Estimation of plant biomass and plant water content through dimensional measurements of plant volume in the Dund-Govi Province of Mongolia

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Summary As the first step to estimate the total plant biomass and the total plant water content on the whole study area, regression equations of dominant shrubs (5 species) and dominant herbaceous plants (1 tall grass type and 10 short grass types) were developed for predicting plant biomass and plant water content per unit area or plant individual through dimensional measurements in the arid area of Dund-Govi Province, Mongolia. As the result of the comparison among three types (linear, quadratic, and logarithmic) of regression equations and dependent variables (height, crown area/coverage, and volume), it was indicated that the linear regression equation by the volume was more applicable to estimate the plant biomass and the plant water contents of the dominant shrubs and the dominant herbaceous plants. It could be possible to estimate easily the plant biomass and the plant water content using those regression equations at many field sites directly. To estimate the total coverage, the total plant biomass, and the total plant water content on the whole study area, it further needs to calculate a regression between Landsat TM data and the plant volume, and/or Landsat TM data and the data of the coverage/plant biomass/plant water content estimated at the field sites.

1. Introduction

Within the framework of the AMPEX (ADEOS II Mongolian Plateau EXperiment for ground truth) project (Kaihotsu, 2001), the field measurement of coverage, plant aerial biomass, the water content of plants, and those estimation on the whole study area (Figure 1) are the main objects on the aspect of the vegetation analysis. Those data will be used for constructing an algorithm to estimate a soil water content using ADEOS II data. By calculating the regression between Landsat TM data and the data of the coverage/plant biomass/plant water content measured at field sites, it is possible to estimate the total coverage/total plant biomass/total plant water content on the whole study area. Hence, it needs as the many data at field sites as possible to get a more reliable regression equation between them.

On the other hand, the most important factors in raising and keeping livestock in arid areas are the amounts of feed and water resources; therefore, an understanding of those amounts is vital to the management of livestock. However, many technical facilities and great laborious efforts, such as cutting, drying, and weighing, are required to measure plant biomass. These processes sometimes become an obstruction to measuring the plant biomass and the plant water content in such remote areas as the Mongolian steppe.

Thus, there is a need to develop a methodology for estimating plant biomass and plant water content easily at as many survey sites as possible, especially in remote and arid areas. In this study, as the first step to estimate the total coverage/total plant biomas/total plant water content on the whole target study area, regression equations were developed to predict plant biomass and plant water content per unit area or plant individual by only dimensional measurements in the arid area of Dund-Govi Province, Mongolia, which are directly applicable at the survey sites.

2. Methods

2-1. Study area

The study area, 160 km east-west and 100 km north-south, is located in an arid area of the Dund-Govi Province of Mongolia where the average annual precipitation is only 150 to 250 mm (Figure 1). As to the vegetation classification by Ю н а т о ь (1976), the type of vegetation in the study area is classified as steppe and/or semi-desert. The study area is only used for flock grazing controlled by local nomads.

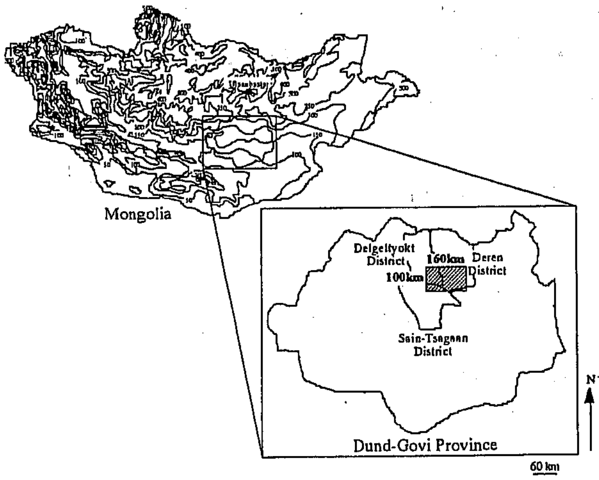

Figure 1 Annual precipitation of Mongolia and the location of the study area(▨)

2-2. Field survey

Field surveys were conducted from May to October of 2001 in the study area. Shrubs (4 species), a long grass type of herbaceous plant (1 specie), short grass types of herbaceous plants (10 species), and a dwarf shrub (1 specie) were measured by different methods to estimate the plant biomass and the plant water content. They are representatives of the plant species in the study area. The measured plant species are listed in Table 1. The plants covering the entire range from very small/short to very large/long were randomly taken as the samples for regression analysis (Thalen 1979: 383; Catchpole and Wheeler 1992).

Table 1 Plant list on analyzing regressions for estimation of plant biomass and plant water content

		Genus species	Samples*
Shrub	Leguminosae	*Caragana micropylla*	47
	Leguminosae	*Caragana pygmaea*	64
	Chenopodiaceae	*Salsola passerina*	18
	Chenopodiaceae	*Reaumurica soongorica*	24
Dwarf shrub	Compositae	*Artemisia* spp.	45
Long-type herbaceous plant	Graminae	*Achnaterum splendens*	54
Short-type herbaceous plants	Graminae	*Cleistogenes squarrosa*	78
	Graminae	*Agropyron cristatum*	35
	Graminae	*Stipa* spp.	68
	Graminae	*Leymus chinensis*	5
	Liliaceae	*Allium* spp.**	74
	Cyperaceae	*Carex duriuscula*	78
	Convolvulaceae	*Convolvulus Ammanii*	25
	Rosaceae	*Potentilla bifurca*	25
	Rosaceae	*Sibbaldianthe sericea*	25
	Zygophyllaceae	*Peganum harmala*	15
	Herbacious plants***		60

*: Collected sample numbers for the regression analyses
**: There are 2 species of *Allium* spps: *A. mongolicum* and *A. polyrrhizum*
***: Herbacious plants contain all plants which appeared in the each surveyed site

For the short grass types of herbaceous plants and the dwarf shrub, the natural height (cm) and the coverage (%) were measured by a modified Penfound and Howard method (1940). The plants were collected by unit sampling using a 50 cm x 50 cm quadrat at the ground level.

For the shrubs and the long grass type of herbaceous plants, the natural height and two maximum values for the diameters (cm), which are perpendicular to each other at the crown area and the basal area, were measured (Figure 2). The plants were individually collected at the ground level.

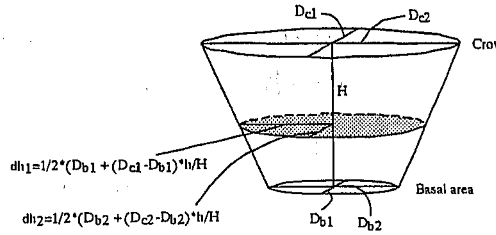

Figure 2 Dimensional measurements of the diameters at the basal area (D_{b1} & D_{b2}) and the crown area(D_{c1} & D_{c2}), and the height (H) of the individual shrubs and long grass type herbaceous plant for calculating the plant volume from the differential equation of the area

$$\text{Plant volume (V)} = \int_0^H dh1 * dh2 * \pi \, dh$$

2-3. Measurement of dry matter (DM) and plant water content (WC)

The weight of fresh matters (FM) of the collected plants was immediately measured at the field using a portable electronic balance (minimum scale: 0.1 g). The plants were oven-dried (at 130° C for 2 h) to measure the dry matter (DM) present. The water content of each plant was calculated by subtracting DM from FM.

2-4. Calculation of plant volume (V)

For the short grass types of herbaceous plants and the dwarf shrub, each plant volume was calculated by multiplying the area (2500 cm^2) within the 50 cm x 50 cm quadrat by each coverage and height as,

$V (cm^3/0.25\ m^2) =$

$2500 (cm^2) \times \text{coverage} (\%) / 100 \times \text{height} (cm)$

For the shrubs and the long grass type of herbaceous plant, each plant volume was calculated using the modified Okubo conical model (Okubo and Endo 1998) as follows (Figure 2):

Crown area (g/individual) = Dc1/2 x Dc2/2 x π

V (g/individual) = (0-H){dh1 x dh2 x π dh

dh1: 1/2 (Db1 + (Dc1 - Db1) h/H),

dh2: 1/2 (Db2 + (Dc2 - Db2) h/H)

where, Dc1 and Dc2 are two maximum diameters at the crown area, Db1 and Db2 are two maximum diameters at the basal area, H is height, and h is variable of height.

2-5. Regression calculation

Regression analyses were carried out by linear, quadratic, and logarithmic function,

Linear equation:	$Y = a + bX$
Quadratic equation:	$Y = a + bX + cX^2$
Logarithmic equation:	$LogY = a + bLogX$

where Y is the plant biomass or the plant water content, X is the height, the crown area/the coverage, or plant volume, a, b, and c are regression coefficients.

The sample number of each plant used for calculation of regression equations ranged from 5 to 78 (Table 1).

3. Results and Discussion

Coefficients of determination (r^2) on linear, quadratic, and logarithmic regression equations between plant biomass/plant water contents and plant volumes are shown in Table 2. The coefficients of determination on the linear equations were almost equal to those of the logarithmic equations, but quite a bit lower than those of the q uadratic equations. Simple but reliable equations are favorable because such equations provide plant biomass and water contents easily in the field when it is difficult to take such measurements directly. In terms of simple and easy calculation, the linear equations are greatly superior to the logarithmic equations. Further, in such as cases of *Caragana micropylla*, and *Agropyron cristatum*, large errors in the plant biomass and water contents estimated by th e quadratic equations occurred when the equations were applied beyond the range of the volumes used in this study (Figure 3). It was, therefore, indicated that the linear equations would be more reliable and proper than quadratic equations.

Table 2 Comparison on coefficients of determination (r2) among linear*, quadratic**, and logarithmic*** regressions

Plants	Plant biomass // Plant volume			Plant water content // Plant volume		
	Linear	Quadratic	Logarithmic	Linear	Quadratic	Logarithmic
Caragana micropylla	0.86	0.92	0.88	0.79	0.81	0.79
Caragana pygmaea	0.77	0.83	0.77	0.79	0.83	0.79
Achnaterum splendens	0.83	0.85	0.83	0.81	0.81	0.81
Salsola passerina	0.77	0.83	0.77	0.94	0.94	0.94
Reaumurica soongorica	0.88	0.88	0.88	0.69	0.71	0.69
Allium spp.	0.78	0.79	0.79	0.81	0.83	0.81
Cleistogenes squarrosa	0.72	0.75	0.72	0.64	0.65	0.64
Carex duriuscula	0.75	0.75	0.74	0.57	0.57	0.57
Stipa spp.	0.58	0.59	0.57	0.46	0.47	0.46
Artemisia spp.	0.82	0.93	0.82	0.76	0.90	0.83
Convolvulus Ammanii	0.47	0.61	0.76	0.61	0.69	0.61
Potentilla bifurca	0.86	0.86	0.86	0.74	0.74	0.74
Sibbaldianthe sericea	0.86	0.89	0.72	0.73	0.73	0.73
Agrpyron cristatum	0.69	0.76	0.72	0.49	0.56	0.49
Leymus chinensis	0.82	0.97	0.82	0.82	0.90	0.81
Peganum harmala	0.66	0.66	0.66	0.86	0.86	0.86
Herbaceous plants	0.53	0.59	0.53	0.52	0.53	0.52

*: Y = a +bX, **: Y = a +bX + cX2, ***: LogY= aLogX + b

Table 3 shows comparisons of coefficients of determination when heights, crown areas/coverage, and volumes were used as an independent variable in linear equations. All the coefficients of determination for the heights were lower than those for the volumes. Further, the coefficients of determination for the volumes of some shrubs and some herbaceous plant were lower than those for the crown areas/coverage, but higher in most plants. Hence, it was suggested that the volumes could become the most accurate independent variable in estimating the plant biomass and water content of each plant.

Table 3 Coefficients of determination (r2) on the linear equations of the each plant assigned to independent variables for plant biomass/plant water content and to dependent variables for height, crown area/coverage, and volume

Plants	Plant biomass			Plant water content		
	Height	Crown area	Volume	Height	Crown area	Volume
Caragana micropylla	0.37	0.77	0.86	0.41	0.49	0.79
Caragana pygmaea	0.40	0.64	0.77	0.44	0.66	0.79
Achnaterum splendens	0.56	0.62	0.85	0.53	0.56	0.81
Salsola passerina	0.62	0.85	0.77	0.67	0.86	0.94
Reaumurica soongorica	0.18	0.90	0.88	0.34	0.56	0.69
	Height	Coverage	Volume	Height	Coverage	Volume
Allium spp.	0.50	0.50	0.78	0.54	0.47	0.81
Cleistogenes squarrosa	0.35	0.59	0.72	0.18	0.26	0.64
Carex duriuscula	0.49	0.47	0.75	0.50	0.27	0.57
Stipa spp.	0.17	0.56	0.61	0.12	0.48	0.46
Artemisia spp.	0.28	0.63	0.82	0.29	0.55	0.76
Convolvulus Ammanii	0.07	0.73	0.47	0.00	0.71	0.61
Potentilla bifurca	0.26	0.94	0.86	0.15	0.88	0.73
Sibbaldianthe sericea	0.16	0.85	0.86	0.14	0.79	0.76
Agrpyron cristatum	0.34	0.45	0.69	0.22	0.43	0.49
Leymus chinensis	0.12	0.84	0.84	0.12	0.82	0.82
Peganum harmala	0.25	0.64	0.66	0.34	0.90	0.86
Herbaceous plants	0.34	0.48	0.53	0.40	0.28	0.52

The results of linear regression equations of each plant between the plant biomass/plant water contents and the volumes are listed in Table 4. The highest and lowest values of coefficients of determination were 0.94

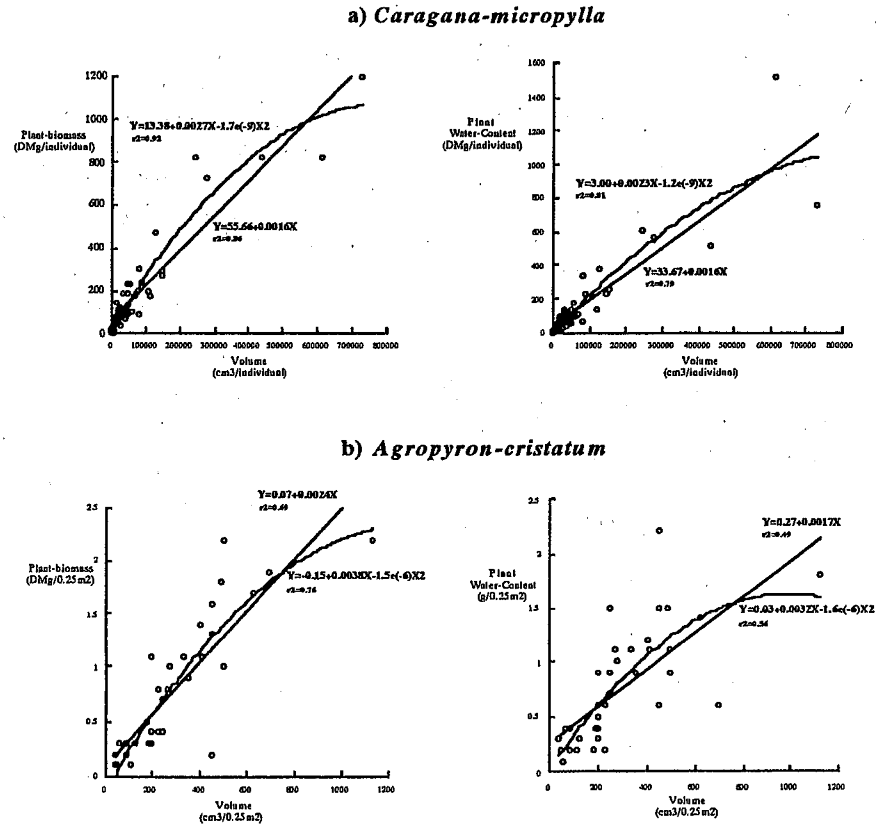

Figure 3 Linear and quadratic regressions between plant biomass/plant water content and plant volume of Caragana-micropylla(a) and Caragana-micropylla(b) in the Dund-Govi Province, Mongolia

and 0.46, respectively. Herbaceous plants, which include all plants appearing at the survey site, also had high values of coefficients of determination. Again, from the results of the comparison among three types of regression equations and among dependent valuables, it was indicated that the linear regression equations by the volumes were more applicable to estimate the plant biomass and the plant water contents of each plant. The simplicity of the linear regression equation is also attractive for easy calculation at survey sites.

Table 4 Linear regression equations between plant biomass/plant water content and volume

Plants	Plant biomass // Plant volume		Plant water content // Plant volume	
	Regression equation	r2	Regression equation	r2
Caragana micropylla	Y=0.001635X+55.66	0.86	Y=0.001579X+33.67	0.79
Caragana pygmaea	Y=0.004542X - 2.86	0.77	Y=0.002522X - 0.68	0.79
Achnaterum splendens	Y=0.000405X+ 4.79	0.85	Y=0.000499Y+ 1.86	0.81
Salsola passerina	Y=0.009510X+ 5.40	0.77	Y=0.015830X+ 0.82	0.94
Reaumurica soongorica	Y=0.007346X+ 2.43	0.88	Y=0.004267X+ 5.15	0.69
Allium spp.	Y=0.001282X+ 0.01	0.78	Y=0.005301X - 0.51	0.81
Cleistogenes squarrosa	Y=0.003426X+ 0.12	0.72	Y=0.002256X+ 0.29	0.64
Carex duriuscula	Y=0.001157X+ 0.27	0.75	Y=0.001046X+ 0.31	0.67
Stipa spp.	Y=0.001003X+ 0.05	0.58	Y=0.000832X+ 0.21	0.46
Artemisia spp.	Y=0.003398X - 0.08	0.82	Y=0.004254X+ 0.12	0.76
Convolvulus Ammanii	Y=0.001850X+ 0.19	0.47	Y=0.002458X+ 0.30	0.61
Potentilla bifurca	Y=0.005780X+ 0.00	0.86	Y=0.004500X+ 0.12	0.73
Sibbaldianthe sericea	Y=0.005385X+ 0.08	0.86	Y=0.002984X+ 0.26	0.76
Agrpyron cristatum	Y=0.002414X+ 0.07	0.69	Y=0.001666X+ 0.27	0.49
Leymus chinensis	Y=0.000728X+ 0.17	0.82	Y=0.001188X+ 0.09	0.82
Peganum harmala	Y=0.003073X+ 0.55	0.66	Y=0.007008X+ 0.74	0.86
Herbaceous plants	Y=0.001517X+ 1.27	0.53	Y=0.002710X+ 0.68	0.52

From *C. micropylla* to *R. soongorica* ;
Y: estimated plant biomass (DM g/individual), estimated plant water content (DM g/individual),
X: plant volume (cm3/individual)

From *Allium* spp. to Herbaceous plants;
Y: estimated plant biomass (DM g/0.25m2), estimated plant water content (DM g/0.25m2),
X: plant volume (cm3/0.25m2)

Further study

To estimate the total coverage, the total plant biomass, and the total plant water content on the whole study area, it further needs to calculate a regression between Landsat TM data and the plant volume, and/or Landsat TM data and the data of the coverage/plant biomass/plant water content. The equation on those relationships could expand the point data of the coverage/plant biomass/plant water content estimated by the regression equations to the whole target study area.

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References

Catchpole, W. R. & Wheeler, G. J. 1992. Estimating plant biomass: A review of techniques. *Australian Journal of Ecology* 17: 121-131.

Kaihotsu, I., Yamanaka, T., Oyunbaatar, D., Hirata, M., Ohishi, K., Muramatsu, K., Miyazaki, S., Kondo, A. & Koike, T. 2001. Preliminary Ground-Based Observation for the Soil Moisture Measurement Validation of ADEOS II-AMSR/AMSR-E. *Proceedings of the 3rd Symposium of Hydrological Process Analysis Using Remote Sensing and its Application, Chiba University, Chiba* (In Japanese).

Okubo, T. & Endo, N. 1998. The influence of grazing impacts on plant composition and plant biomass in Mongolian free-grazing steppe - Applying the conical model as a ground survey method to remote sensing, 2) Trial for estimating the grazing pressure and the environmental allowance on the steppe vegetation in Dund-Govi Province of Mongolia. *The proceedings of the reports for co-research activities in the fiscal year of 1997, CEReS, Chiba University* (In Japanese).

Penfound, W. T. & Howard, J. A. 1940. A phytosociological analysis of an evergreen oak forest in the vicinity of New Orleans. *La. Amer. Midl. Nat.* 23: 165-174.

Thalen, D. C. P. 1979. *Ecology and Utilization of Desert Shrub Rangeland in Iraq*, Dr. W. Junk bv Publishers, The Hague.

Юнатоь, А. А. 1976. *БУГД Найрамдах Монгол ард улсын улгамлан номрогийн ундсэн шинжууд*. Улаанбатар (In Mongol).