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Original article

Nursery production and morphophysiological response of *Pinus leiophylla* Schl. & Cham in the field

Producción en vivero y respuesta morfofisiológica en campo de *Pinus leiophylla* Schl. & Cham

Produção em viveiro e resposta morfofisiológica em campo de Pinus leiophylla Schl. & Cham

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ABSTRACT

The low survival of forest plants in reforestations makes it necessary to adopt nursery techniques according to the characteristics of the plantation site. An experiment was established to determine the effects of two nursery management factors on morphophysiological variables of *Pinus leiophylla* during initial field development. The factors tested from the nursery were established at two levels: factor 1 substrate: peat moss, raw pine sawdust; factor 2 nutrient addition rate: constant, exponential. It is concluded that the use of raw sawdust as a substrate produces small plants with high nutritional concentrations of N, P and K due to a concentration effect caused by the exponential fertilization rate, which presents adequate survival and initial growth in the field, in shallow soils of low fertility, exhibiting greater increases in height and needle biomass. Exponential fertilization increases nutrient reserves, improving initial growth in the field with both substrates, peat moss and sawdust. All transplanted individuals had a survival rate of 80 % within a degraded site, a Figure that exceeds that reported in Mexico during the last decade.

Keywords: Nutrient concentration; Nutrient dilution; High survival in reforestation.

RESUMEN

La baja sobrevivencia de planta forestal en las reforestaciones hace necesario adoptar técnicas de vivero en función de las características del sitio de plantación. Se estableció un experimento para determinar los efectos de dos factores de manejo en vivero, sobre variables morfofisiológicas de *Pinus leiophylla* durante el desarrollo inicial en campo. Los factores probados desde vivero fueron establecidos con dos niveles: factor 1 sustrato: *peat moss*, aserrín crudo de pino; factor 2 tasa de adición nutrimental: constante, exponencial. Se concluye que el uso de aserrín crudo como sustrato produce plantas pequeñas con altas concentraciones nutrimentales de N, P y K debido a un efecto de concentración causado por la tasa de fertilización exponencial, la cual presenta adecuada sobrevivencia y crecimiento inicial en campo, en suelos poco profundos y de baja fertilidad, exhibiendo mayores incrementos de altura y biomasa de acículas. La fertilización exponencial incrementa las reservas nutrimentales, mejorando el crecimiento inicial en campo con ambos sustratos, *peat moss* y aserrín. Todos los individuos trasplantados tuvieron una sobrevivencia del 80 % dentro de un sitio degradado, cifra que supera lo reportado en México durante la última década.

Palabras clave: Concentración nutrimental; Dilución nutrimental; Alta sobrevivencia en reforestación.

RESUMO

A baixa sobrevivência de planta florestal nas reflorestações torna necessária a adopção de técnicas de viveiro de acordo com as características do local da plantação. Foi estabelecida uma experiência para determinar os efeitos de dois fatores de gestão de viveiros nas variáveis morfofisiológicas de Pinus leiophylla durante o desenvolvimento inicial em campo. Os fatores testados do viveiro foram estabelecidos a dois níveis: substrato de fator 1: musgo de turfa, serradura de pinheiro cru; fator 2 taxa de adição de nutrientes: constante, exponencial. Conclui-se que a utilização de serradura crua como substrato produz pequenas plantas com elevadas concentrações nutricionais de N, P e K devido a um efeito de concentração causado pela taxa de fertilização exponencial, que apresenta uma sobrevivência adequada e crescimento inicial no campo, em solos rasos de baixa fertilidade, exibindo maiores aumentos de altura e biomassa de agulhas. A fertilização exponencial aumenta as reservas de nutrientes, melhorando o crescimento inicial no campo com ambos os substratos, musgos de turfa e serradura. Todos os indivíduos transplantados tiveram uma taxa de sobrevivência de 80 % num local degradado, um número que excede o relatado no México durante a última década.

Palavras-chave: Concentração de nutrientes; Diluição de nutrientes; Alta sobrevivência em reflorestação.

INTRODUCTION

Land use change for livestock and urbanization has been one of the main anthropogenic pressures on forest resources in Mexico. Currently, reforestations are carried out, as the main mitigation measure, in degraded sites with severe fertility problems, resulting in low forest plant survival.

The reforestation of poor soils requires the use of high quality plants, if possible, plants with characteristics according to the conditions of the site to be reforested. Knowledge and management of nutritional aspects is important for the establishment of plants in different types of soil (Soares *et al.,* 2017).

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The fact that fertilization has a significant effect on agricultural and forestry productivity comes as no surprise (Fuentes *et al.*, 2010). In this context, the enrichment of seedlings with nutrients for transplanting could promote the successful establishment and growth of plants in the field. The initial period of a transplant is the most critical phase, within which the plantlets must recover from the stress suffered during transport and establish contact between its roots and the soil, in order to resume the vital functions of water and nutrient absorption in the new environment (Cortina *et al.*, 2013).

This study tested the effects of two factors of the production process of *Pinus leiophylla* plant in nursery, on the development of the plant during the first year of establishment in the field, through a reforestation of protection and restoration (CONAFOR 2010) in the ejido of San Miguel Coatlinchan, Texcoco, State of Mexico, Mexico. A degraded site was selected that in past reforestations presented a survival of three to five individuals of *Cupressus sp*. per hectare. 58.5 % of the vegetation in the municipality of Texcoco was originally composed of pine species; however, only about 10 % is currently preserved (Adame and Martínez 1999). Since 1970, there have been attempts to restore the soils of these areas; however, a large area is still devoid of vegetation or has sick or low-density populations.

MATERIALS AND METHODS

Nursery stage

The nursery stage took place from November 2013 to August 2014, at the nursery of the Colegio de Postgraduados, Campus Montecillo, Texcoco, Estado de México, Mexico. In the site prevails a sub-humid temperate climate with rainfall in summer, average temperature of 15.5 º C, average annual rainfall of 750 mm.

The seed of *P. leiophylla* was donated by the Commission of Natural Resources of the Federal District (CORENA). The source of the seed is the municipality of Tlahuapan, Puebla, Mexico. 500 seeds were selected and soaked for 24 hours as a pre-treatment before direct sowing, in order to break the state of dormancy of the seed, to standardize the speed of germination according to the recommendations of the technological package published by CONAFOR for this species, which suggests soaking the seed from 18 to 24 hours as a pre-germination treatment.

The seeds were sown in containers of 346 ml in volume, containing the corresponding mixtures of substrates, according to the established treatments.

The experimental design was the same, both at the nursery stage and in the field, with four treatments established under a completely randomized experimental design, with a two by two factorial arrangement (2 x 2), and an experimental unit of 25 individuals, with four replicates per treatment. The first factor was "Substrate" with two levels: peat moss (peat moss 60 %, agrolite 20 %, vermiculite 20 %) and sawdust (raw pine sawdust 60 %, agrolite 20 %, vermiculite 20 %). The second factor, the `Rate of Nutrient Addition', also with two levels: constant rate of nutrient addition and exponential rate of nutrient addition. This results in: treatment 1, sawdust and constant rate of addition; treatment 2, sawdust and exponential rate of addition; treatment 3, peat moss and constant rate of addition; treatment 4, peat moss and exponential rate of addition. The variables evaluated were: root neck diameter, height, dry weights (aerial, root, total and 100-needle), Dickson's quality index and slenderness, as well as leaf nutrient concentrations.

The constant fertilization rate consisted of applying a similar amount of nitrogen on all fertilization dates. Aldana and Aguilera (2003) recommend applying for species such as *P. leiophylla*, 0.6 grams of potassium nitrate (*KNO_3*) and boric acid (*H_3BO_3*) fertilizer at a constant 20-20-20+rate per liter of water. Accordingly, 0.395 g of N per plant was used during the whole cycle, amount used for both addition rates.

For the case of the exponential rate, the calculation was made based on the exponential function described by Miller and Timmer (1994). With this system of exponential fertilizer addition, the same amount of *KNO_3* and *$H3BO_3$* fertilizer material was used at 20-20-20+exponential rate as in constant fertilization (0.395 g N per plant) throughout the production cycle. However, in this case, at the beginning a low dose of the fertilising material was applied starting with 0.00011 g and increasing at each application date in an exponential way until completing 0,395 g. The dose increased with the growth of the plants, both exponentially at this nursery stage.

The procedure to calculate the dose of KNO_3 and *H_3BO_3* at 20-20-20+exponential rate to be applied at each date was the following: from the exponential model formula described by Miller and Timmer (1994) (Equation 1), and considering the average nitrogen contents in three *P. leiophylla* seedlings of the same age as those used in the experiment (biomass = 0.2 mg), and that of three commercial size seedlings with 25 cm height (biomass = 40 mg) of the same species, the relative rate of addition (Equation 1).

$$N_T = N_S\ (e^{rt} - 1)\ \text{equation (1)}$$

N_T = Desired increase in nutrient content in the seedling during t applications.
N_s = Initial nutrient content in the seedling.
r = Nutrient addition rate (% day^{-1}).
t= Number of applications in the fertilizer application sequence

Once the relative addition rate was known, it was applied to distribute the previously determined amount of fertilizer material, according to Aldana and Aguilera's (2003) recommendation of 0.395 g N per plant, during the crop cycle, in terms of the number of applications of the fertilizer material. The use of a single rate of nutrient addition, as well as the growth rate, ensured the equilibrium state of the internal nutrient concentration. This procedure also allowed to compare the effectiveness of the addition rates tested in the present work, since the total amount of fertilizer material used at the end of the cycle was the same for both addition rates.

The germination of the seeds of *P. leiophylla* sown was in January 2014. Experimental units of 25 seedlings were formed with four replicates, resulting in four treatments with 100 individuals each (400 individuals in total). In April 2014 began the application of the rates of nutritional addition, five months after planting, considering the time period that took the development of needles, after the cotyledon stage and ensuring the absence of pathogens, mainly damping off. Both rates of nutrient addition were applied with the fertilizer *KNO_3* and *H_3BO_3* at 20-20-20+rate of nutrient addition, with a total of 36 applications, two weekly during four and a half months. The fertilizer was the only source of nutrients. The additional irrigation consisted only of the application of distilled water.

Ten individuals per experimental unit were selected in July 2014, which were processed for the determination of nitrogen (N) concentration in plant tissue by the micro Kjeldahl, phosphorus (P) and potassium (K) method by wet digestion with perchloric nitric acid. In parallel, once concluded the application number 36 of

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fertilizing material, the remaining individuals destined to transplant in field (60 individuals by treatment), were submitted to a stage of hardening or lignification during one month, being applied irrigation every three days, only with distilled water, later every four days, both during one week and finally every seven days during two weeks.

Field stage

The reforestation site is located within the ejido of Coatlinchán, Municipality of Texcoco, State of Mexico, Mexico, between 19° 26' 30" north latitude and 90° 50' west longitude, at an altitude of 2455 meters. The total area of the site has a 10 % slope and east exposure. The soil is shallow, less than 40 cm with outcrops of limestone. The vegetation cover is basically composed of *Agave salmiana*, *Opuntia sp*. and *Acacia sp*. The texture of the soil is variable, dominating the clayey texture, but some portions of the soil are located with a sandy texture due to the existence of small temporary runoff.

Field experiment design

The same experimental design was used in the field as in the nursery and the effect of the four treatments applied from the nursery was tested. Each of the treatments was replicated 60 times, with one plant being the experimental unit, *i.e.* 60 plants were selected completely at random from each of the four treatments tested in the nursery. The plants corresponding to each treatment were randomly distributed in the experimental area, in which previously hole of 40 x 40 x 40 cm were made under a real frame scheme, with a spacing of three meters between holes. The experiment was set up in August 2014.

Variables evaluated

Once the plant is established in the field, its development and survival are evaluated using morphological and physiological variables. We measured: diameter in millimeters, height in centimeters, and survival in percentage in November 2014, December 2014, January 2015, February 2015 and July 2015. Based on the initial and final measurements, the increases in: diameter and height were estimated. One year after transplanting, leaf samples were taken to estimate: leaf concentrations of nitrogen (%) by the micro Kjeldahl method, phosphorus (ppm) and potassium (ppm) by wet digestion with nitric and perchloric acid. Sixteen samples composed of field-collected needles were prepared, i.e. four samples composed by treatment. In addition to the variables mentioned, a soil sampling was performed by collecting three composite samples in the lower part of the experimental area, three in the middle part and three in the upper part. The single samples were taken from the upper 30 cm of the soil.

Data processing and analysis was performed by comparing the effects of factors and their interactions on morphological and physiological variables through an analysis of variance (ANOVA), using the SAS statistical package. The effects were considered to be statistically significant, when the P>F value was less than 0.05 (reliability greater than 95 %). Where effects were significant, statistical differences between means were identified using the Tukey test ($\alpha = 0.05$). For the concentration and content of N, P and K, the vector graphic method developed by Timmer and Stone (1978) was used, interpreting the nomograms as suggested by López *et al*., (2010) and Gang Dong *et al.,* (2019).

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RESULTS AND DISCUSSION

According to the levels of the different macro and micro elements in the soil, necessary for plant development, established by the Nom-021-RECNAT-2000 of Mexico, for the macro elements of study in the soil of the experimental area, N and organic matter presented high levels, P presented low levels and K is in medium levels (Table 1). Coincidentally, these soils have been described by Etchevers *et al.,* (1992) as extremely poor in N, P and organic matter, in addition to having low Cation Exchange Capacity (CEC), which gives them low natural fertility (Gama *et al.,* 2007); being very clear the scarcity of P, a nutrient that needs to be introduced to the ecosystem from chemical or organic fertilization

Table 1. - Chemical analysis of the soil at the reforestation site in Coatlinchán, Texcoco, State of Mexico, Mexico

Variables	Sample location		
	Lower part	Middle part	Upper part
Nitrogen (%)	0.130	0.161	0.154
Phosphorus (ppm)	5.263	7.895	3.684
Potasio (ppm)	138.06	118.56	134.16
Calcium (ppm)	1100	1020	900
Magnesium (ppm)	435.6	363	369.05
Boron (ppm)	0.122	0.077	Nd
Copper (ppm)	0.906	0.622	0.713
Iron (ppm)	48.777	47.854	54.397
Manganese (ppm)	21.051	14.823	10.381
Zinc (ppm)	1.836	1.651	1.552
pH	5.660	5.59	5.45
Organic matter (%)	2.681	2.681	3.083
Cation exchange capacity (CIC) cmol (+) kg^{-1}	8.160	8.4	8.32

Effects of nursery management on plant development in the field

As for morphological variables, the substrate factor did have significant effects on the variables: diameter, height, Dickson's quality index and increase in height. Tukey's grouping indicates that the *peat moss* presented the highest mean for all variables, except for the increase in height, in which case, sawdust gave rise to the highest mean and dry weight of 100 needles, a variable in which no significant differences existed. The rate of nutrient addition had significant effects on the variables of diameter and height increase (Table 2). Larger diameters and heights were promoted by the constant rate of nutrient addition.

Table 2. - Characteristics of the plant at the time of transplanting to the field (at the end of the nursery stage), for the four treatments

	Variables at the end of the nursery stage						
Treatments	**Diameter (mm)**	**Heigth (cm)**	**Index of quality by Dikson**	**Index slender**	**Leaf concentration of N (%)**	**Leaf concentration of P (ppm)**	**Leaf concentration of K (ppm)**
1	2.40	5.52	0.098	22.94	2.47	2344	3771
2	2.18	4.56	0.096	20.89	2.72	2646	3569
3	5.55	17.26	0.389	28.25	2.05	1678	4126
4	3.59	11.54	0.242	33.58	2.59	1960	4900

Figure 1 (a and b) shows the greater diameter and height that resulted from treatment factor 3 (*peat moss* and constant rate) for both variables, one year after planting. However, for height in the field the greatest increases were given by treatment 2 (sawdust and exponential rate) (Figure 1a, Table 3).

Table 3. - Analysis of variance and Tukey tests (*α = 0.05*) for physiological variables of *Pinus leiophylla* in the field (Coatlinchán, Texcoco, Estado de México)

Variables	**Source of variation**		**Pr>F**	**Value of F**	**Tukey´s media**	**Tukey's grouping**
Diameter (mm)	Model		<0.0001	79.64		
	Substrates	AS	<0.0001	231.65	15.2988	B
		PM			25.4275	A
	Nutrient addition rate	TC	0.0365	5.54	3.98	A
		TE			2.893	B
	Interaction		0.2125	1.73		
Height (cm)	Model		0.0015	9.76		
	Substrates	AS	0.0002	28.15	28.002	B
		PM			30.5213	A
	Nutrient addition rate	TC	0.3095	1.13	11.391	A
		TE			8.052	B
	Interaction		0.9322	0.01		
Dry weight 100 needles (g)	Model		0.4663	0.91		
	Substrates	AS	0.5046	0.47	6.8889	A
		PM			6.5389	A
	Nutrient addition rate	TC	0.5046	0.47	6.5389	A
		TE			6.8889	A
	Interaction		0.2075	1.77		
Increase in diameter (mm)	Model		<0.0001	40.56		
	Substrates	AS	<0.0001	115.53	13	B
		PM			20.8513	A
	Nutrient addition rate	TC	0.5246	0.43	17.165	A
		TE			16.686	A
	Interaction		0.0341	5.72		
Increase in height (cm)	Model		<0.0001	39.55		
	Substrates	AS	<0.0001	91.45	22.958	A
		PM			16.1213	B
	Nutrient addition rate	TC	0.0019	15.72	18.1225	A
		TE			20.9575	B
	Interaction		0.0054	11.48		

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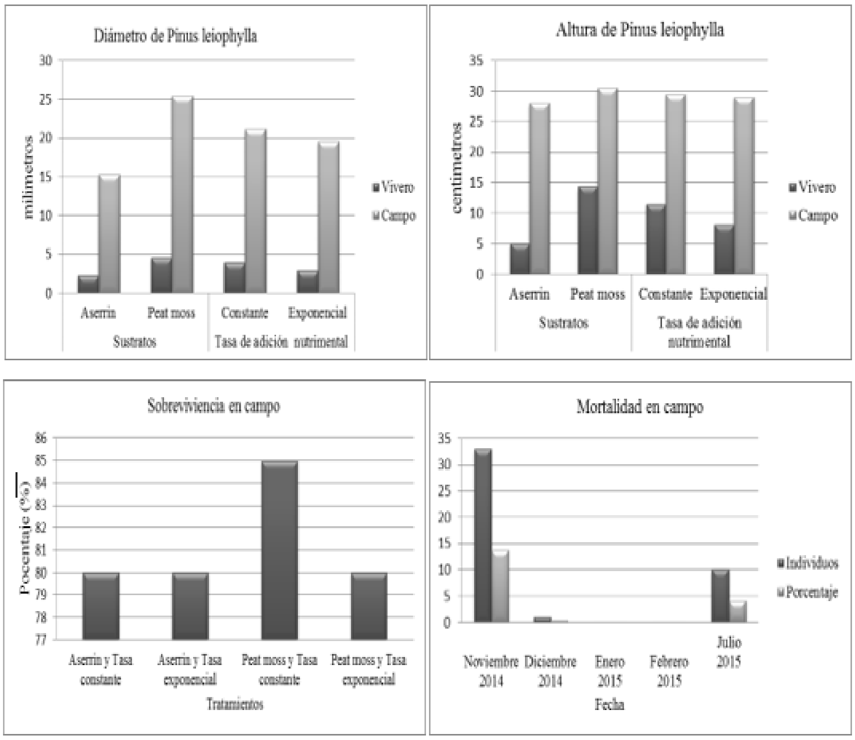

Figure 1. - a) diameter of *Pinus leiophylla,* b) height, c) total census of survival by field treatment (2014-2015), d) total census of field mortality (2014-2015)

In the following nomograms, negative slopes make clear the dilution effect for all treatments. Only the sawdust treatments (1 and 2) increased the biomass of 100 needles and the nutrient content during the first year in the field, while the *peat moss* treatments (3 and 4) did not increase the K content (Figure 2C).

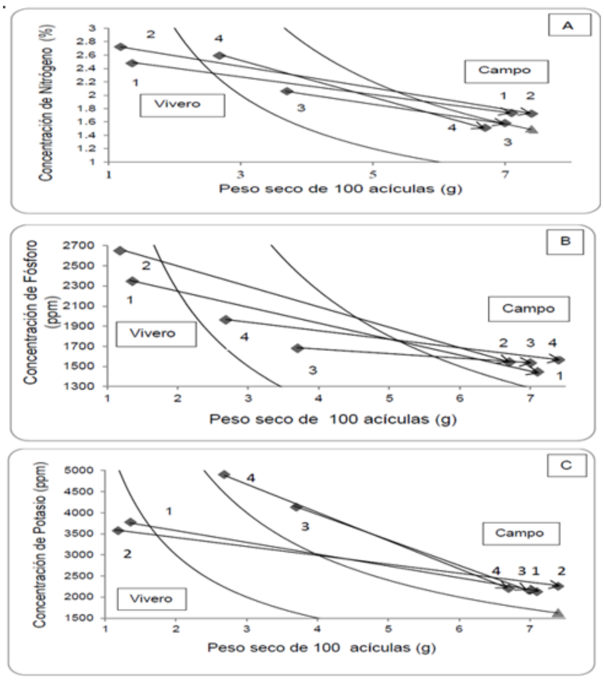

Figure 2. - Timmer nomograms. Dry weight of 100 needles (x), nutrient concentration (y), nutrient content (z, isolines) of N, P and K in *Pinus leiophylla* at the end of the nursery stage (9 months of age) and one year after planting in the field (22 months of age) for the four treatments

It is observed that there are no significant differences in any of the nutrition variables (Figure 2). The greatest field dilutions occurred in the treatments that showed the greatest concentrations in the nursery with treatment 2 (sawdust and exponential rate), for concentration of N and P treatment 4 (*peat moss* and exponential rate) for concentration of K; with regard to the nutritional contents, the regularity of the trend between the isolines, as well as the repeated location of the treatments between them, support the absence of significant differences between the levels of the factors tested (Table 4). Sawdust treatments (1 and 2) had higher gains in biomass of 100 needles (dry weight of de 100 needles), compared to peat moss treatments (3 and 4). Similarly, the plants supplied by the exponential nutrient rate showed the highest dry weight gain of 100 needles, after transplanting to the field.

From the total of the plant produced in the nursery, 25 % of the total population resulted as a good quality plant, according to CONAFOR (2010), and this corresponded to treatment 3 (*peat moss*) and constant rate. Another 25 % of the population was found to have the highest nutritional concentrations, corresponding to treatment 2 (Table 2). Once the individuals were transplanted to the field, it was expected that the trends resulting from the nursery stage would continue, in terms of growth and survival variables. Morphologically, treatment 3 performed better in the field in 2015 for diameter, height and Dickson's quality index. In other words, one year after planting, the effects of the nutrient addition rates generated during the nursery stage on diameter and height were still evident. However, the greatest increase in height was the result of treatment 2 (sawdust and exponential rate) (Table 3), treatment with high concentrations of N and P from the nursery. Duarte *et al.,* (2019) attribute the differences in species nutritional efficiency to absorption, translocation capacity and nutrient utilization. In the present study we are talking about the same species, which indicates that the growing shot is the cause of the high nutrient reserves presented by the treatment 2 plant (sawdust and exponential rate).

Table 4. - Analysis of variance and Tukey tests (*α = 0.05*) for *Pinus leiophylla* nutrition variables in the field (Coatlinchán Texcoco Estado de México)

Variables	Source of variation		Pr>F	Value of F	Tukey´s media	Grouping by Tukey
Concentration N %	Model		0.7523	0.4		
	Substrates	AS	0.3025	1.16	1.725	A
		PM			1.592	A
	Nutrient addition rate	TC	0.9524	0	1.6625	A
		TE			1.655	A
	Interaction		0.8268	0.05		
Concentration P (ppm)	Model		0.9976	0.01		
	Substrates	AS	0.9005	0.02	1455.6	A
		PM			1469.5	A
	Nutrient addition rate	TC	0.8935	0.02	1455.1	A
		TE			1469.9	A
	Interaction		0.9344	0.01		
Concentration K (ppm)	Model		0.8628	0.25		
	Substrates	AS	0.9382	0.01	2146.6	A
		PM			2136.8	A
	Nutrient addition rate	TC	0.6954	0.16	2166.5	A
		TE			2116.9	A
	Interaction		0.4647	0.57		
Content N (g)	Model		0.3863	1.1		
	Substrates	AS	0.207	1.78	0.1193	A
		PM			0.1037	A
	Nutrient addition rate	TC	0.6846	0.17	0.10913	A
		TE			0.1140	A
	Interaction		0.2674	1.35		
Content P (g)	Model		0.7647	0.39		
	Substrates	AS	0.6996	0.16	0.01	A
		PM			0.0096	A
	Nutrient addition rate	TC	0.7164	0.14	0.0096	A
		TE			0.0100	A
	Interaction		0.3707	0.86		
Content K (g)	Model		0.8219	0.3		
	Substrates	AS	0.4943	0.5	0.0140	A
		PM			0.0138	A
	Nutrient addition rate	TC	0.8375	0.04	0.0142	A
		TE			0.0144	A
	Interaction		0.5535	0.37		

Salifu *et al.*, (2009) found that plant nutrient recharge in the nursery favours higher initial growth rates in the field. This finding, in the present study, indicates that plant nutrient recharge effectively increases initial growth in the field, improving the competitive capacity of the newly established plant, due to rapid root development and colonization in the deep soil, which reduces the intensity of competition with neighboring plants or weeds (Vallejo *et al.,* 2012).

In conifers, Dickson's lower quality index (0.15) could mean problems in establishing a plantation (García 2007). According to this, the plant coming from the sawdust treatments is of lower quality than the plant grown in *peat moss* (Table 2), and it would be expected that the field performance of the first mentioned ones would be suboptimal, which did not happen, since at least the increase in height and dry weight of 100 needles in the field were higher in the plants grown in sawdust. Coincidentally, Villalón *et al.*, (2016) concluded that quality plant selection in nurseries should not be determined solely by height. The failure to predict Dickson's quality index in terms of plant behavior in the field was probably due to the high nutrient reserves in the plant produced in sawdust. In this study, the slenderness index was a better predictor of plant behavior in the field, since the plant with the lowest slenderness index (from sawdust) showed the greatest height increases in the field (Table 3).

According to Sáenz *et al*. (2010), only the plant larger than 15 cm should be used for reforestation programs in Mexico, since the height of the plants is the best indicator of the probability of mortality (Antón *et al*., 2015). However, the present study demonstrates that the small plant (4.5 to 5.5 cm high) can be successful in surviving and growing in difficult terrain, which coincides with the findings of Gradel *et al*., (2017), who found that young individuals of *Betula platyphylla* Sukachev had better growth responses than older individuals with larger dimensions, in a degraded site.

It is highly likely that the key aspect for the survival and initial growth of the small plant in this study was the high amount of nutrient reserves, since the plant produced in sawdust, once established in the field, resulted in higher nutrient concentrations with both constant and exponential addition rates.

The negative slopes in the nomograms make clear the dilution effect for all treatments (Figure 2), mainly by the plants that exhibited the highest concentrations of nursery nutrients by concentration effect (López and Estañol 2007). Figure 2 indicates that the plants with the largest nutrient reserves are those that showed the greatest biomass increases of 100 needles (dry weight of 100 needles). This points out the relationship between the level of nutrient reserves and increases in the field.

The recharge of plant nutrients in the nursery could be considered as a fertilization procedure in which the nutrients are included in the plant itself. According to the results of this study (Table 3 and Figure 1b), this system improves the immediate growth of the plants, which can be fundamental for the plant to dominate many weeds in a short period of time, theoretically increasing the survival of the plantation (Salifu *et al*., 2009 and Timmer and Aidelbaum 1996). Studies suggest that highly nourished seedlings may play a better role in restoration reforestations (Cortina *et al.,* 2013). In the present study, this is evident because the plants with the highest nutritional reserves of treatments 1 and 4 (1. sawdust and constant rate, 4. *peat moss* and exponential rate) exceeded by 84.4 % and 43.8 % respectively, the needle biomass (dry weight of 100 needles) of the plants produced in treatment 3 (*peat moss* and constant rate), representative of the system used in the technified nurseries of Mexico.

Chen *et al*., (2018) recommended applying nutrient load to *Betula alnoides* seedlings before transplanting to improve their quality and productivity in the field. Pokharel *et al*. (2016) found that accumulation in the nutrient reservoir of *Populus tremuloides Michx*. promoted satisfactory results for saline soil restoration purposes.

In the present study, it is clear that there was a good response of the individuals towards the poor conditions of the site (Table 1), since finally, in survival there was only a 5 % difference between treatments. In fact, the highest survival in the field was 85 % and corresponded to treatment 3 (*peat moss)* and constant rate. For the other three treatments (1, 2 and 4) the survival was 80 %, values that exceed the range of 40.28 % to 57.5 % of survival, registered in the reforestations at national level by UACh-EC (2012).

The highest mortality (Figure 1c) was presented at the end of the rainy period of the first field cycle (November 2014); that is, three months after transplanting. In descending order, it was presented again in the following summer (2015), one year after transplanting.

When observing the results by treatment (Figure 1d), it can be seen that the mortality rate was maintained in 13 individuals, or 20 % for all the treatments, except for treatment 3 (peat *moss* and constant rate), which presented a mortality of only nine individuals (15 %).

The plants with the best morphological characteristics were the same for the field and nursery stage, as a result of the constant fertilization rate. Plants with undesirable morphological characteristics for the proposed nursery stage led to higher growth rates in height and dry weight of 100 needles in the field, due to the effect of concentration of the high contents of N and P in plant tissue, resulting from the exponential fertilization rate.

The higher concentrations of N, P and K in the nursery, resulting from the exponential nutrient rate, equaled the constant rate concentrations during field establishment, due to the dilution effect.

Pinus leiophylla is a species suitable for plantations for restoration purposes, which shows a favourable morphophysiological response, over the initial development with low soil fertility conditions at the plantation site and a minimum survival well above the range recorded at national level, during the last decade.

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