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Original Paper

Leaf, Stem and Root Biomass of Artemisia Ordosica in the Semiarid Inland Dunes

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Abstract

Previous research has established A. ordosica as the dominant shrub species in the Mu Us sandy grasslands of Northwestern China. To further confirm its dominance, we used the dominance index equation (RC+RD+RH)/3 and performed on-field data collection to calculate the actual dominance of A. ordoscia based on relative coverage, relative density, and relative height, compared to all other shrub and grass species within the ecosystem. The result confirmed A. ordosica's dominant role, suggesting it plays a crucial role in maintaining the stability of the region's ecosystem.

To accurately estimate A. ordosica's biomass is important, as ecosystem functions such as carbon and nutrient sequestration can be assessed, and the health, abiotic, and biotic change within the ecosystem could be closely monitored. By estimating biomass, researchers can also evaluate the sustainability of the ecosystem, and policymakers can make informed management decisions based on the data. Totally, the 30 individuals of A. ordosica with different canopy sizes were excavated, and their components including leaf, stem/branches (new branches versus old branches), and root (fine roots versus coarse roots) organs. The biomass estimation model was created using the least squares regression line of scatterplots. The scatterplot includes data on the canopy area and the compartment biomass of the excavated A. ordosica individual. All equations demonstrate strong, positive, correlation (r) values with the actual data and have P<0.001, meaning the biomass can be predicted by easily measured canopy area. This biomass estimation model enables quicker data collection, requiring only the canopy area of the plant species without the need to excavate, compartmentalize, and weigh individual plants.

Keywords

A. Ordosica, Dominance index, Carbon and nutrient sequestration, Biomass estimation model, Canopy area

1. Introduction

Biomass calculation often requires sophisticated processes with the need to excavate individual plants from the soil for calculation. A biomass estimation model has the capacity to yield accurate results without the need for that. It increases the efficiency of the process, allowing the resources and time required to be shortened.

Common methods for biomass estimation include direct method, allometric equation, and remote sensing. The direct method involves cutting vegetation and plants, drying it, and weighing the biomass directly. Although the direct method is the most accurate method for estimating biomass, it is an extremely time-consuming and destructive method. It is also generally limited to small areas and sample sizes (Ketterings et al., 2001).

The allometric equation method requires the creation of equations using statistical information collected on measurable plant attributes such as (leaves, branches, height, weight, area, roots, etc). It is mostly used for plants and could be efficient in calculating biomass as it only requires a few attributes to calculate the whole thing. However, it is too species-specific and region-specific, meaning it could only accurately estimate a single species in a single type of ecosystem.

Remote sensing methods require the use of satellite, aerial imagery, and drones to gather information on the plant colonies' vegetation cover, height, and other compartments for biomass measurements. Although this method ensures large areas can be monitored and allows frequent updates on the situation, the estimation method is associated with various errors and uncertainties. Studies from (Chen et al., 2000; Heath & Smith, 2000; Mascaro et al., 2011) have all suggested that the relative errors of this estimation method could vary from 5% to 30%, depending on ecosystem, topographic, and data or spatial resolutions, etc. (Lu et al., 2014). Moreover, there are three main challenges regarding the accuracy and uncertainty of remote sensing-derived biomass estimation. 1. Obtain field observations from sample plots. 2. Find major factors influencing biomass estimation performance. 3. Account for spatial variability in the estimation accuracy (Lu et al., 2014).

The method used for biomass estimation in this research is the allometric equation. Despite its disadvantage of high specificity, the only information we need to estimate the overall health of the ecosystem and carbon sequestration ability is the information regarding A. ordosica in Mu Us sandy grasslands of Northwestern China. This weakens the disadvantage of species-specificity and ecosystem-specificity. A. ordosica biomass alone would inform substantial information about the ecosystem.

Introductory information regarding A.orodsica:

A. orodsica has been used as a traditional Chinese/Mongolian medicine for treating certain inflammatory ailments (Shi et al., 2022). Its alcohol extract (AOAE) has been tested by (Shi et al., 2022) and results suggest AOAE's capacity to enhance immunity, inhibit inflammation, and could be used as a potential novel feed additive with applications in treating inflammation-related diseases and bacterial infection in broilers. Moreover, A. orodsica's essential oil showed strong antibacterial activity against species such as Staphylococcus aureus, Salmonella abony, and Escherichia coli, indicating its notable antibacterial properties and antioxidant capability to be used as a natural ingredient and substitute for antibiotics in the animal feed industry(Jize Zhang et al.). A. ordosica is considered a shrub species within the Mu Us sandy grassland ecosystem. The above-ground part of the shrub has a well-branched stem and a low, dense crown, which provides wind and sand resistance as well as soil and water conservation. Due to shrub species' deep and extensive root systems, A. ordosica can absorb large amounts of water from a wide range of sand bodies. Shrubs ensure a good water balance by forming scrubby dunes and distributing them at a suitably sparse density. They are an important part of natural grasslands and have a strong regenerative capacity and excellent sand fixation properties as forage plants. The A. ordosica community is considered to be the main natural grazing land in the area and has a good sand fixation function. They are of paramount importance and significance in protecting the ecological environment and supporting the economy of grassland husbandry. (Zhang.)

Dominance of A.orodsica:

A. ordosica's dominance index within the semi-arid environment Mu Us sandy grassland ecosystem was calculated and compared, and the result justified the dominance of A. ordosica.

A. ordosica is the most widely distributed plant species in the sandy plant communities of the Maowusu Sandland (Zhang, 1994), making it one of the dominant species in the region. Dominant species like A. ordosica play a particularly critical role in the ecosystem. With a few subdominant species contributing significantly less to the overall biomass, carbon storage, or ecosystem health, it is justifiable to focus primarily on *A. ordosica*.

As a dominant species, A. ordosica is the controller of ecosystem function (Melinda D. Smith & Alan K. Knapp), suggesting that they have substantial influence on nutrient flow, meaning its biomass is closely tied to the overall productivity and nutrient amount present in the ecosystem. Dominant species in natural communities contribute substantially to conferring short-term resistance to reductions in ecosystem function, such as the loss of rare and uncommon species.

Thus, dominant species impart short-term stability to ecosystems experiencing non-random patterns of species loss (Melinda D. Smith & Alan K. Knapp).

The health of A. ordosica reflects the health of the ecosystem. *A. ordosica*, with its dominant role, suggests it is one of the most well-adapted plants. Any decline in *A. ordosica*'s health could signal significant changes in the environment, such as climate change, extended periods of droughts, or land degradation. Changes in *A. ordosica*'s biomass would be most noticeable, as stress on the ecosystem could diminish its dominant role, making the environment no longer suitable for its growth. Therefore, factors such as rainfall, temperature, and soil nutrient amount could be compared with previously recorded data to identify the causes of such ecological shifts. Given *A. ordosica*'s important role and sheer indications through biomass change, focusing on it alone could yield valuable insights regarding the ecosystem.

2. Material and Method

2.1 Study Site

A. ordoscia is a semi-shrubby species native to the arid and semiarid regions of northern China, particularly prevalent in Inner Mongolia. The study and field experimentation are located near Ordos Sandland Ecological Research Station (39°29'37.6" N, 110°11'9.4" E) in Yijinhuoluo County, Ordos City, Inner Mongolia, China. The research station has a multi-function building of 2000 square meters and an experimental area of 2133,33 square meters. (https://deims.org/683db6fd-cc96-4698-bcce-2fe015948a87)

The study site's elevation ranges from 1,000m to 1,300m. The average annual temperature was around 7.4–9.0 °C, annual relative humidity was 47% − 51%, annual mean wind speed was 1.9–2.6 m s^{-1}, annual sunshine hour was 2674–3023 h, pan evaporation of 1800–2500 mm (Sun et al., 2021b), average annual precipitation was 250-400mm, with the most rain occurring in summer. The groundwater table in the study area varies between 2 to 17 meters, low occur during summer, and high levels during spring. Seasonal frozen periods range from January to March and from November to December.

2.2 Determination of Dominance of A. Ordosica

A. Ordosica is a dominant species in the region of Ordos plateau at different stages of vegetation succession (Liu, 1996). However, for clearer reference, we will examine A. ordosica's importance by using the dominance index, which is commonly used in plant community research. The formulae of the dominance index is as follows (Li et al., 2017): DI = (RC + RH + RD)/3, where RC, RH, and RD denote relative cover, relative height, and relative density, respectively. The population number for shrub species was divided by 25 to match the unit of herbaceous species. (Both in number/square meter)

We choose six quadrats along a transect from the inter-dune lowland to the top of the dune, and the distance between adjacent plots is 10 m. For the shrub layer, the quadrat size is set as 5 m x 5 m. The coverage of shrub species was first estimated by eye, and the height of each A. ordosica was measured individually, while for other shrub species, 5 individuals were randomly selected. The average height, maximum, and minimum height of individuals from each shrub species were recorded and the total number of individuals for each respective species was counted. At the center of the shrub quadrat, the small quadrat (1m × 1m) is used for the herbaceous plant community investigation. For herbaceous plant species, the coverage of each species is estimated (percent occupied in the whole quadrat), the number of individuals for each species is counted, and 5 individuals from each species were randomly selected to give the average, and min, and max height.

2.3 Data Collection for Individual A. Ordosica:

First, individual A. Ordosica were randomly selected near the study site and excavated.

Before excavation, the crown dimensions (where CL is the crown length at its widest point, and CW is the perpendicular crown extent at the same height) were measured using a tape ruler for each individual plant. The crown area (CA, cm^2) was calculated using the equation CA = p(CL/2)(CW/2) (Sah et al., 2004).

The surrounding of the plant intended for excavation was cleared, including any other organisms and debris. Next, tools such as shovel and chisel were used to carefully clear the topsoil, then hands were used to gently clear soil around the roots, until all roots, both coarse and fine were excavated out and preserved with integrity. Any broken roots were collected and later measured together.

Once the entire plant is taken out, it will be moved to the lab to be cleaned and prepared for compartmentation.

The compartmentation process will separate A. Ordosica into five components:

(1) Leaves - green in color and have a unique scent,

(2) New branches - flexible and light in color,

(3) Old branches - brittle and dull in color,

(4) Coarse roots - root diameter > 2mm,

(5) Fine roots - root diameter <= 2 mm.

After each component is separated, they are weighed on a weight tray and the fresh biomass* for each will be recorded. Each component is put into paper envelopes and marked, then placed into a lab drying oven at 70°C for 48 hours before being taken out where the dry mass would be subsequently recorded.

Aboveground biomass components (Leaves, New branches, Old branches) and belowground biomass components (Coarse roots, Fine roots) were aggregated based on the five components.

2.4 Statistical Analysis

All analyses were used in in R4.3.0 (R Core Team, 2023) and scatterplots were conducted to demonstrate the relationship between the canopy and each compartment's biomass and the relationship between different compartments' biomass.

The data for the canopy area and each compartment was put into a scatterplot where the canopy area is the x-value (explanatory variable), and the compartment's biomass is the y-value (response variable). A regression line was then calculated and represents the relationship between the variables. It gives an equation that allows the y value to be predicted using the x value. The significant level for all statistical tests was set at $P < 0.05$.

3. Results

3.1 Equation in Overall Biomass Calculation

By gathering information for the above- and below-ground biomass of individual *A. ordosica* and utilizing the recorded canopy area, a predictive equation was established to estimate the biomass components based on the canopy area (Figure 1). The relationships between canopy area and aboveground biomass, belowground biomass, and total biomass were found to be highly significant ($P < 0.001$). The least-squares regression analysis demonstrated a strong positive linear trend, with each increase in canopy area corresponding to an increase in predicted biomass, indicating a positive association between variables.

3.2 Equation in Compartment Biomass Calculation

By gathering information for the new branch, old branch, fine root, and coarse root biomass of individual *A. ordosica* and utilizing the recorded canopy area, a predictive equation was established to estimate the biomass components based on the canopy area (Figure 2, 3). The relationships between canopy area and new branch, old branch, fine root, and coarse root biomass were found to be highly significant ($P < 0.001$). The least-squares regression analysis demonstrated a strong positive linear trend, with each increase in canopy area corresponding to an increase in the predicted compartment's biomass, indicating a positive association between variables.

3.3 Equation in Leaf Biomass Calculation

The leaf biomass estimation model uses aboveground biomass and total biomass rather than canopy area as explanatory variables to predict the biomass of the leaf (Figure 5). The relationship between above ground biomass and total biomass with leaf biomass is still highly significant ($P < 0.001$). The least-squares regression analysis also demonstrated a similarly strong positive linear trend, with each increase in above ground or total biomass corresponding to an increase in the predicted leaf biomass, indicating a positive association between variables.

3.4 Exception to the Model Equation

Following the collection of new and old branches, fine root and coarse root, and aboveground and belowground biomass, a statistical analysis was conducted to investigate the ratios for each group, using canopy area as an explanatory variable (Figure 4). The analysis revealed a significant relationship ($P < 0.05$) between canopy area and both the ratio of new to old branches and the root-to-shoot biomass. In contrast, no significant relationship ($P > 0.05$) was found between canopy area and the ratio of fine to coarse roots.

Canopy vs. leaves

Canopy vs. New branches

r^2=0.73; y=-3.93+51.8x; P<0.001

Canopy vs. Old branches

r^2=0.85; y=-113+453x; P<0.001

Canopy vs. Coarse roots

r^2=0.75; y=-3.34+71.4x; P<0.001

Canopy vs. Fine roots

r^2=0.67; y=-0.339+23.1x; P<0.001

4. Discussion

Estimating A. ordosica's biomass based on the canopy area provides a more efficient and cost-optimizing method. The Canopy area(m^2) to Aboveground biomass(g) is graphed as a scatterplot demonstrating a coefficient of determination (r^2) of 0.90 and a correlation (r) at around 0.95. The canopy area is the x-value, or explanatory variable while the above-ground biomass is the y-value, or response variable. A coefficient of determination at 0.90 means around 90% of the variability in the aboveground biomass is accounted for by the least squares regression line with x=canopy area. A correlation at around 0.95 suggests there is an extremely strong, positive, linear relationship between canopy area and aboveground biomass; There is a small residual between the actual amount of above-ground biomass and the predicted amount of biomass.

The Canopy area(m^2) to belowground biomass(g) is also graphed as a scatterplot demonstrating a coefficient of determination of 0.80 and a correlation at around 0.89. The canopy area is the x-value, or explanatory variable while the below-ground biomass is the y-value, or response variable. A coefficient of determination at 0.80 means that around 80% of the variability in the belowground biomass is accounted for by the least squares regression line with an x=canopy area. A correlation at around 0.89 suggests there is an extremely strong, positive, linear relationship between canopy area and belowground biomass; There is a small residual between the actual amount of below-ground biomass and the predicted amount of biomass.

Besides using canopy area to estimate biomass, setting the volume(cm^3) as an explanatory variable to estimate the response variable of Aboveground biomass(g) is also feasible. The scatterplot demonstrates a coefficient of determination of 0.78 and thus, a correlation of around 0.88. A coefficient of determination at 0.78 means around 78% of the variability in the aboveground biomass is accounted for by the least squares regression line with x=volume. A correlation at around 0.88 suggests there is an extremely strong, positive, linear relationship between volume and aboveground biomass; There is a small residual between the actual amount of aboveground biomass and the predicted amount of biomass.

All three models of canopy vs. aboveground biomass, canopy vs. belowground biomass, and volume vs. aboveground biomass demonstrate $P<0.001$, indicating that the correlation between the two variables is considered extremely significant and that this observed relationship is not due merely to chance but is likely a real effect. (Less than 0.1% probability that there is truly no relationship between variables).

Examining data collected through field experiments and analysis of the six quadrats, each shrub and grass species' relative cover, relative density, relative frequency, and relative height were calculated. Using the dominance index equation: $DI = (RC + RH + RD)/3$, A. Ordosica has the third largest dominance mean, proving it to be one of the most dominant species in the Mu Us sandy grassland ecosystem.

The relationship between fine roots vs canopy area and coarse roots vs canopy area is examined.

The Canopy area(m^2) to coarse root biomass(g) is graphed as a scatterplot demonstrating a coefficient of determination (r^2) of 0.67 and a correlation (r) at around 0.82. The canopy area is the x-value, or explanatory variable while the coarse root biomass is the y-value, or response variable. A coefficient of determination at 0.67 means around 67% of the variability in the fine root biomass is accounted for by the least squares regression line with x=canopy area. A correlation at around 0.82 suggests there is an extremely strong, positive, linear relationship between the canopy area and the coarse root biomass; There is a small residual between the actual amount of fine root biomass and the predicted amount of biomass.

The Canopy area (m^2) to fine root biomass (g) is graphed as a scatterplot demonstrating a coefficient of determination (r^2) of 0.75 and a correlation (r) at around 0.87. The canopy area is the x-value, or explanatory variable while the fine root biomass is the y-value, or response variable. A coefficient of determination at 0.75 means around 75% of the variability in the fine root biomass is accounted for by the least squares regression line with x=canopy area. A correlation at around 0.87 suggests there is an extremely strong, positive, linear relationship between the canopy area and the fine root biomass; There is a small residual between the actual amount of fine root biomass and the predicted amount of biomass.

Fine roots generally obtain nutrients, oxygen, and water while coarse roots often support fine root networks, helping to transport nutrients and water or to support plant structure (Zhang & Wang, 2015; Keplin & Hüttl, 2001; Knorr et al., 2005; Tobin et al., 2007). Fine roots represent a substantial proportion of net primary productivity (Hobbie et al., 2009). Moreover, fine roots can convey the situation for the aboveground environment, soil temperature, moisture, and nutrient availability (Cheng & Bledsoe, 2002) through its seasonal variation of biomass (EISSENSTAT et al., 2000; GILL & JACKSON, 2000; Wells & Eissenstat, 2001; Anderson et al., 2003; Guo et al., 2008). One report specifically suggested that, under drought conditions, root systems will adapt to soil water stress by changing anatomical structure such as increasing absorptive capacity by reducing roots' diameter (Nikolova et al., 2020). Another report emphasized a similar idea by stating that plants react to water or nutrient deficiency through two ways: 1. quick growth of fine roots for fast water/nutrient acquisition 2. thick root production for the long-term ability to store resources(Zadworny et al. (2016, 2017), as to achieve the best growth state (Li et al., 2022). (Zhi-Shan Zhang et al.)'s research paper investigated the relationship between fine root growth and SWC(soil water content), suggesting that fine root growth was closely related to SWC, and an increase in SWC would lead to abundant propagation of fine roots and a decrease in SWC negatively affect fine root growth.

Coarse root, on the other hand, is mainly responsible for the storage of reserves, distribution of nutrients/water to the above-ground part, and providing physical support for the plant. (Zhang & Wang, 2015; Montagnoli et al., 2020).

The individual function of fine root and coarse root is established to suggest their existence serves different purposes. The model estimating fine root biomass and coarse root biomass can convey characteristics regarding the environment A. ordosica is within. Any changes in the environment would involve phenotypic plasticity (Fantozzi et al., 2024) where the fine root and coarse root biomass will alter, and their ratio would shift to indicate significant changes within the ecosystem.

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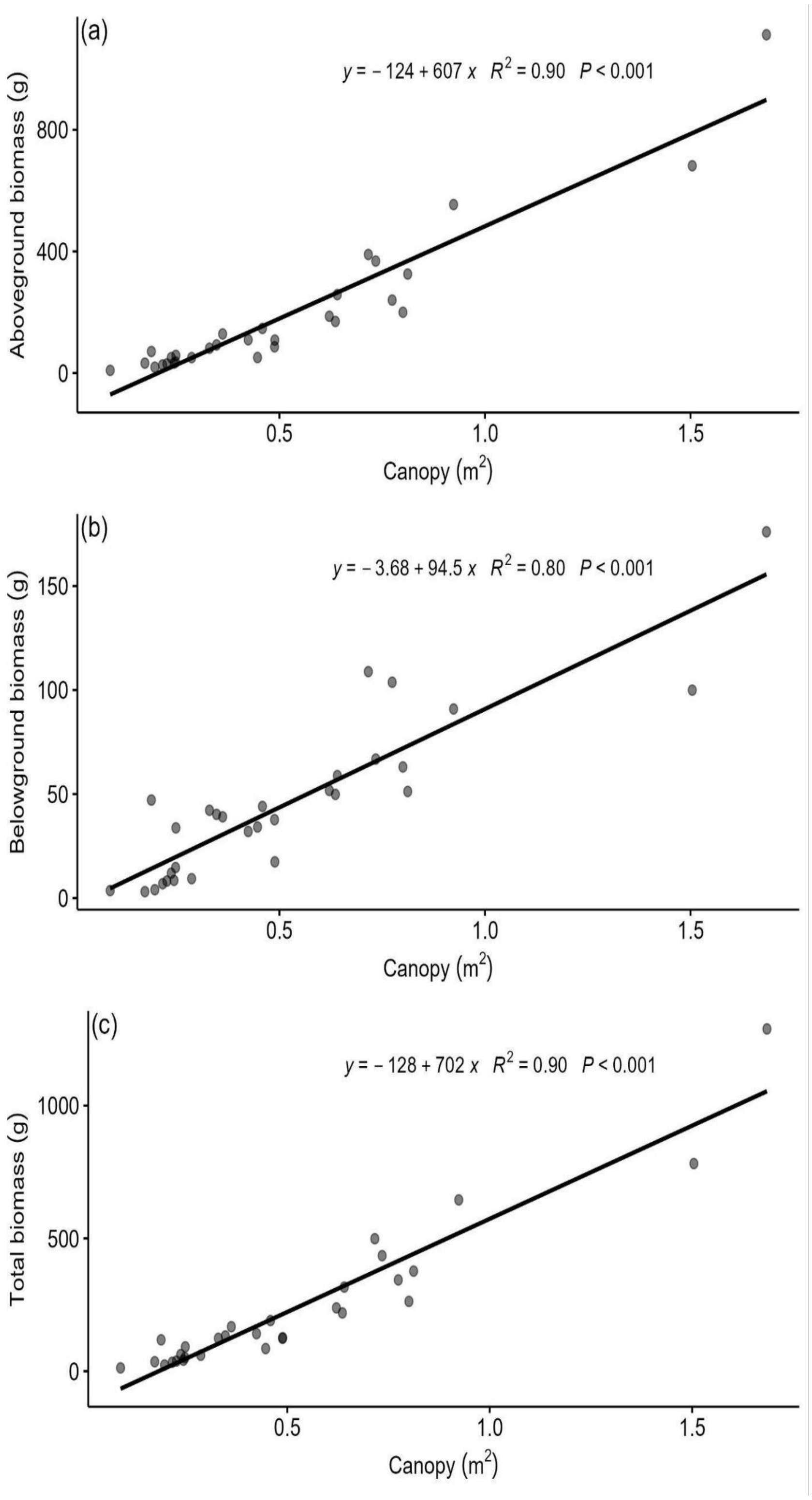

(a)
y = − 124 + 607 x R2 = 0.90 P < 0.001
Aboveground biomass (g)
0
400
800
0.5
1.0
1.5
Canopy (m2)
(b)
y = − 3.68 + 94.5 x R2 = 0.80 P < 0.001
Belowground biomass (g)
0
50
100
150
0.5
1.0
1.5
Canopy (m2)
(c)
y = − 128 + 702 x R2 = 0.90 P < 0.001
Total biomass (g)
0
500
1000
0.5
1.0
1.5
Canopy (m2)

Figure 1. Relationships of aboveground biomass, belowground biomass and total biomass of *A. ordosica* with the canopy. The solid line represents a significant relationship at *P* < 0.05.

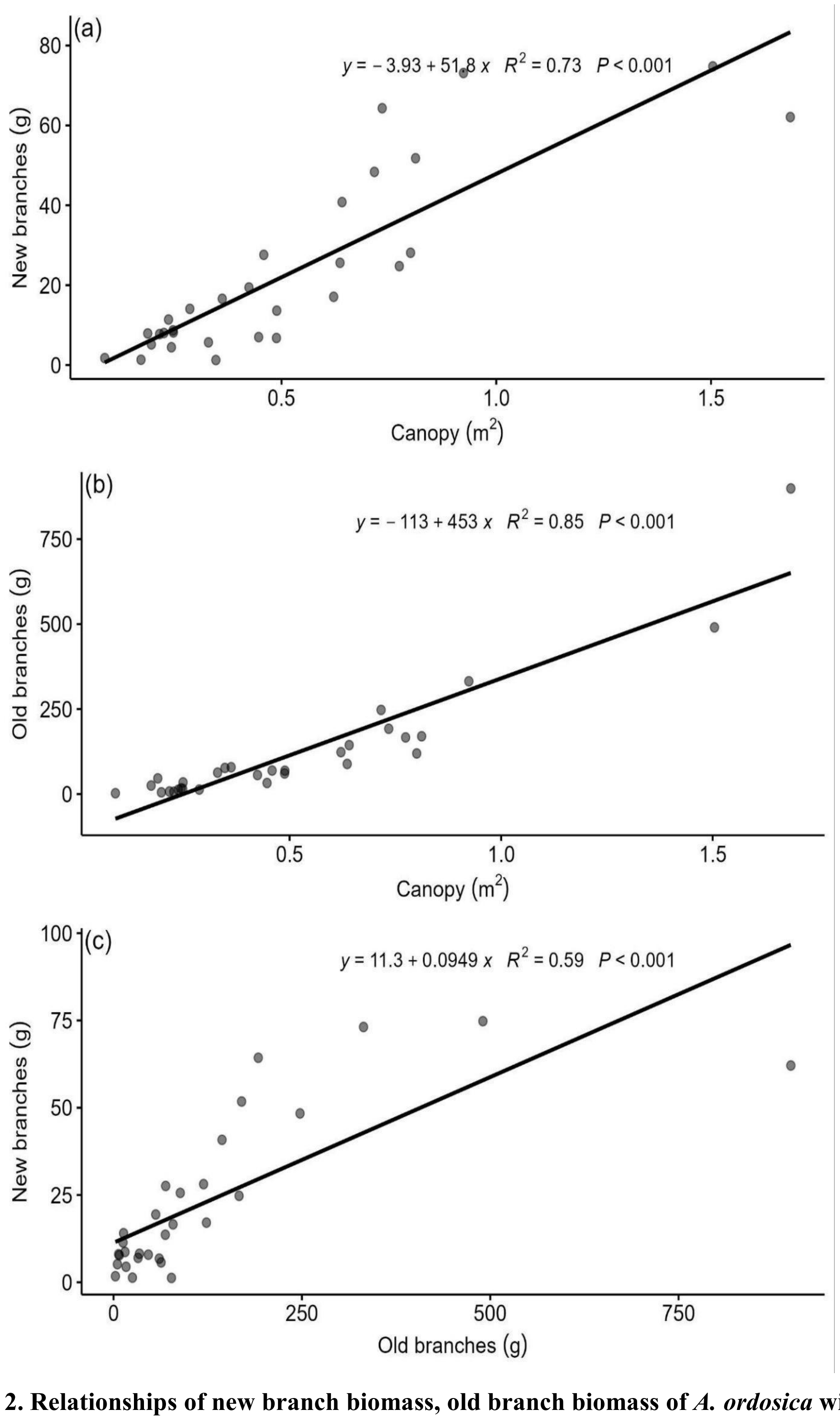

Figure 2. Relationships of new branch biomass, old branch biomass of *A. ordosica* with the canopy and the relationship new and old branch biomass of *A. ordosica*. The solid line represents a significant relationship at *P* < 0.05.

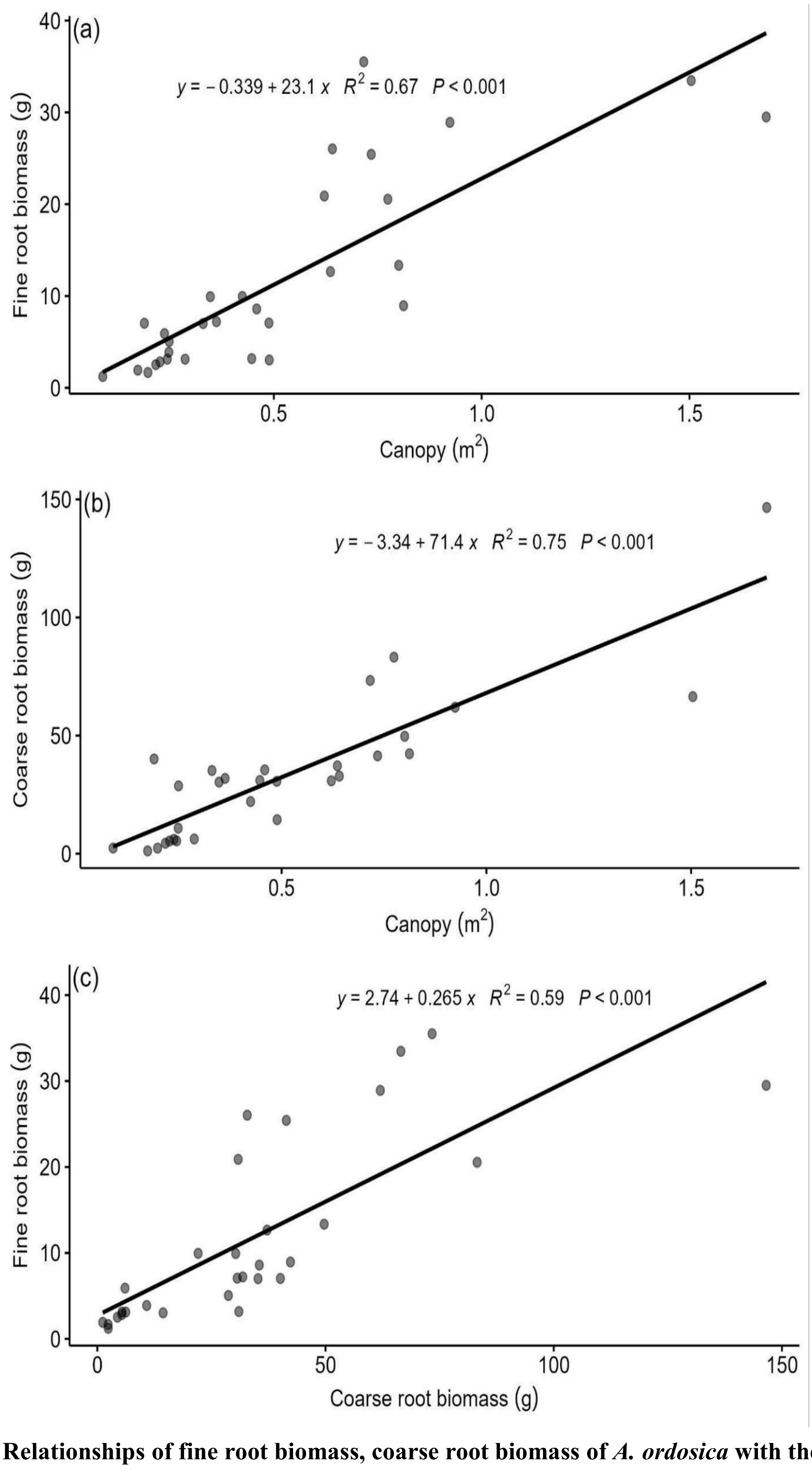

Figure 3 Relationships of fine root biomass, coarse root biomass of *A. ordosica* with the canopy and the relationship fine and coarse root biomass of *A. ordosica*. The solid line represents a significant relationship at *P* < 0.05.

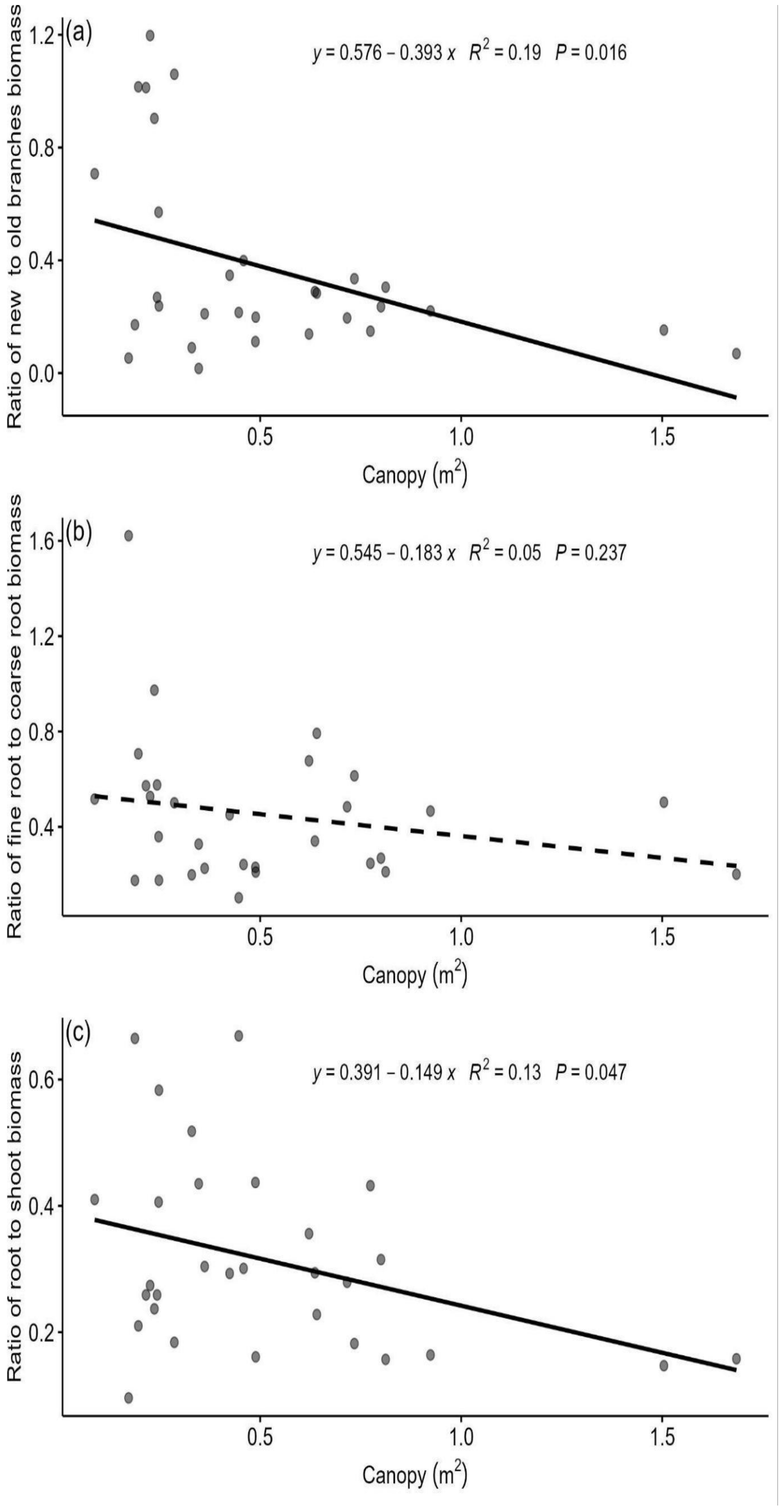

Figure 4. Relationships between ratios of new to old branch biomass, fine root to coarse root biomass, and root to shoot biomass of *A. ordosica* with the canopy. The solid line represents a significant at *P* < 0.05 and the dashed line represents a non-significant relationship at *P* < 0.05.

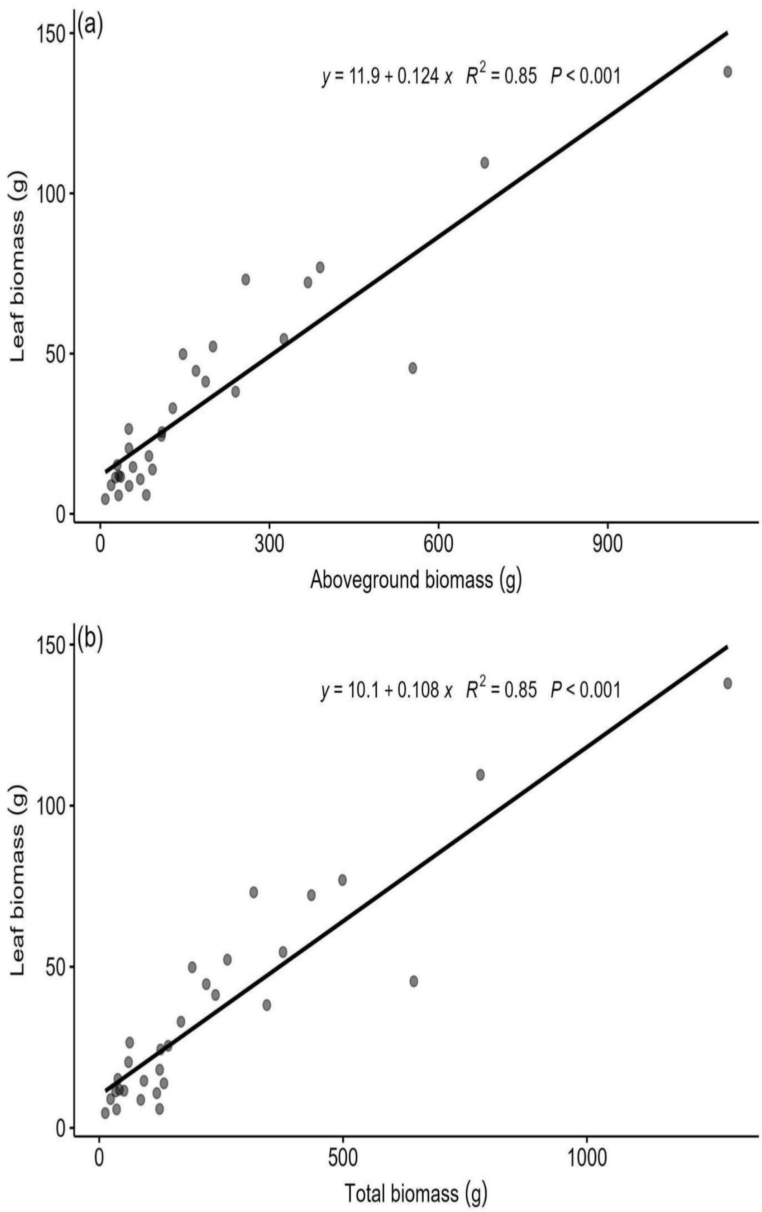

Figure 5. Relationships between leaf biomass and aboveground biomass or total biomass of *A. ordosica*. The solid line represents a significant at *P* < 0.05