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Urban forest of Mendoza (Argentina): the role of *Morus alba* (Moraceae) in carbon storage

Eduardo Martínez Carretero [a,b], Gabriela Moreno[c], Andrea Duplancic[c], Adonis Abud[c], Barbara Vento[d] and Jorge Alcalá Jauregui[e]

[a]Instituto Argentino de Investigaciones de las Zonas Áridas, Geobotany and Phytogeography, Av. Adrian Ruiz Leal s/n°, Parque Gral. San Martín, Mendoza, 5500 Argentina; [b]Universidad Nacional de San Juan, Fac. Cs. Ez. F. y Nat. Dpto- Biología, Ignacio de la Roza y Meglioli, San Juan, Argentina; [c]Geobotánica y Fitogeografía (IADIZA), Mendoza, Argentina; [d]Instituto Argentino de Nivologia Glaciologia y Ciencias Ambientales, Mendoza, Argentina; [e]Universidad Autonoma de San Luis Potosi, San Luis Potosi, Mexico

ABSTRACT

Carbon dioxide emissions have partially been attributed to urban areas. Nevertheless, cities provide valuable ecosystem services such as carbon storage. The aim of this study is to estimate the carbon storage of *Morus alba* trees as a dominant species in the urban forest of Mendoza city. A stratified random sampling was selected for both urban and suburban areas. Trees were analyzed considering the following parts: stem, primary and secondary branches, and leaves. Underground dry matter was also estimated. Tree dry matter was distributed as follows: crown 53%, stem 25%, root 20%, and leaf 2%. Considering the total *M. alba* coverage, the urban area accumulates 24,208 tonnes and the suburban area 43,000 tonnes of carbon, from which 544.6 tonnes (1998.6 t CO_2) and 1123.3 tonnes (4,118.8 t CO_2) are annually removed by leaves. These quantities are relevant considering the 13,000 t/year of CO released to the atmosphere in Mendoza city. The accumulated carbon values evidence the importance of preservation and conservation tasks that are essential in the management of the urban forest located in drylands.

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Dry lands; urban forestry; carbon sink; canopy cover; carbon storage; national inventory

Introduction

Urban areas, that globally occupy around 2.4% of the land mass [1], are responsible for more than 70% of anthropogenic release of carbon dioxide to environment [2,3]. At a global scale, increasing levels of energy consumption from fossil reservoirs, and their carbon emissions to the atmosphere, are increasing the greenhouse effect [4]. There has been a notorious increase in carbon dioxide and other greenhouse gasses emissions in the last few years due to the burning of fossil fuels destined to energy uses, and also from changes in land use, as deforestation for agricultural practices or urbanization [5–7]. At global scale, Catesana and Puliafito [8] estimated an increase in CO_2 from 700 $\times$ 10^9 Mg (year 1950) to 800 $\times$ 10^9 Mg (year 2015) due to anthropic activities. At a global level, forest ecosystems store approximately 90% of annual carbon released into the atmosphere [9].

A particular kind of forest is that developed in cities. This forest consists of native and non-native trees located in urban and suburban areas, and one of the most important benefits is carbon storage through their biomass [10]. Urban trees are frequently under different stress situations compared to those in natural areas, such as soil and air contamination, annual pruning, limited growing area (pavement, sidewalks), and annual exportation of nutrients [11,12]. They are usually transplanted from nurseries and pruned every year for aesthetic reasons. The annual pruning removes an important amount of the stored carbon in the trees [13]. On the other hand, many different microhabitats exist in urban environments – for example squares, trees along roads, and home gardens. Johnson and Gerhols [14] and Mattson *et al.* [15] found differences in growth between species of the same diameter and also in the carbon storage values for trees under different stress and micro-environmental diversity conditions compared to those in natural areas [16].

The urban forest provides important environmental benefits to the urban ecosystem such as improvement of urban aesthetics, provision of shade and consequently energy saving by cooling of buildings [17,101], and reduction of air pollution by particulate filtering [12], and also plays an important role as a carbon reservoir for taking up atmospheric carbon dioxide and storing it as dry matter, among other things [12,18,19].

Carbon-storing is a dynamic process throughout the tree life cycle (growth, foliage turnover, death). Nevertheless, human management, mostly the frequent pruning tasks, can negatively affect the carbon sink process. The presence of urban trees in cities has an important impact on the local climate and even on the

CONTACT Eduardo Martínez Carretero ✉ mcarrete@mendoza-conicet.gob.ar

carbon cycle [20–23]. However, detailed information about the ecosystem dynamic in urban areas is still scarce [24].

Several studies have evaluated carbon storage by various urban forests during the last few years, to develop management strategies: Hangzhou (China) [25], Leicester, United Kingdom [26,27], Germany [28,29], the United States [3,13,23,30–41], Australia [42], Korea [43], Barcelona [44], Nova Scotia (Halifax) [10] and Italy [45], among others.

Rowntree and Nowak [46] estimated the stored carbon in above- and belowground biomass, considering stem diameter distribution, in urban trees from the United States at approximately 725 million tonnes, and more recently Nowak *et al.* [23] estimated the total tree carbon storage, for the above- and belowground biomass of trees, including urban and natural forest areas, in the United States at 20.6 billion tonnes. Freedman, Love and Oneil [10] and Turner, Lefler and Freedman [47] studied the carbon sequestration in urban and natural areas of Nova Scotia by several species of trees, most of them non-native, and they postulated that the average carbon content in an old residential neighborhood was 44 t/ha, in a natural area 65.7 t/ha and in a young residential neighborhood 12 t/ha. Lamlon and Savidge [48] and Martin and Thomas [49,50] suggested splitting the sample into components – roots, stem, bark, branches and leaves – for a more accurate carbon analysis, and performing the analysis on each of these tissues.

The number of urban dwellers around the world is expected to rise, and the increasing atmospheric contamination also follows this process. For this reason, the conservation of urban trees is relevant to improve the quality of the environment by helping to reduce the levels of atmospheric carbon dioxide [1,31]. Currently, there is an emerging interest of urban managers in collaborating on the climate change topic and pollution mitigation initiatives. The carbon storage data from urban trees provides important information about the national carbon estimation, and allows assessing the role of urban forests in reducing atmospheric carbon dioxide. Quantification of biomass and carbon storage, even in local forest ecosystems, is a significant contribution to the global carbon budget. Most of the studies made on carbon storage come from natural forests [51–53,102], but information about carbon storage in urban ecosystems is still scarce and more research is necessary. An adjusted estimation of the carbon storage by trees in urban environments would be useful for quantifying ecological and economic benefits of these ecosystems. The urban forests have a greater impact per area of tree canopy cover than non-urban forests do. In arid lands, as in the case of the province of Mendoza, the urbanization process increases the carbon stock compared to wild or natural areas [54,55] where native forests are scarce or very sparse [56,57].

The urban forests have a greater impact per area of tree canopy cover than non-urban forests do, and produce secondary effects such as reduction of energy used in winter or summer time if managed properly [58–60,101].

The Mendoza Metropolitan Area or Gran Mendoza (an urban conglomerate that comprises six counties) currently has 1,086,633 inhabitants, 86% of them located in the urban area [61]. The urban area of Mendoza city has increased its surface in a 13-year period (1986–1999) to be around 39% (9513 ha) larger than in previous years [62]. This urban growth was developed mainly during the last 30 years by means of individual houses, towns, and many non-integrated illegal settlements [61]. Taking this into account, the estimated number of urban trees in the study area is approximately 456,600 (provincial forestry census, unpublished data; and authors' own data). These trees are important carbon sequesters, especially because the atmospheric carbon dioxide level reaches 13,000 tonnes/year in the urban area of Mendoza [63,64].

The main purpose of this paper is to estimate the amount of carbon stored by the non-native species *Morus alba* in the urban and sub-urban areas of Mendoza city, Argentina.

Material and methods

Study area

The Mendoza Metropolitan Area (32°50′11.7″S, 68°45′22.5″W to 32°59′52.7″–68°52′19.2″W) is located in the central-west part of Argentina. The climate is arid with 234.7 mm/year rainfall; 70% of the rain occurs during the summer period, and the average annual temperature was 16.8 °C [65,103], for the 1983–2014 period. Daily maximum temperature ranges from 43 °C in summer to − 9 °C minimum in winter, and average relative humidity is 43% [66]. The core city consists of dense and developed areas with cultural, administrative and financial facilities, where all the streets are forested. In Mendoza city the non-native species *M. alba* is the most frequent species, reaching almost 70–80% of the total trees widespread in both urban and suburban areas (authors' data, unpublished); meanwhile in the core city area *M. alba* reaches 39% of presence [67,68]. In Mendoza, *M. alba* public tree are planted with 7–8 m between plants, and on both street-sides, normally in monospecific stands, with approximately 30 trees per block (Figure 1).

Data collection

The urban and suburban areas defined for this study are indicated in Figure 2.

Figure 1. **Relative location of the studied area showing the distribution and plant cover of *Morus alba* on the sidewalks in the Mendoza urban area.**

Field data were recorded in both urban and suburban areas to determine the total urban carbon stored. To determine the size of the samples the formula for simple random sampling was used: $n = NxZ^2_axpxq / d^2x (N-1)+ Z^2_axpxq$, where N is population size, Z is the level of confidence, P is the probability of success, Q is the probability of failure, and d is the precision or maximum error accepted. The calculation of the sample size

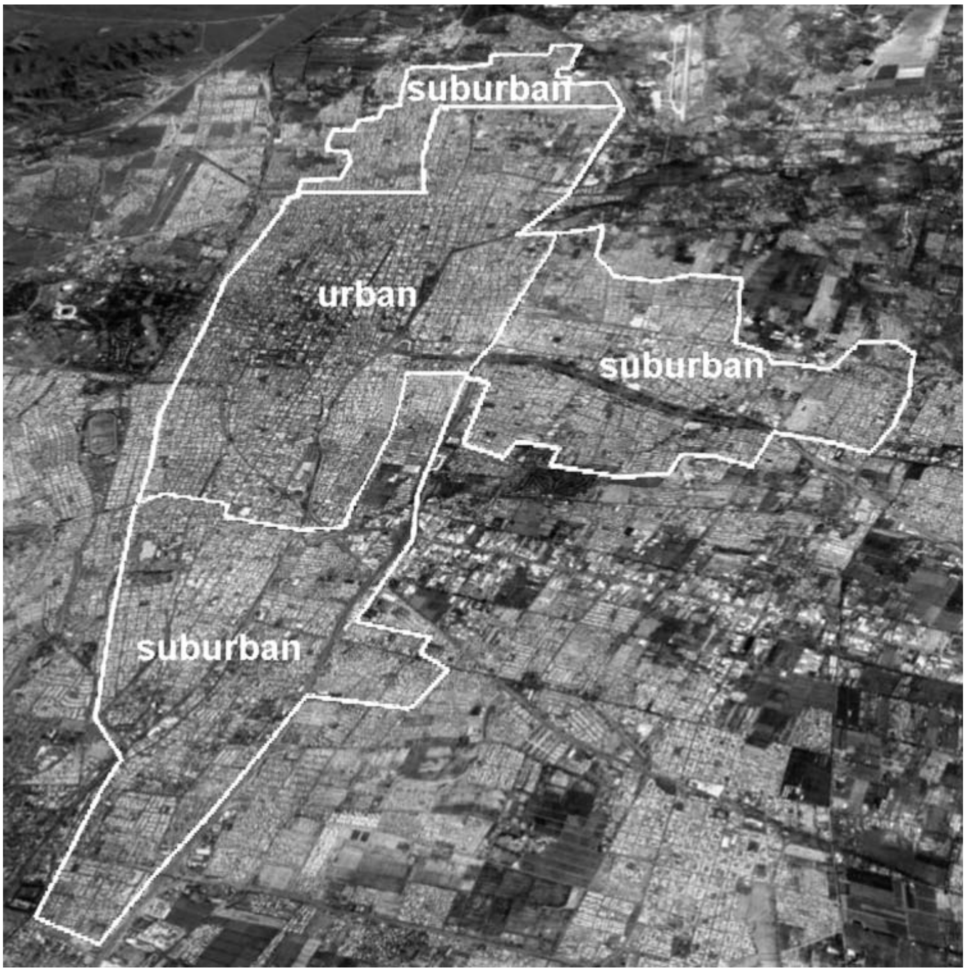

Figure 2. **Mendoza Metropolitan Area. Urban and suburban areas considered in this study.**

was 1981 trees, but considering the internal variation (trees are modified by pruning, etc.) the sampling was increased up to 3000 trees, a number of trees possible to be surveyed in the field. In both studied areas blocks were numbered on a SPOT (Satellite Pour l'Observation de la Terre) image and selected by a random number generator, resulting in 150 blocks for urban and 150 for suburban areas, respectively. Ten trees located on the street-side of each block were randomly chosen and sampled, resulting in the 3000 trees analyzed. On the other hand, considering the difficulties in collecting data from secondary and minor branches of the tallest trees, and only for these measurements, 200 randomly selected trees were sampled. These sampled trees were located 100 in the urban area and 100 in the suburban area. Information about urban and suburban surface and the total tree coverage (only for street-side trees) were measured from a SPOT satellite image (April 2015) at 1:25000 scale, obtained from USGS GLoVis (USGS Global Visualization Viewer, U.S. Geological Service; http://glovis.usgs.gov), using the QGIS (Quantum Geographic Information System) 2.14 software. The stem diameter at breast height (dbh) was measured at 140 cm. Diameter and length of primary and secondary branches together with the total number of primary and secondary branches were recorded for each tree. Crown diameter (major and minor) and height of crown were also measured in the 3000 trees. The collected morphometric data allowed the definition of the average size of *Morus alba* trees. As deciduous trees drop their leaves annually, the biomass of small branches and foliar biomass was also recorded. For the small branches quantification, the tree crown was divided into quarters, all branches of one quarter of the tree were counted, and this data was multiplied by four, giving an approximation of the total small branches per tree. During sampling, all trees with strongly modified physiognomy were avoided. The dry weights of the stem and branches were calculated using 400 wood slices of different sizes. Each slice was clearly identified, and the diameter together with the height of the slices was measured. The samples were dried in an oven at 105 °C until constant weight was reached. The volume of each sample was estimated using the ellipsoid equation ($V = 3.14^{*} R^{*}r^{*}h^{*}1.33$), and the relationship between volume and dry weight was analyzed from a linear regression model [69]. The volume of the stem and the primary and secondary branches was estimated using the cylinder volume equation ($V = 3.14^{*}r^{2*}h$). The mean values were compared with multivariate analysis of variance (MANOVA) ($\alpha = 0.05$) using the INFOSTAT [104] software.

The foliar dry matter per tree was estimated from the volume–dry weight relationship. Four foliar samples for each of the 3000 trees were taken, two from the edge of the crown (external) and another two closer to the stem (internal). To collect the leaves a metallic rectangular sampler of 2500 cm^2 area was raised through the crown, collecting all leaves and portions of the leaves that were placed into the sampler. Collected leaves were dried in oven at 60 °C to constant weight. Internal and external leaf biomass was compared with analysis of variance (ANOVA) using INFOSTAT [104]. Crown volume was estimated using the ellipsoid formula. The functional relationship between biomass and volume was determined through a linear regression analysis ($\alpha = 0.01$).

The equation that predicts underground dry matter was converted to total tree biomass based on a root–shoot ratio of 0.26 according to Cairns *et al*. [70]. The carbon storage was estimated by multiplying biomass by 0.5 according to Isaev *et al*. [71]. This value was multiplied by 3.67 (ratio of the atomic weight of CO_2 to C) to estimate the weight of stored CO_2.

To estimate the carbon stored by trees from urban and suburban areas of Mendoza, the total carbon storage was divided by the total city forest coverage, determining carbon density per unit of tree coverage (t C/m^2 coverage). The mean carbon value was multiplied by the total urban *Morus alba* coverage.

Results and discussion

In this paper, a surface of 9688 ha was analyzed, being 2970 ha for the urban area and 6718 ha for the suburban. From 10 years of field data the average *M. alba* tree coverage was 50 m^2, and considering the area effectively forested and that this species represents 70–80% of the tree cover, its estimated coverage was 272 ha in urban and 625 ha in suburban areas.

The multiple equations used for individual diametric classes (stem, primary and secondary branches) were combined to obtain one predictive equation, which produced a result 2% less than employing individual formulas. The obtained equation was $DM = 0.656 + (0.673 \times \text{volume})$. Differences in dry matter were found among primary, secondary and minor branches.

The height of the crown proved to be the best estimator of crown volume ($r^2 = 0.79$, $p < 0.01$), the equation being as follows: Crown volume = $-$ 183,323 + (52,612 × crown height). Internal and external leaf dry matter does not differ statistically. Considering the total dry matter, all parts of the tree were statistically different between urban and suburban areas (Table 1). Tree dry matter was partitioned with similar values in the urban

Table 1. Dry matter (DM) contents (t) per complete tree.

	Urban	Suburban
Trunk	0.24	0.16
Primary branches	0.43	0.34
Secondary branches	0.03	0.04
Twigs	0.0014	0.0009
Leaves	0.021	0.019
Root	0.18	0.13
Total DM	0.90	0.69

Table 2. **Carbon stored (t) by *Morus alba* trees in the urban and suburban areas of Mendoza city.**

	Stem	Primary branches	Secondary branches	Leaves	Twigs	Root (adjusted 0.26)	Total carbon (aboveground)	Total carbon (tree)
Urban	0.12	0.21	0.015	0.010	0.0007	0.09	0.355	0.445
Suburban	0.08	0.17	0.02	0.009	0.0004	0.065	0.279	0.344

and suburban environment: crown 53%, stem 25%, root 20%, and leaf 2%. The values of dry matter distribution herein are similar to those obtained by Nowak [72] for the urban forest in Oakland (California, USA).

Carbon storage for Morus alba

Carbon stored in the foliage of internal and external parts of the crown does not show statistical differences. The total carbon storage differences for each part of the tree were analyzed for urban and suburban areas, and the results are shown in Table 2.

Considering the total coverage of *M. alba*, the urban area accumulates 180 tonnes DM/ha and the suburban area accumulates 138 tonnes DM/ha, or 24,208 tonnes and 43,00 tonnes of carbon, respectively, from which 544.6 tonnes (1998.6 tonnes CO_2) and 1,122.3 tonnes (4118.8 tonnes CO_2) are annually removed by leaves. Relevant quantities of CO_2, considering the 13,000 t/year, are released by public and private transportation in Mendoza [73,74]. On the other hand, obtained data of carbon stored are significantly higher than the storage, for example, by the native *Larrea* sp. shrub in the piedmont and flatland with 1.757 t/ha and 9.593 t/ha, respectively [54].

The average carbon stored in the urban and suburban areas of Mendoza city is in the range of the values published by different authors in some cities of the United States, Europe, and Asia [10,25,26,31,32,43,44]. More recently, Mattson *et al*. [15] studied trees located in home gardens of a dry zone of Sri Lanka, suggesting that the carbon estimations reflect differences due to management practices, showing a wide range of carbon values between 1 and 56 t/ha, and a mean aboveground biomass stock of 13 t/ha.

The carbon storage in the urban forest of Syracuse, United States, increased up to 165,900 tonnes in 2009, resulting in carbon storage of 58.33 tonnes in residential areas, 41.58 tonnes in green spaces and almost a 50% percent lower value (28.25 t C) in non-forested areas [23]. Studies made in a city of Germany suggested that the stored carbon is heterogeneous across different land-cover areas [28].

The total amount of carbon stored in trees of Mendoza city located in the suburban area was minor compared to that of other cities. Trees in the suburban area are younger and with trunks of minor size compared to those located in the urban sector. The carbon stored in primary branches with higher values in the urban area is a consequence of the intense and periodic pruning to avoid interference with services such as electricity or cable, removing principally the secondary and minor branches. On the other hand, important amounts of carbon are removed yearly (especially by leaves) and collected into vast solid repositories outside of the city. The ecosystem services provided by an urban forest are directly related to the forest structure within the context of local environmental conditions; changing the forest structure through natural or human processes will affect ecosystem services. Long-term monitoring of urban forests can provide valuable information on how urban forest structure and ecosystem services are changing through time [23].

Conclusions

Carbon results in an important pollutant being present in the Mendoza urban ecosystem. The carbon stored in the urban and suburban areas of this city for the dominant tree (*M. alba*), compared to natural shrublands, evidences the relevance of the urban forestry for carbon storage.

The accumulated carbon values found are clear evidence of the necessity of preservation and conservation tasks to improve and contribute to the management practices of the urban forests, especially in cities located in drylands.

In addition, the development of more exact tree biomass equations is essential to estimate tree decomposition rate and to study the influence of urban soils on carbon storage for a better understanding of carbon cycling in this urban public forest. A management plan for public forest and a better knowledge of the biological processes in urban ecosystems, such as the carbon storage, are necessary.

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ORCID

Eduardo Martínez Carretero http://orcid.org/0000-0001-5670-4945

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