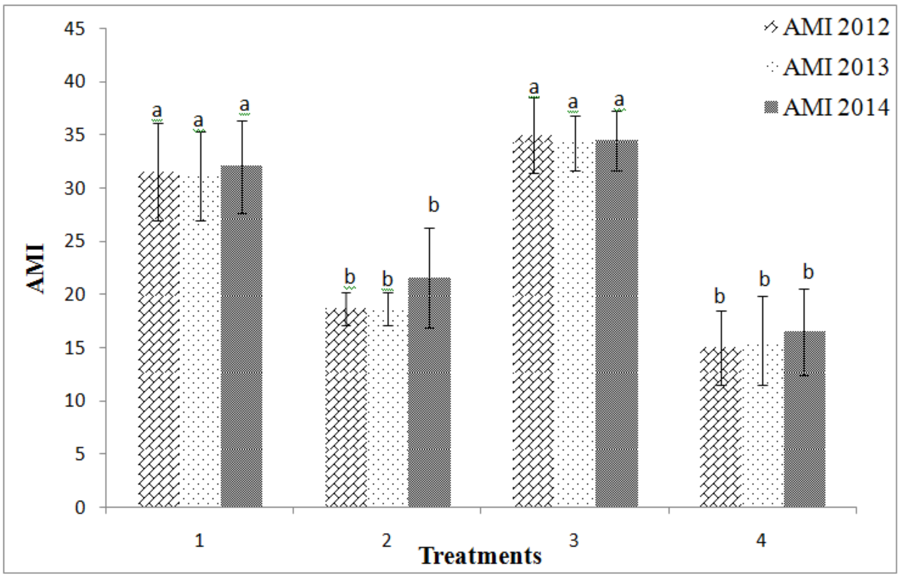
With regard to the Tukey tests, treatments 2 and 4 had a significant effect on the volumes 2012, 2013 and 2014. Treatment 3 increased the volumes during the period evaluated (Figure 1).



TREATMENTS: 1: WITHOUT FERTILIZATION AND WITHOUT THINNING; 2: WITHOUT FERTILIZATION AND WITH THINNING; 3: WITH FERTILIZATION AND WITHOUT THINNING; 4: WITH FERTILIZATION AND WITH THINNING.

FIGURE 1.VOLUMES 2012, 2013 AND 2014 IN THE *PINUSPATULA* PLANTATION IN PALO BENDITO, HUAYACOCOTLA, VERACRUZ, MEXICO.

Figure 2 shows the results of the annual mean increment (AMI) 2012, 2013 and 2014. Treatments 2 and 4 had a significant effect on the AMI 2012, 2013 and 2014. Treatment 3 increased the AMI during the period evaluated.

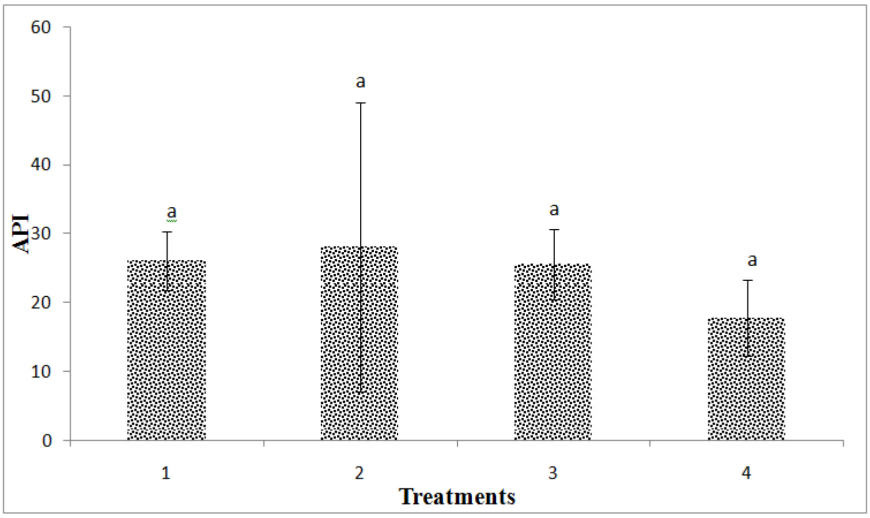


TREATMENTS: 1: WITHOUT FERTILIZATION AND WITHOUT THINNING; 2: WITHOUT FERTILIZATION AND WITH THINNING; 3: WITH FERTILIZATION AND WITHOUT THINNING; 4: WITH FERTILIZATION AND WITH THINNING.

FIGURE 2.ANNUAL MEAN INCREMENT (AMI) 2012, 2013 AND 2014 ON THE *PINUSPATULA* PLANTATION 1998 IN PALO BENDITO, HUAYACOCOTLA, VERACRUZ, MEXICO.

Treatment 2 had the greatest annual periodic increment (API) 2012-2014, although it did not have a significant effect (Figure 3).

Although there was no significant difference in the four treatments, it can be seen that treatment 4 is the one that had the lowest API value, while the remaining treatments in this variable obtained equal values (Figure 3).



TREATMENTS: 1: WITHOUT FERTILIZATION AND WITHOUT THINNING; 2: WITHOUT FERTILIZATION AND WITH THINNING; 3: WITH FERTILIZATION AND WITHOUT THINNING; 4: WITH FERTILIZATION AND WITH THINNING.

FIGURE 3.ANNUAL PERIODIC INCREASE (API) 2014 IN THE *PINUSPATULA* PLANTATION IN PALO BENDITO, HUAYACOCOTLA, VERACRUZ, MEXICO.

IV. DISCUSSION

With regard to the variable of volume, it is observed that treatments 2 (without fertilization and with thinning) and 4 (with fertilization and with thinning) presented significant differences in the three years of evaluation, since the volume was lower than in the treatments that do not have thinning. This is probably because thinning was evaluated in the short term and in order to observe the positive effect of thinning on the diameter increase, it must be evaluated in the long term. According to Leak (2007), the evaluation of thinning in a long period is the main tool by which the density of the stand is controlled, the patterns of biomass partition are modified, and there is an increase in diameter. Treatment 3 (with fertilization and without thinning) presented the highest volumes 2012, 2013 and 2014. The volume 2014 was550 m^{3}·ha, a value that is high compared to the study by González (2006), who found318.7m^{3}·ha in a *Pinusradiata* plantation of 18 years of age without application of fertilization and thinning treatments. This is because fertilization favored the increase in volume. Concerning the study by Espinosa *et al.* (1994), the volume found was also high, since they found a volume of 126 m^{3}·ha in a *Pinusradiata* plantation of the same age than the plantation under study, although treated with thinning.

With the two prior studies, it can be noticed that the effect of thinning in the long term increases the volume even more than the application of fertilization.

The Annual mean increment (AMI) during the period evaluated was affected significantly by treatments 2 and 4, since the AMI decreased due to the thinning. This is because thinning was evaluated in the short term, in addition to beings light thinning. Something similar was found by Ruiz *et al*.(1996) in a study carried out in a *Pinuscaribea*var. Hondurensis plantation of 8 and 11 years, located in La Sabana, Oaxaca, which evaluated the effect of thinning on the growth of a forest mass and found that in high levels of thinning the volume decreased, and therefore, the AMI also decreased. The same was found by Díaz (2002), who applied low-intensity thinning treatments in *Pinusrudis.*

Rosas and Díaz(2014) confirmed in their study in a *Pinusrudis* plantation in Nuevo León that the AMI and API evaluated in a short period did not have any significant effect in all the intensities of thinning tested.

Treatment 3 (with fertilization and without thinning) increased the AMI values in the period evaluated, which is explained because fertilization provides nutrients for the development and growth of the plants. According to Arteaga (2003), it is necessary to fertilize any young plantation since if even only one of the nutrients necessary is scarce, the growth of the plants is limited and the yields of the crops are reduced. Consequently, in order to obtain high yields, the fertilizers are necessary to provide the plantations with the soil nutrients that are absent or scarce. If the fertilizers are applied with the adequate doses, the yields of the plantations can often be duplicated.

The annual periodic increment (API) in the plantation was not affected significantly by fertilization and thinning, although treatment 2 (without fertilization and with thinning) tended to increase the API in the period evaluated. That is, thinning had a positive response, which means that although it is in the short term, a favorable result is being reflected in this variable. According to Espinosa *et al.* (1994), in response to thinning, the API increases since the individuals have adequate space to develop and grow. The API in this study is 28.09 m^3.ha.year, similar to the study by Espinosa *et al*. (1994), who evaluated the effect of different intensities of thinning on *Pinusradiata* in a period of 3 years, and obtained a value of 28.4 m^3.ha.yearon the third year with an intermediate level of thinning. Muñoz *et al*. (2012) also found that thinning increased the annual periodic increment of a *Pinusmontezumae* plantation 13 years of age, in Michoacán, Mexico.

V. CONCLUSION

Treatments: 2, with fertilization and with thinning, and 4, with fertilization and without thinning, significantly affected the volume and the API 2012, 2013 and 2014in the plantation under study. The treatment that increased the volume and the AMI 2012, 2013 and 2014 in the plantation was treatment 3: with fertilization and without thinning. Thinning tended to increase the API 2012-2014. However, it is necessary to perform more intense thinning on the plantation 1998 for there to be differences and for the results on volume and AMI to be noticeable, since the density is high despite the light thinning that was performed.

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