Flora 241 (2018) 35–45

Contents lists available at ScienceDirect

Flora

journal homepage: www.elsevier.com/locate/flora

Above- and below-ground biomass and allometry of *Moringa oleifera* and *Ricinus communis* grown in a compacted clayey soil

Ofelia Andrea Valdés-Rodríguez[a,*], Filippo Giadrossich[b], Arturo Pérez-Vázquez[c], Juan Carlos Moreno-Seceña[d]

[a] Colegio de Veracruz, Carrillo Puerto 26, Xalapa, Ver., CP. 91000, Mexico
[b] Dipartimento di Agraria, Università di Sassari, viale Italia 39, 07100 Sassari, Italy
[c] Colegio de Postgraduados, Campus Veracruz, 26.5 carretera federal Veracruz-Xalapa, Rancho Tepetates, Municipio de Manlio F. Altamirano, Veracruz, Mexico
[d] Instituto Tecnológico de Xalapa, Secc. 5a Reserva Territorial SN, Xalapa, Ver., CP. 91096, Mexico

A R T I C L E I N F O

Edited by Hermann Heilmeier

Keywords:
Plant morphology
Biomass allocation
Root volume
Root distribution
Root models
Soil compaction
Oil crops

A B S T R A C T

Moringa oleifera Lam. and *Ricinus communis* L. are species known for their ability to survive in different environments; however, analyses of their capabilities to develop and explore clayed compacted soils are still not well covered. This study compares above- and below-ground development of *Ricinus* and *Moringa* in a subtropical compacted clayey soil. Seedlings of each species were germinated and monitored in field conditions during 12 months. After this period, 10 plants of each species were excavated to measure shoot *versus* root data along the soil profile. With the correlated data, we developed a model for each species to estimate root biomass and volume distribution. Results showed that *Ricinus* became a mature plant in a quarter of time than *Moringa*, but *Moringa* had 18% higher survival rate. Root volume distribution of both species was fitted by logistic and exponential models with 90% of their volume within the first 40 cm^3 around the tap root. Average lateral root inclination was $-22°$ for *Moringa* and $-36°$ for *Ricinus*. Root volume in *Moringa* was 5.5 times higher than that of *Ricinus*. The product of stem base by the crown-width for *Moringa* and stem base by plant-height for *Ricinus* were the best estimators ($R^2 > 0.9$) for below-ground biomass. We conclude that both species were capable to grow and reproduce in a clayey and compacted soil; nevertheless, *Ricinus* developed 16% more oblique and sinker roots to maintain its denser crown, while *Moringa* took advantage of the mass of its dense trunk and roots for a shallower exploration.

1. Introduction

Moringa oleifera Lam. (*Moringa*) and *Ricinus communis* L. (*Ricinus*) are fast-growing and multi-purpose plants cultivated in tropical, subtropical, and hot temperate climate such as Mexico, Brazil, India, southeast Asia and Africa (Olson and Fahey, 2011; Severino and Auld, 2013). Their seeds can contain up to 30–60% of oil, making these plants very productive sources for biofuel production (Clixoo, 2016; Kibazohi and Sangwan, 2011).

Roots of *Ricinus* and *Moringa* are suitable for remediation of heavy metal contaminated soils. *Ricinus* roots absorb efficiently cadmium (Cd) with a bioaccumulation factor of 65 with respect to the soil contaminant concentration (Bauddh and Singh, 2012). *Moringa* is suitable for phytoextraction with significant reduction of iron, zinc, and lead accumulating mainly in the root system (Amadi and Tanee, 2014). Besides these properties, roots improve soil physical characteristics such as permeability, organic content, drainage, and can increase soil cohesion through root tensile strength and resistance to bending and/or compression (Giadrossich et al., 2016; Schwarz et al., 2012; Veylon et al., 2015; Giadrossich et al., 2017). Mycorrhizal hyphae associated with roots improve soil aggregation at different scales (micro- and macro-aggregates), and consequently improve the soil structure (Rillig and Mummey, 2006). Recent studies show that *Ricinus* increases soil contents of total N, organic C and microbial biomass, and can be considered a suitable long-term plant for conservation and sustainable management in tropical and subtropical soils (Alguacil et al., 2012).

Moringa and *Ricinus* are known by their capacities to survive under dry climates and poor soils (Olson and Rosell, 2006; Schurr et al., 2000). However, each species has developed a different structural morphology to cope with the challenges of arid environments. For both species, clay soils are not recommended due to their high capacity of water retention and poor aeration, which may cause limitation of the

* Corresponding author.
E-mail addresses: andrea.valdes@gmail.com (O.A. Valdés-Rodríguez), fgiadrossich@uniss.it (F. Giadrossich), parturo@colpos.mx (A. Pérez-Vázquez), juancarlos.moreno@itsx.edu.mx (J.C. Moreno-Seceña).

https://doi.org/10.1016/j.flora.2018.02.002
Received 5 September 2017; Received in revised form 29 January 2018; Accepted 6 February 2018
Available online 07 February 2018
0367-2530/

root system development and root rot problems (Pérez et al., 2010b; Solís et al., 2011). However, world-wide clayey soils (Vertisols; Soil Survey Staff, 1999) occupy around 335 million hectares, covering vast areas of Mexico, India, East Africa and South America, where an estimated 150 million hectares are potential cropland (NRAE, 2001). In these areas the cultivation of biomass and bioenergy crops are becoming even more important for their economy. Nonetheless, detailed information describing root architecture and models for roots and shoots of *Moringa* and *Ricinus* growing in clay soils is missing. Clayey and compacted soils are difficult to penetrate and root systems growing in these types of soils are not easy to excavate and study, due to the hardness of the soil and the difficulties of preserving root integrity during the uprooting process. Therefore, the objectives of this work were to: 1) determine relationships between above- and below-ground variables of *Ricinus communis* and *Moringa oleifera* in order to understand and compare their capabilities to grow under a compacted clayed soil, and 2) estimate below-ground volume and root distribution in relation to above-ground variables.

2. Materials and methods

2.1. Plant description

Moringa is a tree which usually has a straight long trunk (20–40 cm in diameter and 10–12 m height) with a spreading, open crown of drooping, fragile branches and feathery foliage of tripinnate leaves (Parrotta, 2009). *Ricinus* is a perennial shrub which can reach the size of a small tree, with the stem 7.5–15 cm in diameter, and up to 10 m height in the tropics; it grows several branches and large palmately lobed leaves which may be over 15–45 cm long (Duke, 1983). Below-ground differences in morphology are also remarkable. *Moringa* produces a swollen tuberous tap root and very sparse lateral roots (Parrotta, 2009). *Ricinus* has a large stem-root base with a long tap root and several highly branched long sinkers with many fine roots (Ghestem et al., 2014).

2.2. Study site

The experimental plantation was located in the municipality of Manlio Fabio Altamirano, State of Veracruz (19° 16′ 00″ N, 96° 16′ 32″ W, 16 m asl). According to the Köppen-Geiger climate classification, the climate of the study site is Tropical savanna (Aw). The region is characterized by monthly mean temperatures above 18 °C in every month of the year, rains during the summer and mild dry winters (December to March) with the driest month (January, February or March) having precipitation less than 60 mm and less than 4% of the total annual precipitation of 1200 mm (García, 2004). During the 12 month experimental period, the weather station recorded an average (± standard deviation SD) maximum temperature of 30.5 ± 3.3 °C, minimum of 21 ± 2.7 °C, humidity 78 ± 5.9%, and cumulative annual precipitation of 1298 mm (Fig. 1a,b).

2.3. Sowing and growth conditions

Seeds of *Ricinus* and *Moringa* belonging to mother plants growing naturalized at the Mexican plateau were selected for their healthy appearance and weight. Before sowing, seeds were weighed and measured. Average (± SD) *Ricinus* seeds were 14.7 ± 0.3 mm long, 6.7 ± 0.2 mm wide, 478.8 ± 29.0 mg in weight and 55% in oil content; seeds of *Moringa* were 12.9 ± 1.1 mm long, 11.4 mm ± 0.8 mm wide, 268.9 ± 42.9 mg in weight and 34% in oil content. The seeds of both species were sown during the rainy season (September 1st), to avoid irrigation demand. The land, an area of 32 m × 36 m, was previously plowed. Three seeds were sown in 3.0 cm deep holes spaced at a distance of 2.0 m in the row and 6.0 m in between rows. The species were intercropped between rows (one row of *Ricinus* was followed by one row of *Moringa*). Seven days after the emergence the excess of plants were removed from each planting site, leaving only the largest plant (38 seedlings per species remained). The land was weeded every time the weed exceeded 20 cm in height and only during the rainy season. No fertilizers or pesticides were used.

2.4. Above-ground measurements

Fifty days after sowing, the surviving 38 plants of *Moringa* and 32 plants of *Ricinus* were labeled. For each of them and until the plants were 12 months old, we measured monthly survival, plant height (as the length from the base to the highest leaf tip), root collar diameter (RCD), number of branches, maximum crown spread (CW), number of leaves and average leaf area, which has been estimated as the average of six mature leaves from the first and second branch that were measured by length and width, and whose area was obtained as a product of 0.55 × width × length (Jain and Misra, 1966) for *Ricinus*. For *Moringa* each sampled leaf was measured in length and width, and after this, the leaf was scanned, and processed with the program ImageJ v.1.48, where it was escalated to the measured width and length values and, with the help of Analyze functions provided by the software, the area of the compound leaf was estimated.

2.5. Soil profile

At the end of the experiment, in the middle of the field, and between a row of *Ricinus* and *Moringa,* the soil profile was exposed and the depth of each soil horizon was visually identified and measured. One sample per each horizon was taken and labeled to perform analysis of soil texture (Bouyoucos, 1962), pH in an aqueous extract (soil: water relationship 2:1; electronic potentiometer), electric conductivity in saturation extract (EC meter), bulk density (clod method), organic matter (Walkley-Black method), N (Kjeldahl method), P (Olsen-Kitson-Mellon method), C and Mg (in saturation extract by the Official Mexican Standard; SEMARNAT, 2002). Each horizon was named according to the USDA classification (Soil Survey Staff, 1999).

The soil texture was clay in the horizon Ap, sandy-loam-clay in the horizon Bw, and Sandy-clay in the horizon C1 (Supplementary Table S1). The site was used in the past for agricultural purposes and showed a very firm platy structure between the horizons B and C. The highest nutrient levels were found in the A horizon. This soil was classified as Vertisol (Soil Survey Staff, 2014).

2.6. Calculations

2.6.1. Growth rate estimation

Using measurements of height and RCD, the daily mean growth rate (GR) was estimated according to Eq. (1):

$$GR = \frac{M_2 - M_1}{date_2 - date_1}, \tag{1}$$

where M_2 is the measurement at $date_2$ and M_1 is the measurement at $date_1$.

2.6.2. Root structure

In order to obtain the coarse root distribution, 10 plants per species were selected 12 months after planting, considering average size (too large or too small were discarded); from each plant, the stem was cut at the base and roots were carefully excavated with the help of small rakes, mattocks, shovels and bare hands. During the excavation of the roots, we took pictures to register their original position. Due to the hardness of the soil, some roots were broken. In this case, the remaining part was excavated as far as possible, and then it was glued to its origin for a complete measurement. Once the system was completely excavated, it was mounted over a rigid structure where, with the help of the photos taken while the roots were in their original place, a caliper, a