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Translated from the original in spanish

Reactivation of Christmas tree growth of Pseudotsuga menziesii (Mirb.) Franco by chemical fertilization

Reactivación del crecimiento de árboles de navidad de *Pseudotsuga menziesii* (Mirb.) Franco mediante fertilización química

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ABSTRACT

The demand for Christmas trees has increased considerably in Mexico; where 1.6 to 2.0 million of them are sold annually. *Pseudotsuga menziesii* is a species with high commercial potential, due to the quality of its wood and its preference as a Christmas tree. The research was carried out at Huayacocotla, Veracruz, Mexico to assess the effects of nitrogen, phosphorus, potassium and micronutrients on growth of seedlings of *P. menziesii*, four years after its establishment. The sources and doses for the macronutrients were 0.0 and 16.0, 0.0 and 16.5, and 0.0 and 17.0 grams tree^{-1} of urea, calcium triple superphosphate, and potassium sulfate, respectively. The source for micronutrients was the commercial product Sagaquel combi® (0.0 and 3.0 mililiters tree^{-1}). We conducted a completely randomized factorial experiment 2^4, with a total of 16 treatments fivefold replicated. It was determined that the nitrogen and micronutrients had no significant effects on the response variables since they were just slightly deficient. On the other hand, nutrition with phosphorus increased basal diameter; however, such increase was not significant. Potassium significantly increased needle biomass. The treatments that induced greater retention of needles were those that received nitrogen, phosphorus and potassium or a combination of them. Laboratory soil analyzes are likely to be more efficient than fertilization trials at detecting nutrient deficiencies. The deficient nutrients in the plantation are potassium, phosphorus, and nitrogen, although the deficiency of the latter is slight.

Keywords: soil analysis; Christmas tree; nutrient status; fertilization; foliage retention.

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RESUMEN

La demanda de árboles de navidad se ha incrementado considerablemente en México, donde se comercializan entre 1.6 y 2.0 millones cada año. *Pseudotsuga menziesii* es una especie con alto potencial comercial, debido a la calidad de su madera y su preferencia como árbol de navidad. La investigación se realizó en Huayacocotla, Veracruz, México, para evaluar los efectos de nitrógeno, fósforo, potasio y micronutrimentos en la reactivación del crecimiento de brinzales de *Pseudotsuga menziesii*, a cuatro años de su establecimiento. Las fuentes y dosis de fertilizantes fueron 0.0 y 16.0; 0.0 y 16.5; y 0.0 y 17.0 gramos árbol^{-1} de urea, superfosfato triple de calcio y sulfato de potasio, respectivamente. La fuente de micronutrimentos fue el producto comercial Sagaquel combi® (0.0 y 3.0 mililitros árbol^{-1}). Se condujo un experimento factorial completamente al azar 2^4, con 16 tratamientos replicados cinco veces. Se determinó que el nitrógeno y los micronutrimentos no tuvieron efectos significativos en la variable respuesta, dado que son poco deficientes. Por otra parte, la nutrición con fósforo incrementó el diámetro basal; sin embargo, este incremento no fue significativo. El potasio incrementó significativamente la biomasa de acículas. Los tratamientos que propiciaron mayor retención de acículas fueron aquellos que recibieron nitrógeno, fósforo y potasio o una combinación de ellos. Los análisis de suelo en laboratorio son probablemente más eficientes que los ensayos de fertilización para detectar deficiencias nutrimentales. Los nutrimentos deficientes en la plantación son el potasio, fósforo y nitrógeno, aunque la deficiencia de este último es ligera.

Palabras clave: análisis de suelo; árbol de navidad; estado nutrimental; fertilización; retención de follaje.

INTRODUCTION

Pseudotsuga menziesii (Mirb.) Franco, is a species with high commercial potential, due to the quality of its wood, production of tannins, as well as its preference as a Christmas tree (Arteaga and Zenil, 2005). It is included among the endangered species in Official Mexican Standard 059-SEMARNAT (SEMARNAT, 2010), with a special protection status. For this reason, it is indispensable to help the natural forest to regenerate itself through reforestations and to implement plantations with this species of high commercial value (Arteaga and Zenil, 2005).

The consumption of Christmas trees in Mexico has increased in recent years, marketing between 1.6 and 2.0 million trees annually. The trade balance with the United States and Canada is negative, so it is important to increase the production of this good, improving the technology of the production process.

Chemical fertilization is a silvicultural activity that in Christmas tree plantations can increase growth rate, tree vigour, foliage color and density, resistance to pests and diseases, and needle retention, even after the tree has been cut down (CONAFOR, 2011).

The resources that determine site productivity correspond to the elements that control basic processes of plant growth at the physiological level; these include incident photosynthetically active light or radiation, available water, atmospheric

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CO_2, oxygen (at root and aerial levels), temperature and available nutrients (Espinosa *et al.,* 2017). In order to achieve an adequate rate of growth and development of the plant, the necessary nutrients must be supplied according to the fertility of the site and the requirements of the species. Nutritional and climatic limitations always determine the potential growth of crops (Espinosa *et al.,* 2017).

In Huayacocotla, Veracruz, there is a plantation of P. menziesii, established in August 2011 for the production of Christmas trees; however, the performance of this species in the area seems inadequate and the slow growth of the trees in the site may be due to problems of low soil fertility or other factors that affect its growth, such as temperature, precipitation, soil type among others, even when native species such as Pinus patula Schl. et Cham, P. montezumae Lamb., P. pseudostrobus Lindl. and P. leiophylla Schl. et Cham. show apparently normal growth rates. In the above context, this research was conducted in order to evaluate the effects of nitrogen, phosphorus, potassium and micronutrients on the reactivation of P. menziesii saplings growth four years after establishment and to determine whether the reduced growth rate of P. menziesii saplings can be amended by chemical fertilization with N, P, K and micronutrients.

MATERIALS AND METHODS

The experiment was conducted from August 2015 to October 2018, in the town of Palo Bendito, Huayacocotla, Veracruz, within a Christmas tree plantation of four-year-old Franco Pseudotsuga menziesii (Mirb.). The property is located at geographic coordinates 20º 7' 19.59'' N, 98º 29' 30.59'' W. In this area a humid temperate climate predominates with abundant rainfall in summer, with an average annual temperature between 8 and 12 ºC and average annual rainfall of 1,379.7 mm (INEGI, 2009). The soils of the region are mostly classified as cambisols and regosols (INEGI, 2009) (Figure 1).

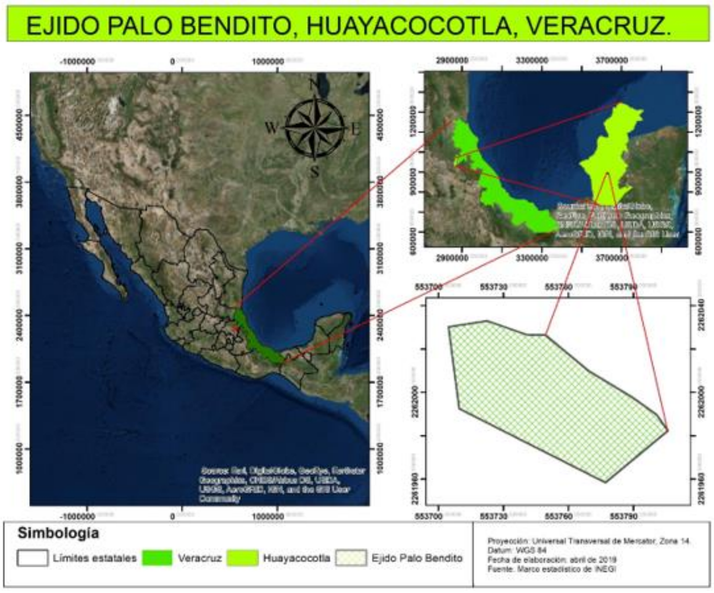

Fig. 1. - Location of the area of the *Pseudotsuga menziesii* fertilization experiment in the ejido "Palo Bendito", Huayacocotla, Veracruz

Experimental and treatment design

A factorial experiment 24 with a completely random distribution of treatments was carried out. The study factors were: nitrogen (N), phosphorus (P), potassium (K) and micronutrients (Mi); each factor was evaluated at two levels (dose/tree) as shown in table #1. The sources of N, P and K were urea (46-00-00), triple calcium superphosphate (00-46-00, 21CaO) and potassium sulfate (00-00-50), respectively; while the source of micronutrients was the commercial product Sagaquel combi® (3.10 % Fe, 4.05 % Zn, 0.05 % B, 0.04% Cu, 0.002 % Co, 0.25% Mn, 5.332 % S, 1.05 % Mg, 0.005% Mo). The resulting 16 treatments were replicated five times and the experimental unit was a tree.

Table 1.- Levels of N, P, K and Micronutrients (dose of fertilizer material per tree) tested in the Pseudotsuga menziesii fertilization experiment in Huayacocotla, Veracruz

Factor de estudio	Niveles de estudio		Unidades
N	0	16.0	g árbol^{-1}
P	0	16.5	g árbol^{-1}
K	0	17.0	g árbol^{-1}
Micronutrimentos	0	3.0	mL árbol^{-1}

N=nitrógeno, P=fósforo, K=potasio

The doses of N, P and K were defined based on the existing critical concentrations for *Pseudotsuga menziesii* published by Zas (2003) and using the principle of the rational method of Rodríguez Suppo, adapted for plant tissue.

The application of granular presentation fertilizers was done in a localized way on the soil of the drip zone of the saplings, while the micronutrients were applied in a foliar way.

Variables evaluated

The evaluated variables were: basal diameter, increase of basal diameter, length and basal diameter of the main shoot, dry weight of 100 needles and foliage retention. The basal diameter was measured at the base of the stem of the trees with a Truper digital vernier, on a mark made with an indelible marker at the time of establishing the experiment. This variable was used to estimate the increase in basal diameter. The length of the main shoot was measured with a graduated flexometer marking Truper, from the base of the shoot to the tip of it. The diameter of the main shoot was measured at the base with a Truper digital vernier. The dry weight of 100 needles was determined by separating 100 needles from the middle of the twigs of each sample collected on 29 January 2018 as indicated by Moilanen *et al.,* (2010). The samples were composed of three twigs per tree, from each of which between 33 and 34 needles were obtained from the middle part, to complete 100 needles per tree or experimental unit. In this way, three repetitions per treatment were processed. The groups of 100 needles were dried in a FELISA forced circulation stove, at 70 oC for 48 h.

For the evaluation of foliage retention, three samples or branches were taken from three experimental units per treatment; one from the lower part, one from the middle part and one from the upper part of the tree crown. The samples were placed in a ventilated room for one month, and then the retained and unretained foliage was collected and dried to a constant weight. The proportion of foliage retained was calculated from the data obtained.

The nutritional status of saplings, in response to treatments, was evaluated with the technique of graphical analysis of vectors (Timmer and Stone, 1978), using the dry weight data of 100 needles, which were subsequently prepared for processing in the laboratory.

The samples of 100 needles were sent to the Salvador Alcalde Blanco laboratory of the Colegio de Postgraduados, to determine in acid digestion extracts, the concentrations of N by the micro-Kjeldahl method, of P, K, Fe, Cu, Zn, Mn and B by means of inductively coupled plasma spectrophotometry (ICP-AES).

Soil analyses were done by zigzag sampling in the experimental area. Nine simple soil samples were taken at a depth of 30 cm. To obtain the simple soil samples, the surface was first cleaned by removing the herbaceous layer and organic matter present on the soil and then a 30 cm square hole was dug on each side, with a depth of 30 cm. Afterwards the hole was then cleaned by removing all the fallen soil when digging, and then taking the simple soil sample from the surface to a depth of 30 cm. Of the nine simple samples that were taken, groups of three composite samples were made. In the laboratory, pH, Cation Exchange Capacity (CIC), organic matter content, N, P, K, Ca, Mg and micronutrients were determined.

Statistical analysis

The variables basal diameter, increment of basal diameter, length and diameter of the main interverticide and the dry weight of 100 needles were analysed by means of a Covariance Analysis (ANCOVA) and Tukey mean comparison tests ($\alpha = 0.05$), using as covariable the initial diameter (basal diameter 2015). Likewise, a Variance Analysis (ANOVA) and mean comparison test (Tukey, $\alpha=0.05$) was performed with the foliage retention data. Foliar concentrations of nutrients analyzed were interpreted by means of the vector analysis technique (Timmer and Stone, 1978).

RESULTS AND DISCUSSION

Morphological variables

The Analysis of Covariance (ANCOVA) showed that the interactions N*Mi, N*P*Mi (Table 2) are statistically significant. On the other hand, Tukey's test ($\alpha=0.05$) indicated that there are no significant effects of the application of N, P, K and Mi in the basal diameter 2018 (Figure 2a). These results show that not every fertilization treatment produces increases in tree diameter, an aspect that should be taken into account when implementing a fertilization program in forest plantations (Vásquez *et al.,* 2015).

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Table 2. - Analysis of covariance for basal diameter 2018 in the fertilization experiment of *Pseudotsuga menziesii* in the ejido "Palo Bendito", Huayacocotla, Veracruz

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Modelo	16	4802.357298	300.147331	11.33	<.0001
N*Mi	1	110.779245	110.779245	4.18	0.0451
N*P*Mi	1	139.550445	139.550445	5.27	0.0251
DM15	1	4330.935263	4330.935263	163.42	<.0001
Error	63	1669.642657	26.502264		
Total corregido	79	6471.999955			

N = nitrogen, P = phosphorus, Mi = micronutrients, DM15 = basal diameter 2015 (before treatments are applied)

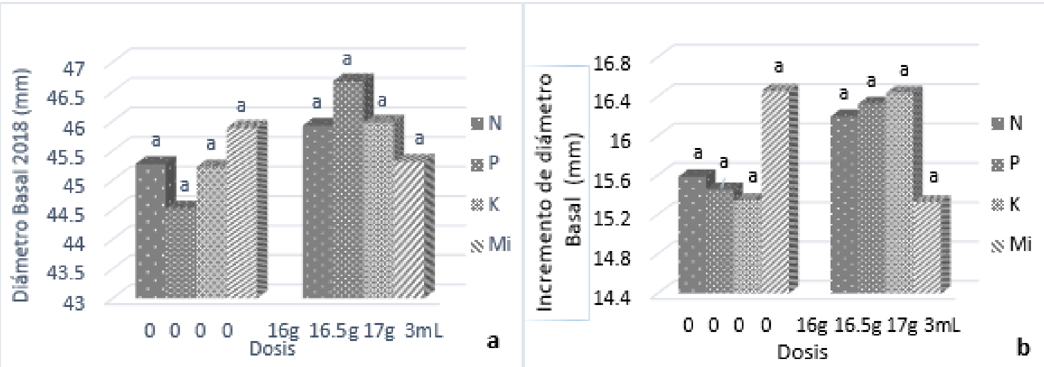

Fig. 2. - Effects of the factors tested in the experiment (applied doses of N, P, K and micronutrients) of *Pseudotsuga menziesii* tree fertilization on the basal diameter reached in 2018 and the increase in basal diameter

For the case of the basal diameter increase, the covariance analysis shows that there were no significant effects of the factors tested (Table 3; Figure 2b). This may be due to the high variability of the initial basal diameter of the saplings between experimental units, since the selection of the experimental units was based on the height of the saplings and not on the basal diameter. The increase in basal diameter of saplings was only significantly influenced by the N*P*Mi interaction (Table 3). Figure 2b shows that there are no significant effects of the tested nutrient levels, although the trends of N, P and K indicate that the application of any of them generated a greater increase in basal diameter than the corresponding treatments without fertilization. Based on the effects of the fertilizers applied (Figure 2b), N is slightly deficient at the study site; on the other hand, P and K are more deficient, since with their application the saplings responded more categorically to the increase in basal diameter, although without statistically significant differences. The lack of more pronounced effects on the application of nutrients is possibly due to the fact that the doses were low with respect to the demand levels and fertility conditions of the plantation. In effect, the experimental site seems to be of low fertility since, in

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the region, the main clay that conforms the soil is kaolinite, a material typically of low cation exchange capacity (Hernández, 2017). On the other hand, the nutritional requirements in the plant tissue of *Pseudotsuga menziesii*, especially those related to K are high (0.80 %; Weetman *et al.,* 1992), if compared with those of *Pinus patula,* 0.63 %; Sánchez, 2013), which is one of the natural conifers of the study site. This means that, probably, the applied doses of K were insufficient to promote greater responses to promote greater responses to the application.

Table 3. - Analysis of covariance for the increase of basal diameter in the experiment of fertilization of *Pseudotsuga menziesii* in the ejido "Palo Bendito", Huayacocotla, Veracruz

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Modelo	16	556.706092	34.794131	1.31	0.2179
N*P*Mi	1	136.0593613	136.0593613	5.13	0.0269
DM15	1	166.8861830	166.8861830	6.30	0.0147
Error	63	1669.642657	26.502264		
Total corregido	79	2226.348749			

N = nitrogen, P = phosphorus, Mi = micronutrients, DM15 = basal diameter 2015

Por otra parte, el ANCOVA realizado sobre los datos de la longitud de brote principal, con un valor p=0.267, indica que no existen diferencias estadísticamente significativas entre tratamientos (Tabla 4). La prueba de Tukey (ɑ =0.05) indica que no existen diferencias significativas entre los niveles cero y uno de N, P, K y Mi (Figura 3a); no obstante, a pesar de la gran variabilidad que normalmente presentan las variables relacionadas con la altura de árboles incluyendo la longitud de brote central, se observó una tendencia a incrementar la longitud del brote cuando se fertilizó con K (Figura 3a). Esto puede significar que este nutrimento presente mayor deficiencia en el sitio de estudio, aunque Vázquez *et al.,* (2018) encontraron que el K favoreció el crecimiento de los brinzales en *Pinus greggii* Engelm, aun cuando este nutrimento no fue deficiente en el sitio experimental. Los autores proponen que este efecto se debió, probablemente, a que K promueve la eficiencia en el uso del agua (Pérez *et al.*, 2016).

Tabla 4. - Análisis de covarianza para longitud de brote principal en el experimento de fertilización de *Pseudotsuga menziesii* en el ejido "Palo Bendito", Huayacocotla, Veracruz

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Modelo	16	2603.12187	162.69512	1.24	0.2670
DM15	1	766.0564970	766.0564970	5.84	0.0188
Error	59	7743.60800	131.24759		
Total corregido	75	10346.72987			

DM15 = basal diameter 2015

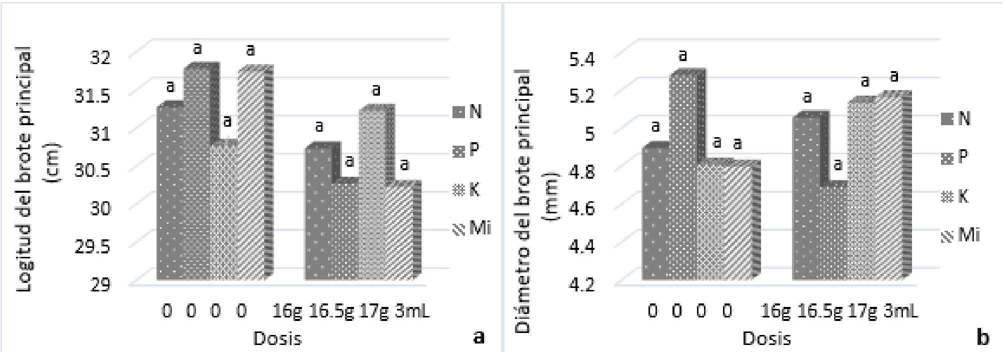

Fig. 3. - Tests of Tukey (α=0.05) for the variables length of the main shoot (a) and diameter of the main shoot (b) in the experiment of fertilization of trees of *Pseudotsuga menziesii* in ejido "Palo Bendito", Huayacocotla, Veracruz

As in the case of main shoot diameter, ANCOVA showed that there are no significant effects of the proven factors (p=0.2121) on the diameter of the main shoot (Table 5). Only significant effects were found on this P*K interaction variable. Tukey's test (α=0.05) confirms that there are no differences between the applied nutrient doses (Figure 3b). On the other hand, although the effects of K were not significant, it was observed that its application increased the bud diameter with respect to the treatment without K. In coincidence with the behavior of other variables such as basal diameter and increase of basal diameter, there are growth increases, although these are not significant. This type of trend may indicate K deficiency at the site, so its application tends to increase the diameter of the shoot (Figure 3b), although not significantly, due to delayed fertilizer effects caused by possible nutrient retention in the xylem of the saplings, as explained by López-López and Flores-Nieves (2016), or because the nutrient deficiency at the site is too acute at the same time as the nutrient demand for the tree is very high, as previously sustained; all this, together with the high variability of the experimental units at the beginning of the experiment, as demonstrated by the effect of DM15 (Table 5).

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Table 5. - Covariance analysis for the diameter of the main shoot in the *Pseudotsuga menziesii* fertilization experiment in the ejido "Palo Bendito", Huayacocotla, Veracruz

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Modelo	16	67.9788981	4.2486811	1.33	0.2121
P*K	1	12.96649066	12.96649066	4.05	0.0488
DM15	1	15.29947337	15.29947337	4.78	0.0328
Error	59	188.9155966	3.2019593		
Total corregido	75	256.8944947			

P = phosphorus, K = potassium, DM15 = basal diameter 2015

Regarding the Dry Weight (DW) of 100 needles, using the 2015 basal diameter as covariable, it is identified that this covariable did not influence the behavior of the dry weight of 100 needles, according to ANCOVA (Table 6). This means that this variable is not affected by the size of the trees, which makes it more reliable than others for evaluating the effects of fertilization on P. menziezii. In the case of this variable, the significant effects found are exerted by K, with the interactions P*Mi; and P*K*Mi being also noteworthy. Tukey's test (α=0.05) confirms this (Figure 4). According to this result, it is possible to affirm that K is a deficient element in the study area. Weetman (1989) mentions that trees with good nutrition tend to grow faster than trees with nutrient deficiencies and that growth usually occurs in height and basal diameter or at breast height, but there is also growth in needle size.

Table 6. - Analysis of covariance for the Dry Weight (DW) of needles in the fertilization experiment of *Pseudotsuga menziesii* in the ejido "Palo Bendito", Huayacocotla, Veracruz

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Modelo	16	0.29771736	0.01860734	2.17	0.0317
K	1	0.06293008	0.06293008	7.33	0.0109
P*Mi	1	0.06006675	0.06006675	7.00	0.0127
P*K*Mi	1	0.04048408	0.04048408	4.71	0.0377
DM15	1	0.00894011	0.00894011	1.04	0.3155
Error	31	0.26618855	0.00858673		
Total corregido	47	0.56390592			

P = phosphorus, K = potassium, Mi = micronutrients, DM15 = basal diameter 2015

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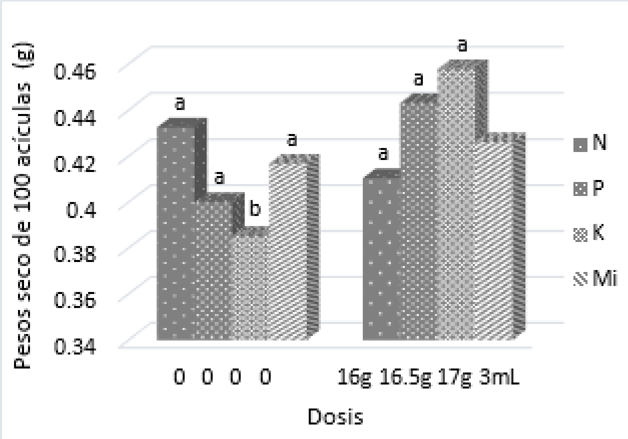

Fig. 4. - Tukey test (α=0.05) for Dry Weight of 100 needles in the fertilization experiment of *Pseudotsuga menziesii* in the ejido "Palo Bendito", Huayacocotla, Veracruz.

For a nutriment, equal letters mean statistically equal averages.

Physiological variables

Retention of foliage

The Variance Analysis (ANOVA), done for needle retention, indicates that there are significant effects among the treatments tested (Table 7; Figure 5). Treatment four, which consisted of the application of P and treatment one (control treatment without fertilizer) were the treatments with the lowest proportion of foliage retained. The control treatment was expected to be one of the treatments with the least amount of foliage retained because it did not receive any of the nutrients tested in this study. The results indicate that P alone does not help foliage retention, but in combination with K, it is the treatment that helps retain the highest proportion of foliage. N and K alone promoted the retention of a greater amount of foliage, since they are statistically equal to treatment seven, which retained the greatest amount of foliage.

Table 7. - Analysis of variance for needle retention in the *Pseudotsuga menziesii* fertilization experiment in the ejido "Palo Bendito", Huayacocotla, Veracruz

Fuente	DF	Suma de cuadrados	Cuadrado de la media	F-Valor	Pr > F
Modelo	15	3796.876637	253.125109	5.37	<.0001
Error	32	1508.839576	47.151237		
Total corregido	47	5305.716213			

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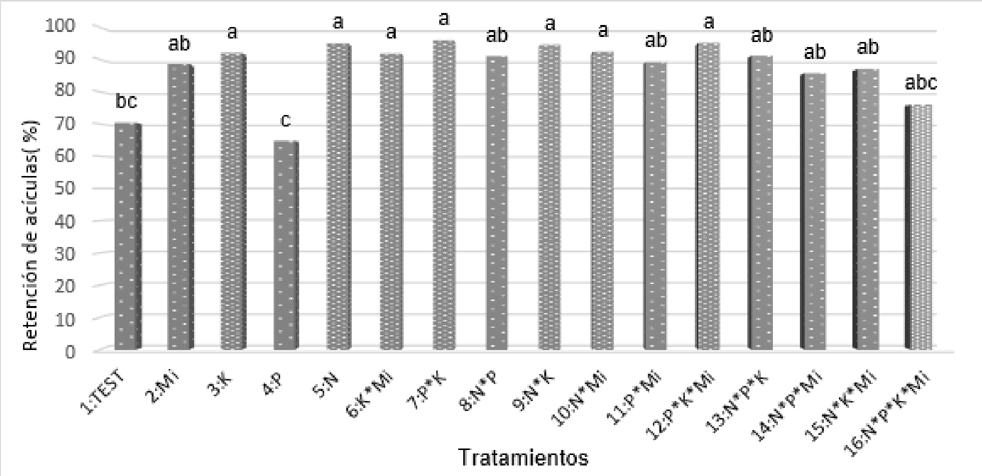

Fig. 5. - Needle retention in the *Pseudotsuga menziesii* fertilization experiment in the ejido "Palo Bendito", Huayacocotla, Veracruz

This result is important because in the case of Christmas trees, foliage retention is a highly desirable feature from a commercial point of view (Chastagner and Riley, 2003) and the market prefers that trees retain foliage for three weeks or more. In accordance with this variable, it is recommended that phosphate and potassium materials be applied at the site to improve foliage retention. This result is congruent with what is indicated by most morphological variables, which, although they did not show significant effects (except the dry weight of needles) of the treatments, did indicate possible deficiencies of K and P in growth trends.

Nutritional status

All treatments resulted in a higher dry needle weight than the control treatment (Figure 6). Also, almost all treatments, except treatment nine, showed low concentrations of N, according to the critical concentrations (1.45 %) established for *Pseudotsuga menziesii* by Ballard and Carter (1986).

Nutritional status

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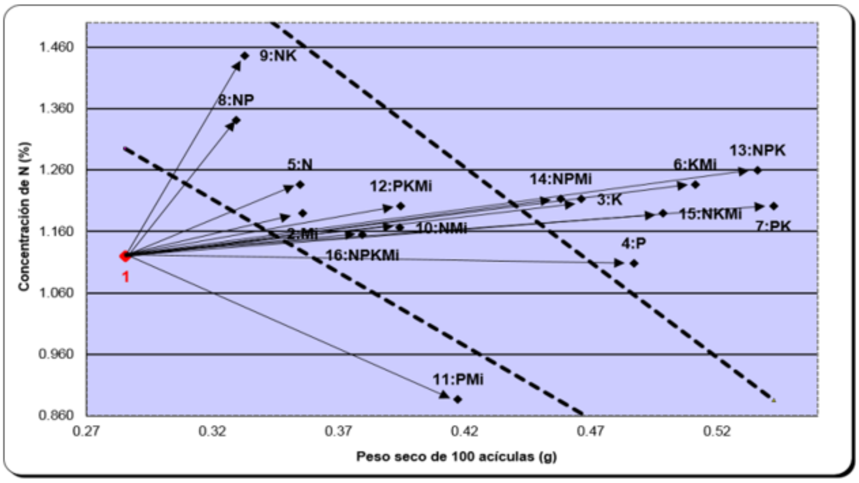

Fig. 6. - Timmer diagram for the analysis of N in the fertilization experiment of P*seudotsuga menziesi*i in the ejido "Palo Bendito", Huayacocotla, Veracruz

In soil analyses, it can be clearly observed that the concentration of N is very low, compared to the appropriate value according to standard 021-RECNAT-2000 (SEMARNAT, 2000). Since the foliar concentration of N in almost all treatments is lower than the critical concentration, it is probable that there is a deficiency of this nutrient in the study site, even when the application of this nutrient did not yield significantly higher values in the morphological variables. (Table 8)

Table 8. - Soil analysis of the experimental site, interpreted according to NOM-021-RECNAT-2000

Parámetro	Muestra	Alto	Bajo	Diagnóstico
CE(dS/m)	0.39	2	1.1	Bajo
pH	4.10	6.5	5.1	Bajo
CIC(meq/100 g)	22.19	25	15	Adecuado
N(%)	0.08	0.8	0.3	Bajo
P Bray (ppm)	0.53	30	15	Bajo
K (meq/100 g)	0.001	0.6	0.3	Bajo
Ca(meq/100 g)	3.00	10	5	Bajo
Mg(meq/100 g)	1.50	3	1.3	Adecuado
Fe(ppm)	13.26	4.5	4.5	Elevado
Cu(ppm)	0.11	0.2	0.2	Bajo
Zn(ppm)	0.18	1	1	Bajo
Mn(ppm)	3.95	1	1	Elevado
B(ppm)	0.00	1	1	Bajo

EC = electrical conductivity, pH = hydrogen potential, CIC = cation exchange capacity, N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Fe = iron, Cu = copper, Zn = zinc, Mn = manganese, B = boron

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The lack of responses to the application of N was due, according to figure #6, to the fact that the deficiencies of P and K, at the experimental site, are probably more acute than those of N. In effect, treatments with N, either alone or combined with P (N*P) or K (N*K), generated the highest concentrations of N, indicating that internally the N is excessive with respect to the other nutrients (López and Alvarado, 2010). Figure #6 also shows that the four treatments that generated the highest needle biomasses included the application of K, while the two most productive included P, which confirms that these nutrients (K and P) are the most deficient in the experimental area.

With respect to phosphorus (Figure 7), all foliar concentrations of applied treatments were low compared to critical concentrations (0.15 %) for this species (Ballard and Carter, 1986). This is in accordance with the soil analysis (Table 8), which shows that P deficiency exists, according to standard 021-RECNAT-2000 (SEMARNAT, 2000).

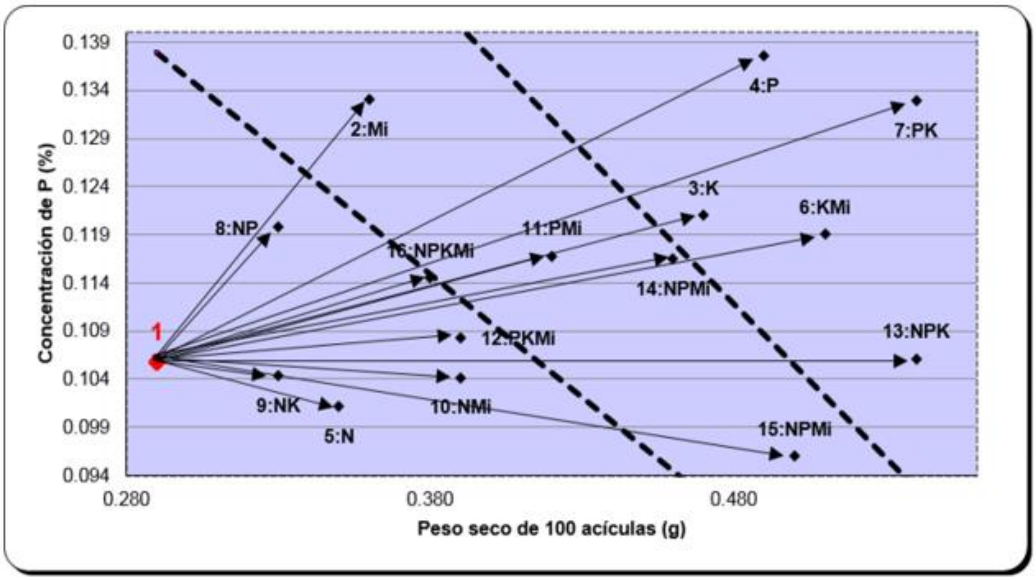

Fig. 7. - Timmer diagram for the analysis of P in the fertilization experiment *of Pseudotsuga menziesi*i in the ejido "Palo Bendito", Huayacocotla, Veracruz

According to figure #7, the fact that treatment with P alone generated higher foliar biomass and higher concentrations of this nutrient in the tissues compared to the control treatment indicates that the nutrient is deficient at the site, but the dose of P used was sufficient to eliminate the deficiency, while one or more other factors limited growth (Lopez and Alvarado, 2010). In this case, it is possible that the limiting factor was K. P deficiency is confirmed because of the seven treatments that generated the highest dry weight of needles, five of them received some dose of P (Figure 7), which according to Lopez and Alvarado (2010) corresponds to Timmer vectors (Timmer and Stone, 1978), type +++ or +-+ (Lopez and Alvarado, 2010), which indicate nutrient deficiency before application.

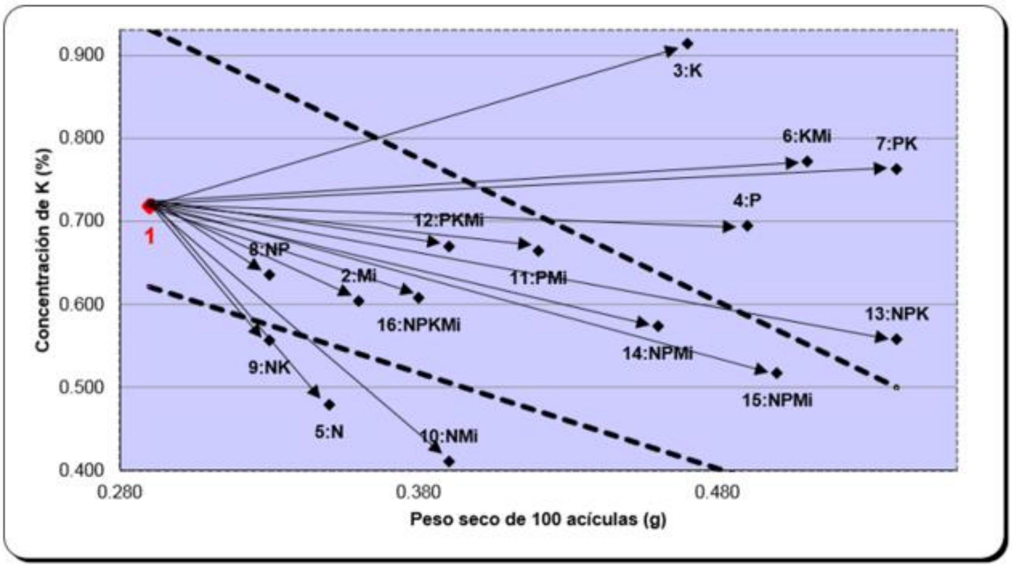

Fig. 8. - Timmer diagram for the K analysis in the *Pseudotsuga menziesii* fertilization experiment in the ejido "Palo Bendito", Huayacocotla, Veracruz

In the case of K, all treatments that received any dose of this nutrient, except when supplied as a single nutrient, generated concentrations lower than the critical concentration of K (0.80 %) of this species (Ballard and Carter, 1986; Van den Driessche, 1989). In most treatments, foliar K dilution was generated by growth [vectors type +-+, or +--; López and Alvarado (2010)], but it is clearly identified that the application of N limited the absorption (lower contents) of K (treatments 5, 8, 9 and 10). This confirms that it is a deficient nutrient. (Figure 8) The high foliar concentration of K in the treatment that only received K was due to the fact that it did not receive N, since the antagonistic relationship between these two nutrients in the soil is well known (Fageria, 2001). According to Van den Driessche (1991), this vector corresponds to the Timmer vector of type +++ (Park *et al.,* 2015), which indicates that this nutrient is very scarce in the study area (Ballard and Carter, 1986). On the other hand, of the four treatments that generated the most needles biomass, three received K, which again indicates possible K deficiency at the site. This deficiency is also confirmed by Tukey's test (α=0.05) for the dry weight of 100 needles (Figure 4), which shows the positive effects of potassium. Soil analyses indicated that K is a deficient nutrient in the study area according to standard 021-RECNAT-2000. It is worth mentioning that in one of the three soil samples sent to the laboratory the K was not detected, and in the other two the determined concentration was very low (Table 8).

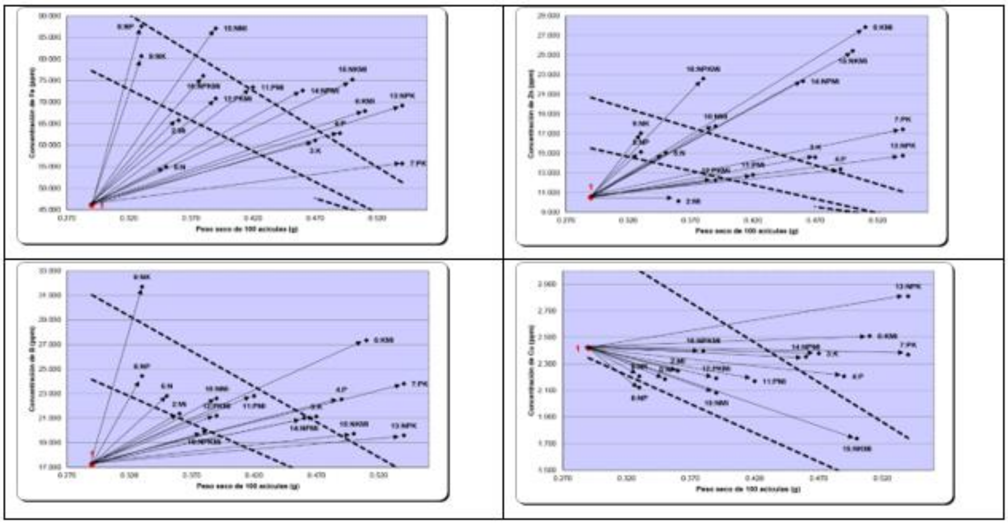

Fig. 9. - Timmer diagram for micronutrient analysis in the *Pseudotsuga menziesii* fertilization experiment in the ejido "Palo Bendito", Huayacocotla, Veracruz

In the cases of Fe and B all the treatments have higher concentrations than the respective control treatments (Figure 9), although the micronutrients did not cause a significant growth of the needles. According to the critical concentrations of Fe (>50 ppm) and B (>20 ppm), determined by Ballard and Carter (1986) and Van den Driessche (1989), these nutrients are not deficient in the study area. According to soil analyses, Fe is not deficient at the site; however, B is deficient (Table 8). In the case of Zn all treatments (except one) generated a higher concentration than the control treatment. Critical concentrations of Zn (15 ppm), established by Ballard and Carter (1986) and Van den Driessche (1989), indicate that this nutrient is possibly inefficient, since Zn concentrations in the plants of five of the 16 treatments are less than 15 ppm. In fact, soil analyses indicate that Zn is deficient at the experimental site. Cu is possibly also deficient in plants, according to critical concentrations (Cu>3ppm; Ballard and Carter, 1986), since all treatments have less than three parts per million, while soil analyses also indicate deficiency of this nutrient.

According to the results obtained in the present investigation, it can be suggested the application of doses equal or greater than those provided by P and K, since these nutrients are deficient in the site. It is also suggested to apply a medium dose of N, since its deficiency is less acute than those of P and K. It is recommended a dose of micronutrients equal or greater than the one used in this study, because, although they did not have a positive effect on growth, they did propitiate an increase in their foliar concentrations, so when the deficiencies of macronutrients are remedied, the development of deficiencies of these minor elements will be avoided.

P is a deficient nutrient at the experimental site and tends to increase the basal diameter of *Pseudotsuga menziesii* saplings.

K is the most deficient nutrient at the site and its application to trees generates significant increases in some morphological variables.

N is a slightly deficient nutrient relative to the other macronutrients in the study area.

Laboratory soil analyses are probably more efficient than fertilization tests to detect N deficiencies in the species studied.

Application of micronutrients in the area does not positively affect the morphological variables of *P. menziesii* trees; however, it increases foliar concentrations of some of them, which may prevent micronutrient deficiencies after amendment of macronutrient deficiencies.

The application of a mixture of N, P and K promotes greater retention of needles in the trees in the experimental area.

Tree growth rates respond positively to chemical fertilization, as long as deficient nutrients are applied at the site.

Post-harvest foliage retention of *Pseudotsuga menziesii* saplings can be significantly improved by nutrient management of plantations.

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