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Allometric Equations and Biomass Amount of Representative Tunisian Arid Land Shrubs for Estimating Baseline

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Abstract: As one of the methods to sequester green house gases (GHG), arid land afforestation had been proposed, and some trial experiments have been carried out in Western Australia. The authors attempted to apply this type of afforestation method to Tunisian arid and semi-arid area, and then conventional land-use types and vegetations were investigated. To estimate carbon credit from sequestered carbon amount by planted trees, "Actual net GHG removals by sinks", "Baseline net GHG removals by sinks" and "Leakage" in five carbon pools must be estimated with objective method. As a first step to estimate "Baseline net GHG removals by sinks", allometric equations and biomass amount of representative perennial vegetation in Tunisian arid and semi-arid land were estimated in this study. In future analysis, by repeated tree census and using reported literature data, we will be able to obtain accurate baseline data.

Key Words: Allometric equation, *Eucalyptus camaldulensis*, Gafsa, Sbeitla, Vegetation survey

1. Introduction

One of countermeasures against global warming, afforestation in arid and semi-arid land was proposed and tested (Yamada *et al*., 2003; Kojima and Egashira, 2011). Using arid and semi-arid land as afforestation area rarely competes with crop production and other land use, thus large-scale area can be used with relatively low difficulties. At the same time, afforestation in arid and semi-arid land contributes to restoration of degraded land, and reducing runoff event and erosion (Fraedrich *et al*., 1999; Grünzweig *et al*, 2003). As Maestre and Cortina (2004) indicated, mono-specific plantation had poor improvement effect on natural environment, however, some modification of afforestation methods will possibly avoid such negative impact. And as Kojima and Egashira (2011) indicated, there is high possibility to acquire huge amount of carbon emission credit from large-scale afforestation in arid and semi-arid land. But afforestation inside Australian continent alone did not have enough contribution to avoid global warming, many other candidates of arid land afforestation should be necessary. One of such candidate was considered as arid and semi-arid land of Mediterranean countries, and then Tunisia was considered to become one of the candidate countries.

To calculate carbon emission credit, all the afforestation area must be evaluated according to the method determined by United Nations Framework Conventions on Climate Change (UNFCCC, 2006). UNFCCC (2006) determined that "Actual net GHG removals by sinks", "Baseline net GHG removals by sinks" and "Leakage" in five carbon pools must be estimated with objective method. As a part of the evaluation method, baseline which is the estimation data of CO_2 change of original land use type, e.g. natural vegetation, must be estimated. To estimate baseline CO_2 change in natural vegetation, allometric equations of dominant species of each natural vegetation should be necessary. Therefore, in this study, we will report the results of allometric equation creation and basic biomass data of Tunisian arid and semi-arid land vegetation.

2. Materials and Methods

2.1. Research area

The research area in this study was set around the Gafsa (8˚48'E, 34˚25'N) and Sbeitla (9˚08'E, 34˚14'N) of Tunisia, which belong to arid and semi-arid area. From the climatic data of NOAA (2001-2011)[A], mean annual temperature was 20.3˚C and mean annual rainfall was 174 mm in Gafsa, and from that of NOAA (2009)[A], mean annual temperature was 19.0˚C and annual rainfall was 304 mm in Kasserine (next to Sbeitla). From basic visual interpretation of LANDSAT 5 TM images and google earth with ground truth, 11 representative area of natural vegetation and 6 representative area of forest and afforestation area were chosen as research area. In each research area, 15×15 m quadrate was created in

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relatively homogeneous vegetation area.

2.2. Vegetation research

In each quadrate, plant species, tree or plant height, and major and minor axis of tree crown or plant width with ellipse proximity were measured. For tall tree species (over 2 m and more), Diameter at Breast Height (1.3 m): DBH was also measured. Since the purpose of this study is estimation of baseline data, annual plants and plants under 5 cm height were excluded from this research.

After vegetation research inside each quadrate, aerial part of dominant species and species with relatively high frequency of appearance were measured and cut down, and then oven-dried in 100˚C over 24 hours and weighted.

2.3. Biomass estimation.

From oven-dried biomass data and plant size measurement data, allometric equations were calculated with power function ($Y = aX^b$), and this regression equation's significance was judged by SPSS. Y is gram unit. Independent variable X was set as Cpa [m^2] or Cpa×H [m^3]. Cpa was calculated from π, major and minor axis of plant width. When SPSS detected outlier (over 2×*S.D.* in logarithmic transformation area), such sample data were excluded from regression analysis, and allometric equations were recomputed. When SPSS detected variables of power function were not significant, regression equation was changed from power function to linear function ($Y = aX + b$), and then allometric equations were recomputed.

As a result, one or more significant allometric equations were calculated in each plant species, and then Root Mean Square Error (RMSE) values were calculated to choose most accurate allometric equation. The smallest RMSE value indicates most accurate regression equation. Created allometric equations were used for biomass calculation inside the vegetation research quadrate.

To estimate biomass of plant species whose allometric equations were not created, pseudo allometric equation was created. This pseudo allometric equation was calculated from all the cut down samples except *Retama raetam*. This equation has not so accurate equation but most of the Tunisian arid and semi-arid perennial plants were considered to be covered by this equation.

In addition, allometric equations of tall tree species and some perennial plants were searched from some other scientific articles, since cutting down of tall trees had large difficulties and plants inside national reserve could not be cut down. Pseudo allometric equation and found allometric equations from articles were also used for biomass calculation inside the vegetation research quadrate.

From created and found allometric equations and vegetation measurement results, biomass amount (Mg ha^{-1}) of each site and vegetation cover was calculated. These data contribute to estimate CO_2 emission of afforestation site creation and baseline CO_2 sequestration. In addition, from biomass estimation data of forest and afforestation area, sequestered carbon amount by afforestation was roughly estimated.

Table 1. Allometric equations of Tunisian perennial species.

Species	Independent Value	Allometric equation	R^2	RMSE
Artemisia campestris	Cpa × H	$Y = 1020X^{0.736}$	0.994	3.49
Artemisia herba-alba	Cpa	Y = 1337 X	0.994	42.46
Arthrophytum schmittianum	Cpa × H	Y = 2261 X	0.971	97.43
Arthrophytum schmittianum sB	Cpa × H	Y = 2173 X	0.985	92.25
Arthrophytum schmittianum sH	Cpa × H	Y = 3236 X	0.993	27.01
Astragalus armatus	Cpa × H	Y = 2920 X	0.984	31.42
Gymnocarpos decander	Cpa	$Y = 3895 X^{1.450}$	0.983	62.59
Limoniastrum guyonianum	Cpa × H	$Y = 2138 X^{0.833}$	0.957	158.5
Limonium pruinosum	Cpa × H	$Y = 146.5 \ln X + 721.7$	0.961	147.1
Moricandia arvensis	Cpa	Y = 683.2 X	0.990	13.31
Retama raetam	Cpa × H	Y = 1224 X	0.996	87.78
Salsola sp.	Cpa	$Y = 8163 X^2$	0.997	20.02
Salsola tetrandra	Cpa	$Y = 1247 X^{1.178}$	0.997	30.64
Stipa tenacissima	Cpa	$Y = 1089 X^{1.440}$	0.974	24.98
Suaeda mollis	Cpa × H	Y = 3773 X	0.997	29.47
Thymelaea microphylla	Cpa × H	$Y = 777.5 X^{0.690}$	0.977	5.96
Other species	Cpa	$Y = 1269 X^{1.163}$	0.937	121.6

3. Results and Discussion

3.1. Allometric equations

As shown on **Table 1**, allometric equations of *Artemisia campestris*, *Artemisia herba-alba*, *Arthrophytum schmittianum*, *Astragalus armatus*, *Gymnocarpos decander*, *Limoniastrum guyonianum*, *Limonium pruinosum*, *Moricandia arvensis*, *Retama raetam*, *Salsola* sp., *Salsola tetrandra*, *Stipa tenacissima*, *Suaeda mollis* and *Thymelaea microphylla* were created and chosen. Other species means before mentioned pseudo allometric equation. Independent variable X is Cpa [m^2] or Cpa×H [m^3], and dependent variable Y is biomass [g]. Some allometric equations were created as power function, but the others were created as linear function. Most of the equations were created with high estimation accuracy (quite high R^2 values and low RMSE values). Only allometric equation of *Limonium pruinosum* was created with logarithmic regression equation since sample distribution on scatter plots did not fit to power or linear function. In addition, *Helianthemum hirtum*, *Anabasis articulata* and *Aristida plumosa* were perennial plant species but their plant height was nearly equal, thus biomass of these three species were calculated from proportional expressions according to Cpa [m^2].

Allometric equations found in scientific articles of

Table 2. Research summary of representative Tunisian perennial vegetation.

Site No.	Dominant Species	Site coordinate		Biomass	Vegetation cover
		latitude	longitude	(Mg ha^{-1})	
Site B	*Arthrophytum schmittianum*	34°13'05.0"	8°19'42.1"	1.22	0.12
Site C	*Moricandia arvensis*	34°19'15.1"	8°30'14.1"	0.86	0.12
Site D	*Anabasis articulata*	34°26'33.4"	8°42'31.5"	0.29	0.01
Site E	*Gymnocarpos decander* *Helianthemum hirtum*	34°24'19.5"	8°31'16.6"	1.64	0.12
Site F	*Salsola villosa* *Salsola vermiculata*	34°26'00.1"	8°27'25.6"	0.98	0.05
Site G	*Thymelaea microphylla* *Aristida plumosa*	34°31'20.2"	8°45'44.7"	2.93	0.24
Site H	*Arthrophytum schmittianum*	34°40'08.1"	8°34'13.8"	0.60	0.11
Site I	*Stipa tenacissima*	34°52'07.4"	8°31'37.6"	1.79	0.35
Site J	*Retama raetam* *Artemisia campestris*	35°12'30.4"	9°07'32.2"	3.38	0.37
Site O	*Stipa tenacissima* *Artemisia herba-alba*	35°09'26.3"	8°41'51.5"	4.22	0.40
Site R	*Salsola tetrandra*	34°21'53.0"	8°40'27.2"	2.31	0.25

Rosmarinus officinalis, *Pinus halepensis* and *Eucalyptus camaldulensis* were as follows.

Rosmarinus officinalis (Uso *et al*., 1997)

$$\text{Biomass} = 366.9 + 381.7 \exp(2\times\text{Cpa}\times\text{H}) \qquad (1)$$

where Biomass is gram unit and denotes total plant biomass.

Tall trees of *Pinus halepensis* (López-Serrano *et al*., 2005)

$$\text{Biomass} = 0.128\text{DBH}^{2.29} \qquad (2)$$

where DBH is centimeter unit, and Biomass is kg unit and denotes total tree biomass.

Low trees of *Pinus halepensis* (Massada *et al*., 2006)

$$ln\ (\text{Biomass}) = -1.35 + 1.48\ ln\ (\text{Crown width}) + 1.67\ ln\ (\text{H}) \qquad (3)$$

where Biomass is kg unit and denotes total tree biomass, Crown width is meter unit and denotes mean tree crown width and H is meter unit and denotes tree height.

Eucalyptus camaldulensis (Suganuma *et al*., 2006)

$$\text{Biomass1} = 332.0\times(\text{DBH}^2\times\text{H}) \qquad (4)$$

$$\text{Biomass2} = 189.3\times(\text{DBH}^2)^{0.8119} \qquad (5)$$

where Biomass1 is kg unit and denotes stem plus branch biomass, and Biomass2 is kg unit and denotes leaf biomass, and DBH is meter unit and H is meter unit.

Appropriate allometric equations of *Quercus ilex* and *Juniperus phoenicea* were not found in scientific articles, and both tree species has not high tree height and rarely appeared, so equation (3) was temporally used for biomass estimation of these two species in this study.

3.2. Biomass estimation results of perennial vegetation.

As shown on **Table 2**, biomass amount of 11 Tunisian representative perennial vegetation was estimated. Some of the research area belongs to slight saline area and dominant plant species had salinity tolerance. Such saline area should be excluded from afforestation candidate, but representative vegetation conditions were acquired. From Table 2, biomass amount of all the research sites was revealed under 5 Mg ha^{-1}. Since perennial plants in arid and semi-arid area grew quite slowly, baseline CO_2 capture from atmosphere as plant biomass was considered not to exceed 1 Mg-CO_2 ha^{-1} $year^{-1}$. As *Stipa tenacissima* was cut down with regular interval, i.e. 18 months (Barbara *et al*., 2005), *Stipa* species vegetation such as Site I has possibly high growth rate. Thus, *Stipa* community was considered to have relatively high baseline data. But the biomass data of Site O (conserved area near national reserve) and that of Site I (regularly cut down for pulp production) had not so large difference, and therefore, *Stipa* community was considered to grow fast but reach constant biomass soon. These 11 vegetation data will become the basic data for future satellite image analysis of biomass distribution and baseline distribution estimation.

3.3. Biomass estimation results of woody vegetation.

As shown on **Table 3**, biomass amount of 4 Tunisian forest in semi-arid area and 2 afforestation sites in arid and semi-arid area was estimated. 4 sites (Site K, L, M and N) located inside the national reserve of Mt. Chambi, thus these forests of *Pinus halepensis* were well conserved. Since the highest biomass of *P. halepensis* forest was over 100 Mg ha^{-1}, Tunisian semi-arid area was considered to have very high carbon mitigation potential. However such huge potential, growth rate of *P. halepensis* forest was very low value under semi-arid climate condition as reported in several articles (Grünzweig *et al*, 2003; Montes *et al*., 2004; Massada *et al*., 2006). As Smiris *et al*. (2000) reported that *P. halepensis* grew fast and its biomass amount finally became over 1000 Mg ha^{-1} under humid and temperate condition, afforestation in semi-arid degraded area near Sbeitla must be adopted some water -harvesting technologies or some equivalent techniques to

Table 3. Research summary of representative Tunisian forest and afforestation sites.

Site No.	Dominant Species	Site coordinate		Biomass (Mg ha^{-1})		Canopy coverage	Vegetation cover
		latitude	longitude	upper	lower		
Site K	*Pinus halepensis*	35°10'25.6"	8°40'21.6"	15.8	6.70	0.29	0.84
Site L	*Pinus halepensis*	35°10'59.3"	8°40'1.0"	86.5	7.13	0.68	0.97
Site M	*Pinus halepensis*	35°12'14.4"	8°39'58.9"	130.9	8.34	0.80	1.00
Site N	*Pinus halepensis*	35°11'12.5"	8°39'59.9"	42.9	5.62	0.62	1.00
Site P	*Eucalyptus camaldulensis*	35°11'47.0"	8°52'33.2"	102.5	0.13	0.79	0.80
Site Q	*Eucalyptus camaldulensis*	34°37'13.0"	8°35'35.6"	70.2	n.a.	0.72	0.72

encourage biomass growth of *P. halepensis*.

On the contrary, afforestation area of *Eucalyptus camaldulensis* in Tunisian arid and semi-raid area had relatively high growth rate (over 2 Mg ha^{-1} $year^{-1}$). In addition, over 70 Mg ha^{-1} biomass will be accumulated in afforestation area, i.e. there were high carbon mitigation capacity. However, since *E. camaldulensis* is alien species, application of this tree species to afforestation should become carefully. But considering the situation that all the forests around Gafsa (arid area) were observed only in oasis area, afforestation using *E. camaldulensis* should be introduced in certain extent for carbon mitigation and restoration of degraded land.

From these results, comparing with accumulated biomass amount in forest and afforestation sites to that of natural vegetation or assumed baseline data, "baseline net GHG removals by sinks" should be negligible data and initial carbon loss of clear-cut of natural vegetation should be small amount in this Tunisian arid and semi-arid area.

4. Conclusion

From this research, allometric equations of representative perennial plant species, biomass amount of representative natural vegetation and woody vegetation were estimated. These obtained data will contribute to estimate "Actual net GHG removals by sinks", "Baseline net GHG removals by sinks". In future studies, more accurate estimation values and many data sets should be acquired for statistical analysis and detailed discussion. Since observation data of forest and afforestation sites revealed that huge amount of carbon as tree biomass was sequestrated, much carbon credit was considered to gain in future afforestation activities.

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Note

A) NOAA NNDC climate data online (http://www7.ncdc.noaa.gov/CDO/country)

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