Foliar biomass production and litterfall pattern of five timber species in forest plantations of semi-arid lands of the northeastern Mexico

Maginot Ngangyo-Heya[1]*, Rahim Foroughbakhch-Pournavab[1], Artemio Carrillo-Parra[2], Lidia Rosaura Salas-Cruz[3], Marco Antonio Alvarado-Vazquez[1], Verónica Bustamante-Garcia[4†]

1 Department of Botany, Faculty of Biological Sciences, Autonomous University of Nuevo León, San Nicolás de los Garza, Nuevo León, Mexico.

2 Instituto de Silvicultura e Industria de la Madera, Universidad Juárez del Estado de Durango, Durango, Mexico.

3 Faculty of Agronomy, Autonomous University of Nuevo León, Gral. Escobedo, Nuevo León, Mexico.

4 Faculty of Forestry Sciences, University of Juárez of the Durango State, Durango, Mexico.

* Corresponding author: nheya-maginot@yahoo.fr

Abstract

Background: Fodder shrubs and trees have both economic as well as ecological values in most extensive systems of arid and semiarid regions.

Hypothesis: The litterfall represents an important way in maintaining the productivity of these ecosystems, and we hypothesized that its production pattern is related to the foliar biomass production, associated with seasons and species.

Studied species: *Acacia berlandieri*, *Acacia wrightii*, *Ebenopsis ebano*, *Havardia pallens* and *Helietta parvifolia*.

Study site and years of study: The foliar biomass was evaluated seasonally, from the dry weight of a representative branch of each species. The litterfall was collected every 15 days through litter traps installed under tree canopies, in experimental plantations of 30 years old, in the semi-arid zone of northeastern Mexico.

Results: The foliar biomass values showed highly significant differences ($P < 0.01$) among species as well as seasons, whereas leaf litter values presented highly significant differences ($P < 0.01$) among seasons but not ($P > 0.05$) among species. The maximum foliar biomass production was registered in summer by *E. ebano* (9,029 kg ha^{-1}), while the lowest value (103 kg ha^{-1}) was recorded in winter by *A. wrightii*. The greatest leaf litter accumulation was observed in winter (296 kg ha^{-1}) by *A. wrightii*, and the lower value was recorded in spring, by *E. ebano* (97 kg ha^{-1}). A significant linear correlation ($R^2 = 68{,}79$ %) was determined between accumulation of leaf litter and foliar biomass production in autumn.

Conclusions: As conclusion, the leaf litter pattern can be related to the foliar biomass production, depending on the seasons and species. That constitutes a practical tool for the management of the forest ecosystems in semiarid areas.

Key words: Foliar biomass, litterfall, timber species, semi-arid zone.

Producción de biomasa foliar y hojarasca de cinco especies leñosas en plantaciones forestales de la zona semi-árida del noreste de México

Resumen

Antecedentes: Los arbustos y árboles forrajeros constituyen un valor tanto ecológico como económico en la mayoría de los sistemas extensivos de las regiones áridas y semiáridas.

Hipótesis: La caída de hojarasca representa una importante vía para el manutenimiento de la productividad de estos ecosistemas, por lo que se plantea como hipótesis que su patrón de producción está relacionado con la producción de biomasa foliar, en función de las estaciones y de las especies.

Especies en estudio: *Acacia berlandieri*, *Acacia wrightii*, *Ebenopsis ebano*, *Havardia pallens* y *Helietta parvifolia*.

Sitios de estudio y fechas: La biomasa foliar se evaluó estacionalmente a partir del peso seco de una rama representativa de cada especie. La colecta de hojarasca se hizo quincenalmente, a través de trampas de hojarasca, instaladas en la base de los árboles en plantaciones forestales de 30 años de edad, en la zona semi-árida del noreste de Mexico.

Resultados: Se presentaron diferencias altamente significativas ($P < 0.01$) tanto en función de especies como en función de estaciones para la biomasa foliar, mientras que la hojarasca no presentó diferencias significativas entre especies ($P > 0.05$), pero con diferencias altamente significativas por estación del año ($P < 0.01$). La biomasa foliar alcanzó su máximo producción en verano (9,029 kg ha^{-1}) con *E. ébano*, mientras que el valor menor (103 kg ha^{-1}) se registró con *A. wrightii* en invierno. El mayor aporte de hojarasca foliar ocurrió en invierno (296 kg ha^{-1}) con *A. wrightii*, y el menor valor (97 kg ha^{-1}) se registró en primavera con *E. ebano*. Se determinó una correlación lineal significativa ($R^2 = 68{,}79$ %) entre la acumulación de hojarasca y la producción de biomasa foliar en otoño.

Conclusiones: Como conclusión, el patrón de caída de hojarasca está relacionado con la producción de biomasa foliar, dependiendo da les estaciones y de las especies. Esto constituye una herramienta práctica para el manejo de los ecosistemas forestales de zonas semiáridas.

Palabras clave: Biomasa foliar, hojarasca, especies leñosas, zona semi-árida.

In arid and semi-arid areas where weather conditions are hard for cultivating pasture, grazing depends exclusively on the shrub production (Ramírez *et al*. 2008). Some advantages to use shrubs as forage for animals (von Maydel, 1996) are that, green leaves have high crude protein content throughout most of the year (Ramírez-Orduña 2003); they constitute habitat for wildlife and coverage to prevent soil erosion (González-Rodríguez & Cantú-Silva 2001).

The Tamaulipan Thornscrub is a vegetation of the semiarid zone from the coastal plains of the Gulf of Mexico to the southern shoreline of Texas, U.S.A. (Foroughbakhch *et al*. 2005, 2009). This ecosystem presents a high species richness and diversity of tree and shrub species (Heiseke & Foroughbakhch 1985, Alanís-Rodríguez *et al*. 2008, Jiménez-Pérez *et al*. 2013, Mora-Donjuán *et al*. 2013). Many of them are important in forestry and silvipastoral production (timber, posts, firewood, forage, etc.), which constitute the most common land use in the region (Foroughbakhch *et al*. 2009). During the last 350 years, extensive grazing has been practiced in these areas (Jiménez-Pérez *et al*. 2012), resulting in the loss of both quality and quantity of forage plant species followed by a reduction in the plant layer which covers and protects the soil (Eviner & Chapin 2003, Fahring 2003, González *et al*. 2009). This leads to decrease the vegetable production soil capacity, resulting in an abandonment of the area for the natural regeneration of vegetation (Pequeño-Ledezma 2013), which is a significant shortfall for the people who depend on this resource. That scenario can be reversed through a management plan involving livestock, forestry and agroforestry practices, in which foliar biomass production of the shrubland is an important parameter to consider. According to Ledesma *et al*. (2010), the foliar biomass is a fundamental variable in the tree structure, since it is directly related to primary productivity. The evaluation of this variable is affected by the tree size and requires more time and resources on big trees (Rodríguez-Ortiz *et al*. 2012).

However, plant production in most environments is limited by the scarcity of mineral nutrients (Dominguez-Gómez *et al*. 2013). Under natural conditions, the amount of nutrients available is always limited and external additions are scarce, so the plants need to recycle, reduce losses and maximize efficiency in the use of nutrients for maximum biomass production (Escudero & Mediavilla 2003). This information is key to properly develop conservation, restoration and sustainable management plans (Legendre *et al*. 2005), where the litterfall can be a fundamental tool.

The litterfall is plant material accumulating on the ground, and its decomposition plays an important role in maintaining the productivity of forest ecosystems, affecting the transfer of organic matter, carbon, nitrogen, phosphorus and other nutrients of vegetation to the soil (Pérez-Suárez *et al*. 2009). It is the main nutrients source of forest soil (Landsberg & Gower 1997, Vitousek & Sanford 1986) and represents about 80 % of nutrients returned to the soil by the detritus of the tree (Santa Regina *et al*. 2001). The quantification of litterfall accumulation and its nature are crucial to understanding nutrient cycling in forest ecosystems (Zapata *et al*. 2007). However, litterfall production and accumulation are influenced by climatic variables (temperature and precipitation), soil conditions and anthropogenic interventions (Pavón *et al*. 2005, Prause *et al*. 2003, Roig *et al*. 2005, Zaldívar-Jiménez *et al*. 2004), which make difficult its determination.

There is a tendency to relate the litterfall accumulation and biomass production. Therefore, the objectives of this study were to quantify the leaf litter fluctuations through the seasons of the year and the leaf biomass production, and determine the relationship between fallen leaves pattern and foliar biomass production in forest plantations of five species of the Tamaulipan thornscrub, in the northeastern Mexico, as a tool for an adequate management of this ecosystem.

Materials and methods

Study area. The study was conducted in the school shrub plantations of the Forest Sciences Faculty of the Autonomous University of Nuevo Leon (UANL) in the town of Linares, located within the coordinates 24° 47' north latitude and 99° 32' west longitude in a plain region between 430-450 m altitudes in the foothills of the Sierra Madre Oriental, Mexico (Foroughbakhch *et al*. 2014). The regional climate is defined as semi-arid and sub-humid [(A) C (Wo)] in the scheme of Köppen modified by García (2004), with two rainy seasons (summer and autumn) and a dry season between November and April. Mean annual temperature is 22.3 °C with temperatures

Table 1. Uses, forest measurements and ecological variables of five timber species of the Tamaulipan thorn scrub in the northeastern Mexican semiarid land.

Family	Species	Uses	BD (cm)	DBH (cm)	Ht (m)	C (m²/ind.)	RA (%)	RF (%)	IV (%)
Mimosaceae	*Acacia berlandieri* Benth.	Handcrafts, Firewood, forage	3.10	2.05	3.25	8.53	8.4	4.1	5.36
Mimosaceae	*Acacia wrightii* Benth	Firewood, Charcoal, Handcrafts, Food (seeds), wood, forage.	7.60	4.40	3.70	5.64	2.3	5.6	5.8
Mimosaceae	*Ebenopsis ebano* (Berland.) Barneby & J.W.Grimes	Posts, Firewood, Charcoal, Wood (furniture), shade for animal protection, Food (fruit & pods).	7.90	5.95	4.80	7.60	6.1	6.6	7.60
Mimosaceae	*Havardia pallens* Britton & Rose.	Firewood, construction and manufacture of furniture.	5.20	3.98	4.80	6.72	3.6	5.6	3.73
Rutaceae	*Helietta parvifolia* (A.Gray ex Hemsl.) Benth.	Poles, shelves, wood, Charcoal, medicinal.	4.40	3.05	5.00	6.78	8.7	8.2	8.80

BD. Basal Diameter; DBH. Diameter at breast height; Ht. Height; C. Coverage; ind. Individual; RA. Relative abundance; RF. Relative frequency; IV. Importance value. Sources. Foroughbakhch *et al.* 2009, Velazco-Macías *et al.* 2011, Martínez-Hernández *et al.* 2013, Ngangyo *et al.* 2014a,b.

over 40 ℃ during the summer, and frost from December to March. Mean annual precipitation is 749 mm (Foroughbakhch *et al.* 2001), with the precipitation ratio to free evaporation of 0.48 and precipitation to potential evaporation of 0.62 (Foroughbakhch *et al.* 2009).

Selection of the species. The five woody species with the higher values of ecological characteristics (Alanís-Rodríguez *et al.* 2008, Jiménez-Pérez *et al.* 2009) were selected for this investigation: *Acacia berlandieri*, *Acacia wrightii*, *Ebenopsis ebano*, *Havardia pallens* and *Helietta parvifolia*. The choice was made after careful consideration of their growth rate, potential uses and preferences by local populations (Table 1).

Sampling design. Three plots of 100 m² (10 × 10 m) for each woody species containing 25 trees were installed on a 30 years old experimental plantations. The plantations were not subjected to any type of silvicultural treatment or use.

Foliar biomass estimation. The foliar biomass was determined by "Adelaide" method or "hand reference" method (Forouhbakhch *et al.* 1996), which is the most precise, practical and simplest method for measuring the forage leaf biomass of many shrub species (Forouhbakhch *et al.* 2009). The method consisted in selecting outside the study area, a branch called "reference unit", as representative unit in form and foliar density, for each studied species. Then, the number of the branch units was estimated by counting on the four cardinal points of the crown of 10 trees per plot, resulting in a total of 150 shrub samples. Afterwards, the reference units were brought to the laboratory to separate the leaves and dry them in an oven at 65 °C to constant weight. The dry foliar biomass of each species was obtained by multiplied the number of reference units by the dry weight. The evaluation was conducted by seasons, from June 2013 to May 2014, in order to determine the seasonal production during a year.

Litterfall accumulation. The methodology used was proposed by Návar-Cháidez & Jurado-Ybarra (2009), which consisted of collecting fallen leaves by litter traps of 1 m² (1 × 1 m), with mesh of 1 mm² opening. Three traps per plot were randomly placed under the trees, and the collection was made every 15 days during the year (from May 2013 to April 2014). The litterfall was manually separated into leaves, branches, twigs, seeds and flowers; the leaves fraction was used for this study. The dry mass of the collected leaf litter was determined on a digital balance (Ohaus Corporation, model EP612C, Pine Brook, NJ, USA; 0.001 g of precision), after dried in an oven (Lab-Line, Instruments, Inc., model 3476, Imperial V, Melrose Park, IL, USA) at 70 °C for 72 hours. The annual accumulation of leaf litter was determined by summing the production of all samples taken, per replication and studied species.

Statistical analyses. To verify statistical differences in the foliar biomass production and leaf litter accumulation, a multifactor analysis of variance was applied (Quinn & Keough 2002), and the interactions of each of the two parameters were studied with species and seasons through simple regressions. The statistical analyzes of all data was performed using the statistical program Statgraphics Centurion XVI (STATGRAPHICS 2002). Relationships were adjusted to the averages of foliar biomass and leaf litter, through simple regressions and corresponding equations, by species and seasons.

Results

Foliar biomass production. The foliar biomass production presented significant differences ($P < 0.05$) among species as well as seasons (Table 2). The higher annual average production was registered by *Ebenopsis ebano* with 2687 kg ha^{-1} whereas the lower annual average was recorded by *Acacia wrightii* with 431 kg ha^{-1} (Figure 1).

Figure 2 presents the seasonal production, where summer showed the maximum value (12,253 kg ha^{-1}), registered by *Ebenopsis ebano*, and winter showed the lower value (2,215 kg ha^{-1}), recorded by *Acacia wrightii*.

Table 2. ANOVA for Foliar biomass by Season

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	1,06625E7	3	3,55415E6	**7,06**	**0,0004**
Within groups	2,82085E7	56	503723,		
Total (Corr.)	3,8871E7	59			

The values were ranged from 103 to 371 kg ha^{-1} in winter, corresponding to *Ebenopsis ebano* and *Acacia wrightii* respectively; 248 – 879 kg ha^{-1} in spring, corresponding to *Acacia berlandieri* and *Havardia pallens* respectively; 834 – 9,029 kg ha^{-1} in summer, *E. ebano* and *A. wrightii* respectively; and 418 – 962 kg ha^{-1} in autumn, corresponding to *A. berlandieri* and *A. wrightii* respectively.

Litterfall accumulation. No statistically significant differences ($P > 0.05$) were detected among species. However, highly significant differences ($P < 0.01$) were observed among seasons of the year (Table 3). The annual average of leaf litter accumulation varied from 646 to 721 kg ha^{-1}, values corresponding to *Ebenopsis ebano* and *Acacia wrightii*, respectively (Figure 3).

Figure 1. Annual average production of foliar biomass (Kg ha^{-1}) and standard errors of five species in the semi-arid area of northeastern Mexico

Table 3. ANOVA for Leaf litter by Season
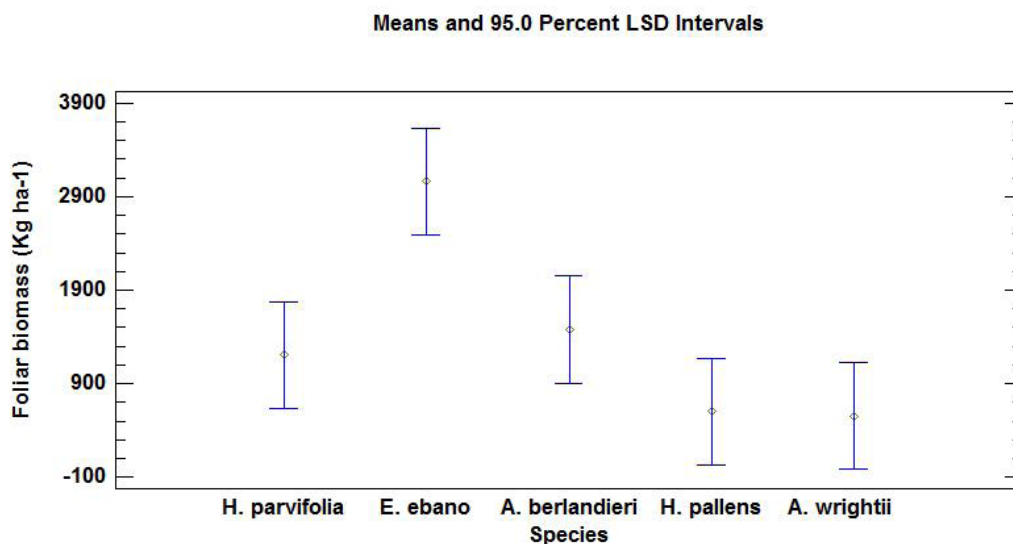
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	292499,	3	97499,7	**122,16**	**0,0000**
Within groups	44694,8	56	798,121		
Total (Corr.)	337194,	59			

Figure 2. Seasonal foliar biomass production of five species of the semi-arid area of northeastern Mexico
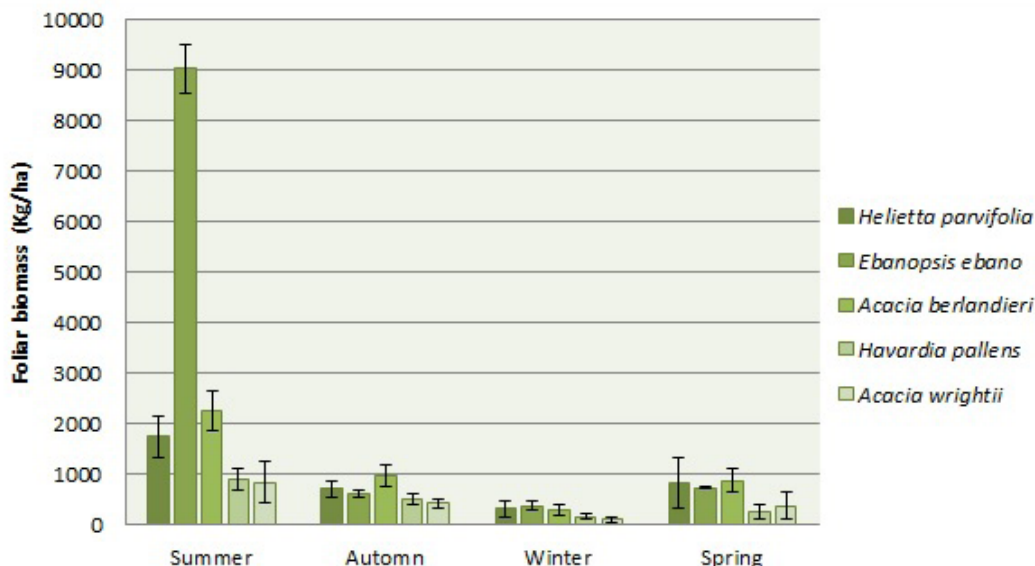
The greater amount of leaf litter accumulated was observed in winter by *Acacia berlandieri* (274 kg ha^{-1}) and *Acacia wrightii* (296 kg ha^{-1}), while the lower value was recorded in spring, by *Ebenopsis ebano* (97 kg ha^{-1}). Summer and autumn presented the ranges from 109 to 163 kg ha^{-1}, values corresponding to *A. wrightii* and *Helietta parvifolia*, respectively; and from 139 to 162 kg ha^{-1}, values corresponding to *A. berlandieri* and *Havardia pallens*, respectively (Figure 4).

Relationship between foliar biomass production and litterfall accumulation. Table 4 shows the results of fitting a linear model to describe the relationship between Leaf litter and foliar bio-

Figure 3. Annual average of litterfall deposition (Kg ha^{-1}) and standard error of five species of the semiarid zone of northeastern Mexico
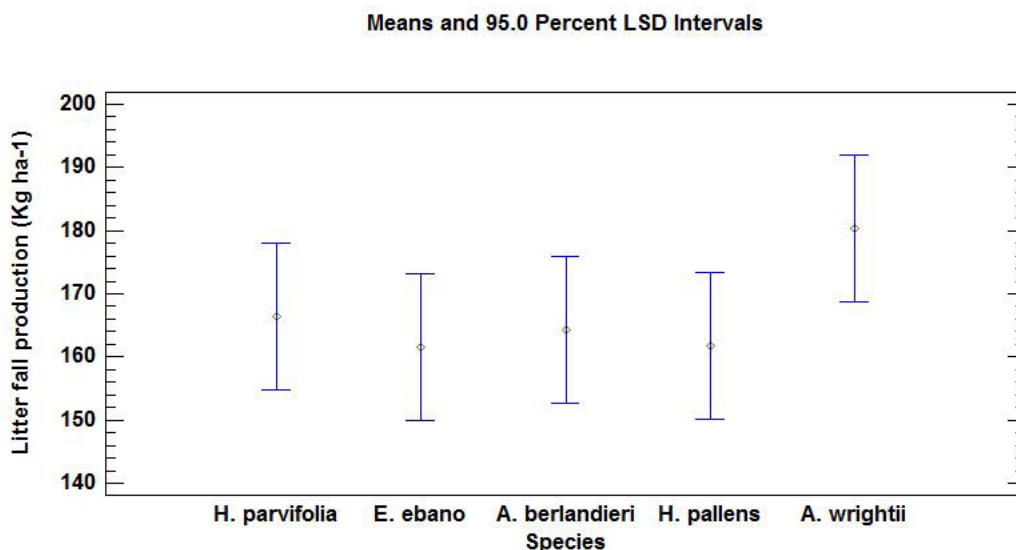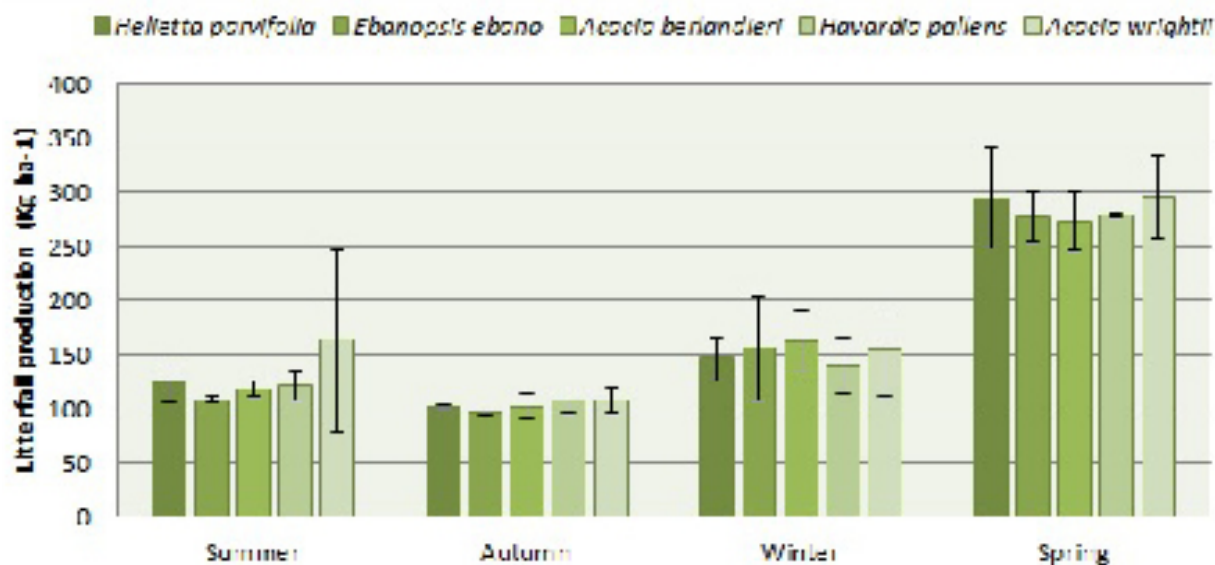
Figure 4. Seasonal rate of litterfall production (kg ha⁻¹) and its standard deviation in five species of the semi-arid land of northeastern Mexico

Table 4. Equations of the correlations between the seasonal leaf litter accumulation and foliar biomass production of five woody species of the semi-arid zone of northeastern Mexico

| Seasons	Equations of correlations	Correlation coefficient	R^2	P-value
Summer	LL = 139,352 - 0,00723143 x FB	-0,524374	27,4968	0,0448
Autumn	LL = 109,788 - 0,00585361 x FB	-0,829411	68,7923	0,0001*
Winter	LL = 149,018 + 0,00245595 x FB	0,143127	2,04853	0,6108
Spring	LL = 172,011 + 0,119417 x FB	0,600633	36,0759	0,0179

LL. Leaf litter, FB. Foliar biomass

mass. The P-value is less than 0.05 in summer and spring, indicating a statistically significant relationship between leaf litter accumulation and foliar biomass production at the 95 % confidence level, while there is a highly significant relationship ($P < 0.001$) between these variables in autumn. With the R-Squared statistic obtained, their correspondent models as fitted explain 27.4968 % of leaf litter variability in summer, 36.0759 % in spring and 68.7923 % in autumn. Therefore, there is a moderately strong relationship between the variables in autumn, since its correlation coefficient equals -0.829411 (Figure 5).

For winter, the P-value is greater to 0.05, indicating that there is no statistically significant relationship between leaf litter and foliar biomass at the 95 % or higher confidence level. The model as fitted just explains 2.04853 % (R^2) of the variability in leaf litter, and the correlation coefficient equals 0.143127, indicating a relatively weak relationship between the variables (Figure 5).

Discussion

Foliar biomass. The higher annual production of foliar biomass registered with *Ebenopsis ebano* can be explained by the more coverage that reported Ngangyo *et al.* (2014b) for the same species, which presented a dense canopy. The lowest values recorded in winter, show that the warm weather is a determining factor in the foliar productivity. As indicated by Návar-Cháidez & Jurado-Ybarra (2009), the species of scrubs bloom and produce leaves in the early stages of spring.
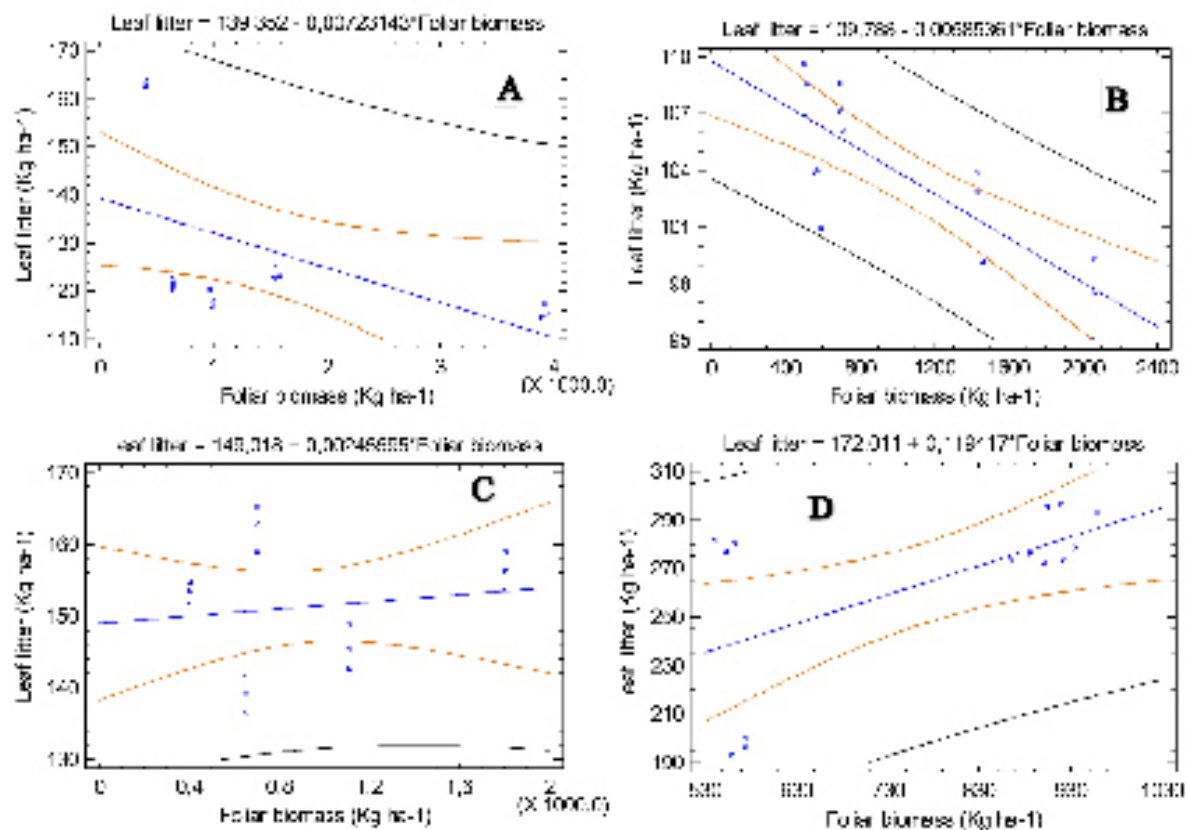
Figure 5. Relationships between foliar biomass production and leaf litter accumulation of five woody species of the semi-arid zone of northeastern Mexico, by season: A) Summer, B) Autumn, C) Winter, D) Spring.

The evaluated values of foliar biomass obtained in this study are lower than 25,000 kg ha^{-1} found by Yerena-Yamallel *et al.* (2011) in a primary scrub, and similar to 12,930 and 13,033 kg ha^{-1} found by Návar-Cháidez (2008) and Búrquez *et al.* (2010) respectively, on a Tamaulipan thorn scrub. The variations in the obtained ranges of foliar biomass prove the wide range of growth patterns, leaf diversity and longevity, that characterize the vegetation of northeastern Mexico, according to Reid *et al.* (1990) and Domínguez-Gómez *et al.* (2013) who studied the dynamics of growth and phenological development of the Tamaulipan thorn scrub.

The high value of foliar biomass observed by *Helietta parvifolia*, *Ebenopsis ebano* and *Acacia berlandieri*, can be related to the larger crown area they covered in comparison to *Havardia pallens* and *Acacia wrightii*, as presented by Ngangyo *et al.* (2014b), by determining the canopy coverage of these five species in study. Moreover, according to Tracy (2014), *H. parvifolia* is characterized by high leaf area, and *E. ebano* is characterized by multiple branches extending in zigzag on a large space to mature. This allows considering the crown density as an important factor in the foliar biomass production.

Leaf litter. The significant differences among seasons in the amount of leaf litter imply a temporal variation of litterfall accumulation during a year. A similar result was observed by González-Rodríguez *et al.* (2013) in a scrubland of the northeastern Mexico. According to Prause *et al.* (1997), spatial and temporal variation is probably associated with the floristic composition of a site. In this study, the higher value of leaf litter was recorded in winter (December and January) and can be related to the extreme temperature conditions, since winter is the coldest season of the year, reaching temperatures of 5.2 °C (CONAGUA, 2014). Such temperatures caused an increase in the abscission of the leaves (Álvarez *et al.* 2009). This occurs mostly in regions with arid or semi-arid climates where gradual leaf abscission seems to be an adaptation to water stress, as indicated by López-Hernández *et al.* (2013).

Moreover, the species *Helietta parvifolia* (295 kg ha^{-1}) and *Acacia wrightii* (296 kg ha^{-1}) which registered high values of litterfall are highlighted by Ngangyo *et al.* (2014b), to present a

high crown area. Degen *et al*. (1997) mentioned that the genus *Acacia* is a great source of foliage. This could explain that the loss of leaves was bigger in this species than the others.

The lower value recorded in spring coincides with the renewal of the leaves, which is proper this season. And *Ebenopsis ebano* which have multiple branches that extending in zigzag (Tracy 2014), does not lose many leaves.

The monthly variation in litterfall production and its components has been reported previously by Prause *et al*. (2003) who found values ranging from 0.42 to 28.2 g m^{-2} per year. The values provided in this study for litterfall accumulation are within the range defined for plantations established with species characteristic of poor and degraded soils (Bernhard-Reversat 1993, Lim 1988).

Relationship between foliar biomass production and leaf litter accumulation. The coefficient of determination observed in winter (R^2 = 2.04853 %) indicating a relatively weak relationship between foliar biomass and leaf litter. In summer (R^2 = 27.4968 %) and spring (R^2 = 36.0759 %), the coefficients of determination indicating a moderately relationship between the variables. The best coefficient of determination (68.7923 %) observed in autumn indicating a moderately strong relationship between the variables, with a negative and significant linear correlation between leaf litter accumulation and foliar biomass production. These significant variations in the relationship foliar biomass/leaf litter can be explained by the weather conditions, in accordance with Estrada-Castillón *et al*. (2012), who found in a study of the structure and diversity of submontane scrub in northeastern Mexico, that the environmental conditions, particularly rainfall, accentuate and favor significant changes in the vegetation structure. In effect, in extreme weather conditions (winter which is the coldest season with lower temperatures, and summer which is the warmest season with higher temperatures), the plants are in stress condition, and present a difficulty in coordinating the mechanisms of production and loss of leaves, whereas in temperate conditions (autumn), there is a certain balance between loss and leaf production, so the model obtained in this case can be used for predictions of future observations. But from the physiological point of view, Návar-Cháidez & Jurado-Ybarra (2009) indicate that it is more acceptable a logarithmic relationship, that is born of origin. However, the same authors note that with the linear model, they obtained a better coefficient of determination (35 %) that is lower than the best coefficient obtained in the present study (68.79 %). Brown & Lugo (1982) had already found a relationship between total litterfall production and biomass. Also in recent studies, Agudelo & Aristizabal (2003) registered association (R^2 = 74 %) between the foliar biomass and litterfall.

Leaves are short-lived organs and therefore, the recycling of nutrients previously incorporated in them and that have already carried out their contribution to photosynthesis can have a great adaptive significance (Escudero & Mediavilla 2003) and represent a considerable part of annual nutrient requirements for construction of foliar biomass.

Acknowledgements

Literature cited

Agudelo SL, Aristizábal CL. 2003. *Estimación de la caída de hojarasca y detritos leñosos en bosques primarios intervenidos y secundarios de la región de Porce, Colombia*. Undergraduate thesis, Universidad Nacional de Colombia.

Alanís-Rodríguez E, Jiménez-Pérez J, Aguirre-Calderón O, Treviño-Garza E, Jurado-Ybarra E, González-Tagle M. 2008. Efecto del uso del suelo en la fitodiversidad del matorral espinoso tamaulipeco. *Ciencia UANL* **11**: 56-62.

Álvarez JA, Villagra PE, Rossi BE, Cesca EM. 2009. Spatial and temporal litterfall heterogeneity generated by woody species in the Central Monte Desert. *Plant Ecology* **205**: 295–303. DOI: 10.1007/s11258-009-9618-z

Bernhard-Reversat F. 1993. Dynamics of litter and organic matter at the soil-litter interface in fast-growing tree plantations on sandy ferrallitic soils (Congo). *Acta Oecologica* **14**: 179-195.

Brown S, Lugo AE. 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica* **14**: 161-187. DOI: 10.2307/2388024

Burquez A, Martinez-Yrizar A, Nuñez S, Quintero T, Aparicio A. 2010. Above-ground biomass in three Sonoran Desert communities: variability within and among sites using replicated plot harvesting. *Journal of Arid Environments* **74**: 1240-1247. DOI: 10.1016/j.jaridenv.2010.04.004

Comisión Nacional del Agua (CONAGUA). 2014. *Servicio meteorológico nacional, resúmenes mensuales de lluvia y temperatura*. <smn.cna.gob.mx/index.php?option=com_content&view=article&id=12&Itemid=112> (accessed March 20, 2015).

Degen AA, Blanke A, Becker K, Kam M, Benjamin RW, Makkar HPS. 1997. The nutritive value of *Acacia saligna* and *Acacia salicina* for goats and sheep. *Animal Science* **64**: 253:258 DOI: 10.1017/S1357729800015812

Domínguez-Gómez TG, González-Rodríguez H, Ramírez-Lozano RG, Estrada-Castillón AE, Cantú-Silva I, Gómez-Meza MV, Villarreal-Quintanilla JA, Alvarado MS, Alanís-Flores G. 2013. Diversidad estructural del matorral espinoso tamaulipeco durante las épocas seca y húmeda. *Revista Mexicana de Ciencias Forestales* **4**: 106-122.

Escudero A, Mediavilla S. 2003. Dinámica interna de los nutrientes. *Ecosistemas* **12**.

Estrada-Castillón E, Villarreal-Quintanilla JA, Jurado-Ybarra E, Cantú-Ayala C, García-Mirnada MA, Sánchez-Salas J, Jiménez-Pérez J, Pando-Moreno M. 2012. Clasificación, Estructura y Diversidad del Matorral Submontano Adyacente a la Planicie Costera del Golfo del Norte en el Noreste de México. *Boletín de la Sociedad Botánica de México* **90**: 1-16.

Eviner VT, Chapin III FS. 2003. Functional matrix: a conceptual framework for predicting multiple plant effects on ecosystem processes. *Annual Review of Ecology, Evolution, and Systematics* **34**: 455-485. DOI 10.1146/annurev.ecolsys.34.011802.132342

Fahring L. 2003. Effects of the habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution, and Systematics* **34**:487–515. DOI: 10.1146/annurev.ecolsys.34.011802.132419

Forouhbakhch R, Reyes G, Hauad LA, Badii ZMH. 1996. Three Methods of Determining Leaf Biomass on Ten Woody Shrub Species in Northeastern Mexico. *Agrociencia* **30**.

Foroughbakhch F, Háuad LA, Cespedes AE, Ponce EE, González N. 2001. Evaluation of 15 indigenous and introduced species for reforestation and agroforestry in northeastern Mexico. *Agroforestry Systems* **51**: 213–221. DOI 10.1023/A:1010702510914

Foroughbakhch R, Reyes G, Alvarado-Vázquez MA, Hernández-Piñero J, Rocha-Estrada A. 2005. Use of quantitative methods to determine leaf biomass on 15 woody shrub species in northeastern Mexico. *Forest Ecology and Management* **216**: 359–366. DOI: 10.1016/j.foreco.2005.05.046

Foroughbakhch R, Hernández-Piñero JL, Alvarado-Vázquez MA, Céspedes-Cabriales E, Rocha-Estrada A, Cárdenas-Ávila ML. 2009. Leaf biomass determination on woody shrub species in semiarid zones. *Agroforestry System* **77**: 181–192. DOI: 10.1007/s10457-008-9194-6

Foroughbakhch R, Hernández-Piñero JL, Carrillo-Parra A. 2014. Adaptability, growth and firewood volume yield of multipurpose tree species in semiarid regions of Northeastern Mexico. *International Journal of Agricultural Policy and Research* **2**: 444-453 DOI: 10.15739/IJAPR.016.

García E. 2004. Modificaciones al sistema de clasificación climática de Koppen para adaptarlo a las condiciones de la República Mexicana. Instituto de Geografía, UNAM.

González Rodríguez H, Cantú-Silva I. 2001. Adaptación a la sequía de plantas arbustivas del matorral espinoso tamaulipeco. *CIENCIA UANL* **4**: 454-461.

González A, Mouquet N, Loreau M. 2009. Biodiversity as spatial insurance: the effects of habitat fragmentation and dispersal on ecosystem functioning. *In*: Naeem S, Bunker D, Hector A, Loreau M, Perrings C. eds. *Biodiversity, Ecosystem Functioning, and Human Wellbeing, an Ecological and Economic Perspective*. Oxford University Press, 134-148.

González-Rodríguez H, Ramírez-Lozano RG, Cantú-Silva I, Gómez-Meza MV, Cotera-Correa M, Carrillo-Parra A, Marroquín-Castillo JJ. 2013. Litterfall production and nutrient returns through leaves in a microphyllous desert scrubland, northeastern Mexico. *Revista Chapingo*. *Serie Ciencias Forestales y del Ambiente* **19**: 249-262. DOI: /10.5154/r.rchscfa.2012.08.048

Heiseke D, Foroughbakhch R. 1985. *El matorral como recurso forestal*. Reporte científico 1. Facultad de Silvicultura y Manejo de Recursos Renovables. Universidad Autónoma de Nuevo León.

Jiménez-Pérez J, Alanís-Rodríguez E, Aguirre-Calderón O, Pando-Moreno M, González-Tagle M. 2009. Análisis sobre el efecto del uso del suelo en la diversidad estructural del matorral espinoso tamaulipeco. *Madera y Bosques* **15**.

Jiménez-Pérez J, Alanís-Rodríguez E, Ruiz-González JL, González-Tagle MA, Yerena-Yamallel JI, Alanís-Flores GJ. 2012. Diversidad de la regeneración leñosa del matorral espinoso tamaulipeco con historial agrícola en el NE de México. *Ciencia UANL* **15**: 66-71.

Jiménez-Pérez J, Alanís-Rodríguez E, González-Tagle MA, Aguirre-Calderón OA, Treviño-Garza EJ. 2013. Characterizing woody species regeneration in areas with different land history tenure in the tamaulipan thornscrub, Mexico. *The Southwestern Naturalist* **58**: 299-304. DOI: 10.1894/0038-4909-58.3.299

Landsberg JJ. & Gower ST. 1997. *Applications of Physiological Ecology to Forest Management*. New York: Academic Press.

Ledesma M, Carranza CA, Balzarini M. 2010. Estimación de la biomasa foliar de *Prosopis flexuosa* mediante relaciones alométricas. *Agriscientia* **27**.

Legendre P, Borcard D, Peres-Neto PR. 2005. Analyzing beta diversity: partitioning the spatial variation of community composition data. *Ecological Monographs* **75**: DOI: 10.1890/05-0549

Lim MT. 1988. Studies on *Acacia mangium* in Kemasul forest, Malaysia. I. Biomass and productivity. *Journal of Tropical Ecology* **4**: 293-302. DOI: 10.1017/S0266467400002856

López-Hernández JM, González-Rodríguez H, Ramírez-Lozano RG, Cantú-Silva I, Gómez-Meza MV, Pando-Moreno M, Estrada-Castillón AE. 2013. Producción de hojarasca y retorno potencial de nutrientes en tres sitios del estado de Nuevo León, México. *Polibotánica* **35**: 41-64.

Martínez-Hernández DD, Jiménez-Pérez J, Alanís-Rodríguez E, Uvalle-Sauceda JI, Canizales-Velázquez PA, Rocha-Domínguez L. 2013. Natural regeneration of the tamaulipan thornscrub in an *Eucalyptus spp*. plantation. *Revista Mexicana de Ciencias Forestales* **5**.

Mora-Donjuán CA, Alanís-Rodríguez E, Jiménez-Pérez J, González-Tagle MA, Yerena-Yamallel JI, Cuellar-Rodríguez LG. 2013. Estructura, composición florística y diversidad del matorral espinoso tamaulipeco, México. *Ecología Aplicada* **12**: 29-34.

Návar-Cháidez J. 2008. Carbon fluxes resulting from land-use changes in the Tamaulipan thornscrub of northeastern Mexico. *Carbon Balance and Management* **3**. DOI: 10.1186/1750-0680-3-6

Návar-Cháidez J, Jurado-Ybarra E. 2009. Productividad foliar y radicular en ecosistemas forestales del Noreste de México. *Revista Ciencia Forestal en México* **34.**

Ngangyo HM, Foroughbakhch PR, Carrillo-Parra A, Salas-Cruz LR. 2014a. Estimation of Timber Production of Five Species of the Tamaulipas Thorny Shrubs Growing in Native Stands and Plantations. *Open Journal of Forestry* **4**: DOI: 10.4236/ojf.2014.43031.

Ngangyo HM, Foroughbakhch PR, Carrillo-Parra A, Guzmán-Lucio MA, Salas-Cruz LR. 2014b. Fodder production under canopy of five species of the Tamaulipan thorn scrub in the northeast of Mexico. *International Journal of Current Research and Academic Review* **2**: 185-195.

Pavón NP, Briones O, Flores-Rivas J. 2005. Litterfall production and nitrogen content in an intertropical semi-arid Mexican scrub. *Journal of Arid Environments* **60**: 13. DOI: 10.1016/j.jaridenv.2004.03.004

Pequeño-Ledezma MA. 2013. *Análisis de la restauración pasiva post-pecuaria en el matorral espinoso tamaulipeco del noreste de México*. Doctoral Thesis, Universidad Autónoma de Nuevo León.

Pérez-Suárez M, Arredondo-Moreno JT, Huber-Sannwald E, Vargas-Hernández JJ. 2009. Production and quality of senesced and green litterfall in a pine-oak forest in central-northwest Mexico. *Forest Ecology and Management* **258**: 1307-1315. DOI: 10.1016/j.foreco.2009.06.031

Prause J, Palma RM, Adámoli JM. 1997. *Aporte de las principales especies forestales a la dinámica de la materia orgánica y de los nutrimentos en un monte nativo del parque chaqueño húmedo*. PhD. Thesis, Universidad de Buenos Aires.

Prause J, Arce de Caram G, Angeloni PN. 2003. Variación mensual en el aporte de hojas de cuatro especies forestales nativas del Parque Chaqueño Húmedo (Argentina). *Quebracho, Revista de Ciencias Forestales* **10**: 39-45.

Quinn GP, Keough MJ. 2002. *Experimental Design and Data Analysis for Biologist*. Cambridge University Press.

Ramírez-Orduña R. 2003. *Dinámica estacional del valor nutritivo y digestión ruminal del forraje de 10 arbustiva de Baja California Sur, México*. PhD Thesis, Universidad Autónoma de Nuevo Léon.

Ramírez OR, Ramírez RG, Romero-Vadillo E, González-Rodríguez H, Armenta-Quintana JA, Avalos-Castro R. 2008. Diet and nutrition of range goats on a sarcocaule shrubland from Baja California Sur, México. *Small Ruminant Research* **76**: 166-176. DOI: 10.1016/j.smallrumres.2007.12.020

Reid N, Marroquín J, Beyer-Münze P. 1990. Utilization of shrubs and trees for browse, fuelwood and timber in the Tamaulipan thornscrub, northeastern Mexico. *Forest Ecology and Management* **36**: 61-79. DOI: 10.1016/0378-1127(90)90064-I

Rodríguez-Ortiz G, De Los Santos-Posadas HM, González-Hernández VA, Aldrete A, Gómez-Guerrero A, Fierros-González AM 2012. Modelos de biomasa aérea y foliar en una plantación de pino de rápido crecimiento en Oaxaca. *Madera y Bosques* **18**: 25-41.

Roig S, del Río M, Cañellas I, Montero G. 2005. Litterfall in Mediterranean *Pinus pinaster* Ait. stands under different thinning regimes. *Forest Ecology Management* **206**: 79-190. DOI: 10.1016/j.foreco.2004.10.068

Santa Regina I, Leonardi S, Rapp M. 2001. Foliar nutrient dynamics and nutrient use efficiency in *Castanea sativa* coppice stands of southern Europe. *Forestry* **74**, 1-10. DOI: https://doi.org/10.1093/forestry/74.1.1

STATGRAPHICS. 2002. Statgraphics plus. Version 5.0. Manguistics, Inc., Rockville, MD.

Tracy M. 2014. *8th Annual Desert Garden Tour.* Desert Horticultural Society of the Coachella Valley. <dhs.cloverpad.org/Resources/Documents/DHSCV_Plant_sheets_group_2014_final.pdf> (accessed April 8, 2015).

Velazco-Macías CG, Alanis-Flores G, Alvarado-Vázquez M, Ramírez-Freire L, Foroughbakhch R. 2011. Endemic flora from Nuevo León, Mexico and adjacent states. *Journal of the Botanical Research Institute of Texas* **5**: 275 – 298.

Vitousek PM, Sanford RL. 1986. Nutrient cycling in moist tropical forest. *Annual Review of Ecology and Systematics* **17**:137-167. DOI: 10.1146/annurev.es.17.110186.001033

von Maydel HJ. 1996. Appraisal of practices to manage woody plants in semiarid environment. *In*: Bruns SJ, Luukanen O, Woods P. eds. *Dry Land Forestry Research*. International Stockholm: Foundation for Science 47-64.

Yerena-Yamallel JI, Jiménez-Pérez J, Alanís-Rodríguez E, Aguirre-Calderón OA, Treviño-Garza EJ. 2011. Contenido de carbono en la biomasa aérea en diferentes sistemas de uso de suelo, en el matorral espinoso tamaulipeco. *Revista Latinoamericana de Recursos Naturales* **7**: 71-77.

Zaldívar-Jiménez A, Herrera-Silveira J, Coronado-Molina C, Alonzo-Parra D. 2004. Estructura y productividad de los manglares en la reserva de la biosfera Río Celestún, Yucatán, México. *Madera y Bosques* **10**: 25-35.

Zapata DC, Ramírez JA, León PJ, González HM. 2007. Producción de hojarasca fina en bosques altoandinos de Antioquia, Colombia. *Revista Facultad Nacional de Agronomía Medellín* **60**: 3771-3784.