RESEARCH ARTICLE | FEBRUARY 28 2019

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AIP Conf. Proc. 2079, 020026 (2019)
https://doi.org/10.1063/1.5092404

Biomass Allocation Between Above- and Below-ground and It Impacted Factors of Shrubby Areas and Grasslands in Upper Heihe River Basin of China

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Abstract. Biomass allocation between above- and below-ground has an important effects on carbon storage, and it change was often affected by soil properties and other disturbances. 22 and 41 plots were selected for shrub and grassland, respectively, in various altitude from 2552 to 4103m in upper Heihe river basin of China, and some physical factors (e.g. cover, species, soil bulk density, field capacity) and chemical factors (e.g. pH, available P and K, soil organic matter) were adopted to explore the relationship between these factors and the biomass allocation between above- and below- ground compartment. The results showed that the above: below ground ratios was 11 and 12 in shrubby areas and grassland respectively, and pH, cover and available P were the main factors that influenced biomass allocation, suggesting that the ratio can be changed by increasing cover and species diversity, and by increasing available P buy fertilization.

INTRODUCTION

Roots have key roles for plants including nutrient and water uptake, and for reducing the susceptibility of soil to rill and gully erosion, and improving soil infiltration capacity [1-3]. They are a large sink for carbohydrates and their senescence and decomposition transfers large amounts of carbon into soils [4-6]. The above-ground biomass of plants is intimately interconnected to that below ground, and both compartments capture resources and interact with neighboring trees and other vegetation. An important root-shoot interaction that might determine the overall response of plants is the ability of the root system to adjust nutrient acquisition capacity to meet variations in shoot demand caused by environmental changes. However, the two compartments have usually been considered in isolation from each other and relatively little is known about the degree to which they interact [2, 7-9].

Revegetation to control gully erosion, such as the planting of grass and shrub hedges, largely stresses the effects of above ground biomass, and little attention is given to the role of below ground biomass. This is related to the difficulties of defining root structural features in situ, and .measuring root biomass is laborious [10-11]. In addition, most existing root studies deal with agricultural crops and little attention has been given to the effects of roots of natural vegetation [3].

Grasslands have a below-ground biomass 3-5 times greater than areas under trees and shrubs, and have mean net primary production in the range from 1000g m^{-2} yr^{-1} for desert steppe to 4400 m^{-2} yr^{-1} for grassy bogs. The productivity of grasslands is due to intensive root growth, and the aboveground production is not more than 30% of the net primary production. The large below-ground production causes a large input of organic matter into the soil and partly accounts for the accumulation of organic carbon in grassland chernozem soils [1].

Ratios of below-ground plant to above-ground biomass reflect the proportion of photosynthates that are allocated below ground and they are often used to characterize plant communities or individual species [1, 12-13]. Variation in the allocation of biomass between above- and below- ground components is one possible source of differences in

2018 International Conference on Biotechnology and Bioengineering (8th ICBB)
AIP Conf. Proc. 2079, 020026-1–020026-7; https://doi.org/10.1063/1.5092404
Published by AIP Publishing. 978-0-7354-1807-3/$30.00

production of biomass associated with variations in soil moisture, soil nutrients, competition regimes, low temperature, high altitude, aridity, overgrazing or oxygen deficiency [1]. Manipulation of biomass allocation between above- and below- ground depends on whether the goal is improved shoot growth for harvest or grazing or for increased root growth for soil stabilization or carbon storage [6].

In most cases, researchers have focused on one or two factors that influence the allocation of above- and below-ground biomass, such as warming [14], a set of paralogous gene pairs [6], soil water [10], livestock grazing [15], rainfall, and declining species richness [2], soil invertebrates and summer drought [16-17].

The objective of this paper is to explore the factors that influence biomass allocation, and put forward some suggestions for vegetation management in a protected watershed area of arid northern China. We analysed the physical factors (e.g. altitude, cover, species, soil bulk density, field capacity) and chemical factors (e.g. pH, available P and K, soil organic matter) effects on the distribution of biomass between the above and below ground compartments in an attempt to identify practices that lead to increased soil biomass and carbon storage in soil.

MATERIALS AND METHODS

Heihe River Basin is a typical inland river basin in the arid zone of northwestern China with a length of 821 km. It is located at the climatic intersection between the westerlies and the East Asian summer monsoon. Qilian Mountains, with an elevation varying between 2000 and 5500 m, and mean annual precipitation from 250 to 500 mm, are a major catchment for the Heihe River, and are characterized by a humid and cold climate. Its upstream flow supplies water for irrigation and ecosystem stabilization in the middle and lower reaches of the Heihe River Basin.

Vegetation and soil patterns show a distinct vertical zonation. Qilian juniper (Sabina przewalskii Kom.), is a dominant tree species and grows on south-facing slopes. Alpine forest gray–brown soils, subalpine shrub meadow soils, alpine meadow soils, and alpine chestnut soils are typical for the upstream areas of the Heihe River. The primary source areas of stream flow are the sub-alpine shrub meadow, alpine meadow and alpine tundra vegetation belts. Soil water holding capacity varies between 55% and 75% at different soil depths [18-19]. Because of its importance Qilian mountain has been a national natural protection zone since 1988.

It was not possible to define specific altitudes for the different vegetation belts and we sampled shrubby areas and grasslands at random at different altitude intervals by observations in July and August of 2011. In all, 75 samples were selected from elevations ranging from 2552 to 4103 m. The sample plot areas for shrubs was 10×10m and 1×1m for grassland. In pure grassland, three replicate quadrats were sampled in 10×10m plots. With each plot, height, cover, and number of the individual species were recorded. For shrub and grassland, the total surface coverage was also recorded. In some plots soil samples were collected by soil auger at depths of 0-10cm, 10-20cm, 20-40cm and 40-60cm, with three replications. As we only aimed to determine the allocation of above- and below- ground biomass in shrub areas and grasslands, and the factors that influence it, plots with trees were excluded from our study. There were 22 and 41 sample plots of shrubby areas and grasslands, respectively. Soil samples were collected from 11 shrubby plots and 13 grassland plots.

The fresh above-ground plant biomass was weighed on site, and other properties were measured in the laboratory. The soil cores were transferred to the laboratory and stored at 2°C for 6 days. After pre-soaking for 12 h the roots were separated using a 0.1 mm sieve. After washing the roots were weighed.

Soil organic carbon (SOM) was analyzed by wet dichromate oxidation in a subsample of 0.2 g soil and titrated by FeSO4.. A ratio 2.5:1 of water to soil was used for determination of soil pH. Available phosphorus (AP) was determined using the Olsen method [20]. Available K (AK) was extracted with ammonium acetate solution (1 $molL^{-1}$) and then determined with a flame photometer. Soil bulk density was measured by steel rings (70mm diameter ×55mm deep). Water holding capacity is expressed as a proportion of soil dry mass (g water/g soil).

The data were analyzed using SPSS 15.0, and $p< 0.05$ was used as the critical threshold for significance to determine differences in the param-eters.

RESULTS AND DISCUSSION

Above- and below-ground biomass, and the ratios of two compartments of shrub and grassland at different altitudes are shown in Table 1. According to Table 1, we found that the below ground biomass was much larger than that of above ground both in shrub and grassland, and cover of grassland was higher than that of shrub. In addition, the differences of biomass were large no matter above ground or under ground of both shrub and grassland, meaning that most plots were different, which may cause by various altitude or other factors.

TABLE 1. Above-and below-ground biomass and its ratio of shrub and grassland

Indices	Average
SA	3404m (±305)
GA	3316m (±427)
AGBS	817.22g/m^2 (±2267.09)
BGBS	2445.90g/m^2 (±4903.35)
AGBG	476.29g/m^2 (±349.41)
BGBG	5588.85g/m^2 (±5883.18)
AGBS/BGBS(AS/BS)	0.11 (±0.18)
AGBG/BGBG(AG/BG)	0.12 (±0.08)
CS	62.77 (±26)
SS	12.00 (±3.65)
CG	69.17 (±31.55)
SG	11.00 (±3.57)

Note: SA means altitude of shrub; GA means altitude of grassland; AGBS means above ground biomass of shrub; BGBS means below ground biomass of shrub; AGBG means above ground biomass of grassland; BGBG means below ground biomass of grassland; CS means cover of shrub; SS means species of shrub; CG means cover of grassland; SG means species of grassland.

The average below ground biomass of shrub and grassland at various soil depths are presented in Fig. 1. At a soil depth of 40-60 cm in grassland only one plot had measureable root biomass, and at 60-80 cm only two plots with shrubs had root biomass and we excluded them from the statistical analysis. The below ground biomass deceased with increasing depth and was significantly different between 0-10 cm, and 10-20 cm, 20-40 cm depths in both shrub areas and grassland ($p<0.05$). The proportions of these three layers' biomass were 87% and nearly 100% in shrubby plots and grasslands respectively. In shrubby plots, above ground biomass had a significant negative correlation with below ground biomass (r=-0.38, $p<0.05$), suggesting that the more the above ground part, the less the below ground part, but there no such trend in grassland plots (r=0.14).

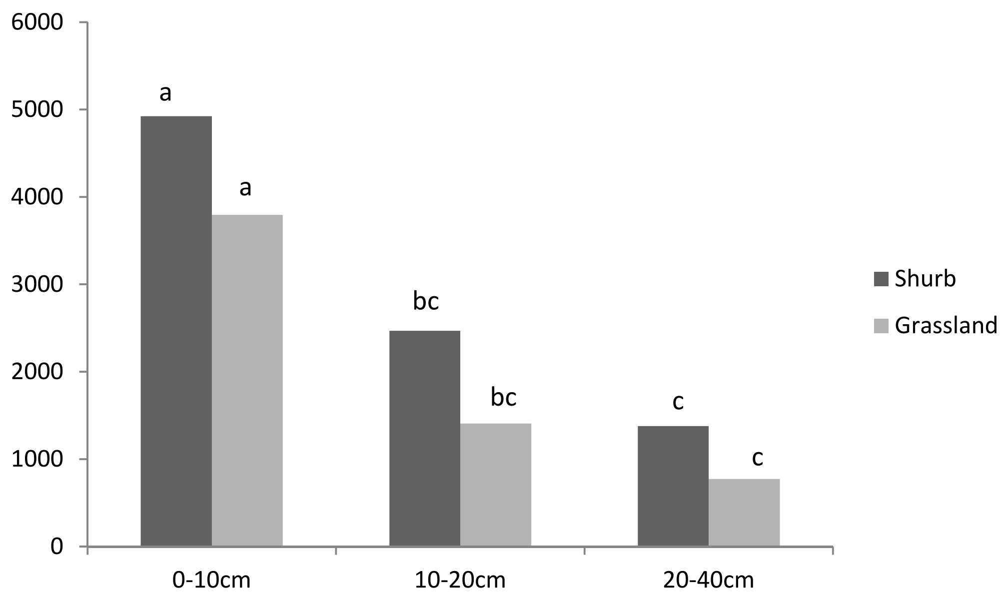

FIGURE 1. The below ground biomass of shrub and grassland at various soil depths.

Note: The difference was significant among a, b and c at the level of $p<0.05$.

The correlations between altitude/species/cover, and above- and below-ground biomass, and AS/BS, AG/BG of shrub and grassland are shown in Table 2. There is a significantly negative correlation between altitude and AGBS, indicating that the above ground biomass of shrubby areas decreased as altitude increased. This result was also supported by Lei *et al.* (2011) [21]. Cover was positively related to AGBG and AG/BG. For the species there were no relationship with these indices in either shrubby and grassland plots. Therefore altitude was an important factor for AGBS in shrub areas, and cover was an important factor for AGBG and AG/BG in grasslands.

TABLE 2. The correlations between altitude/species/cover and above- and below ground biomass, and AS/BS, AG/BG in shrub and grassland

	Altitude	Cover	Species
AGBS	-.44*	.02	-.21
BGBS	-.02	.24	.34
AGBG	-.15	.67**	.16
BGBG	.01	.23	.01
AS/BS	-.37	-.22	-.31
AG/BG	-.24	.27*	0.24

Note: the difference was significant at the level of $p<0.05$. * means $p<0.05$; ** means $p<0.01$.

Table 3 shows the relationship of above-ground biomass and various depths of below- ground biomass with AS/BS, AG/BG in shrub and grassland respectively. Based on Table 3 it appears that AGBS was only related to AS/BS in shrub areas, while in grassland, both the above- and below- ground biomass have relationships with AG/BG.

TABLE 3. The correlations between above- and below- ground biomass with various soil depths and AS/BS, AG/BG in shrub and grassland respectively

	AGBS	AGBG	0-10cm	10-20cm	20-40cm
AS/BS	.94**		-.18	-.35	-.42
AG/BG		0.47**	-.48**	-.47**	-.39*

As shown above the majority of the below ground biomass was in the upper three soil layers, so we analyzed the soil physicochemical properties and their relationships with the biomass allocation in these upper layers only (Table 4, Table 5). Table 4 shows that SBD and SOM were significantly different between the depths of 0-10 cm and 20-40 cm, while for AP, the differences were significant between all the three layers. In grassland, all soil physicochemical properties except AP showed no differences between the depths of 0-10cm and 20-40cm.

TABLE 4. Soil physicochemical properties at various depths

	0-10cm	10-20cm	20-40cm
Shrub: pH	6.91(±0.57) a	7.19(±0.66) a	7.30(±0.65) a
Grassland: pH	7.67(±0.83) a	7.76(±0.99) a	7.95(±0.97) a
Shrub: SBD(g/cm^3)	1.00(±0.19) a	1.18(±0.35) ab	1.27(±0.28) bc
Grassland: SBD(g/cm^3)	1.14(±0.28) a	1.25(±0.31) a	1.34(±0.30) a
Shrub: FC(%)	42.18(±13.23) a	32.08(±14.43) a	32.27(±5.85) a
Grassland: FC(%)	35.92(±15.33) a	28.67(±13.31) a	32.40(±27.03) a
Shrub: AP(mg/kg)	3.80(±1.36) a	2.66(±1.00) b	2.26(±0.59) c
Grassland: AP (mg/kg)	4.92(±3.52) a	2.57(±1.38) bc	1.24(±1.47) c
Shrub: AK(mg/kg)	127.75(±33.87) a	95.04(±41.30) a	100.30(±40.82) a
Grassland: AK(mg/kg)	258.38(±187.53) a	180.62(±)137.42 a	149.89(±179.03) a
Shrub: SOM(g/kg)	100.74(±46.59) a	70.89(±37.59) ab	43.02(24.83) bc
Grassland: SOM(g/kg)	59.3(±34.50) a	57.36(±52.40) a	28.77(±17.82)a

Note: SBD means soil bulk density; FC means field capacity; AP means available P; AK means available K, and SOM means organic carbon. The difference among a,b and c was significant at the level of $p<0.05$.

TABLE 5. The relationship between biomass allocation and soil physicochemical properties in shrub and grassland respectively

	pH	SBD	FC	AP	AK	SOM
		0-10cm	10-20cm	20-40cm		
	0.09	0.20	-0.23	0.35	0.03	0.51
AGBS	0.48	-0.59*	-0.49	-0.07	-0.50	-0.03
	0.25	-0.49	0.51	-0.1	-0.55	0.75*
	0.20	-0.38	0.18	0.35	0.23	-0.10
BGBS	-0.02	-0.71*	0.39	0.44	0.39	0.19
	0.22	-0.02	-0.27	-0.08	-0.14	0.04
	-0.02	-0.21	0.25	-0.53	-0.42	-0.23
AS/BS	-0.19	-0.18	0.48	-0.49	-0.68*	0.34
	-0.04	-0.61	0.68*	-0.02	-0.57	0.53
	-0.41	-0.63*	0.10	0.54*	0.41	0.34
AGBG	-0.30	-0.71*	0.52	0.50*	0.55*	0.18
	-0.36	-0.57*	0.23	0.55*	0.59*	0.38
	-0.31	0.06	-0.35	0.40	0.07	0.28
BGBG	-0.58*	-0.55	0.46	0.62*	0.14	0.88**
	-0.51*	-0.63*	0.83**	-0.09	-0.01	0.44
	-0.13	-0.58*	0.33	0.15	0.14	-0.02
AG/BG	0.16	-0.38	0.40	-0.13	0.17	-0.37
	0.06	-0.14	-0.16	0.28	0.20	-0.05

Table 5 shows that AGBS was positively related to SBD and SOM at the depths of 10-20 cm and 20-40 cm, respectively, and BGBS was negatively related to SBD at the depth of 10-20cm. AS/BS was negatively related to AK at the depth of 10-20cm, and was positively related to FC at 20-40cm in shrubby areas. In grassland, AGBG was negatively related to SBD in the three layers, and positively related to AP and AK, with the former at three various depths, and the latter at depth of 10-20cm and 20-40cm. BGBG was negatively related to pH and SBD at the depths of 10-20 cm and 20-40 cm, but it was positively related to FC, AP and SOM at the depths of 20-40 cm, and 10-20 cm, both for AP and SOM, respectively. AG/BG was only negatively related to SBD in the uppermost layer.

DISCUSSION

Figure 1 showed that below ground biomass decreased as depth increased both in shrubby areas and in grassland. Biomass of the upper 10 cm of soil accounted for 58% and 67% of the total below-ground biomass for shrub areas and grasslands, respectively, and this is consistent with the results for other areas in China [22-24]. However, the ratio of above- and below- ground biomass in grassland in our study was only 12, and much smaller than the global (74) and Chinese (82) averages [25]. However, small values have been also been found in other studies - Li *et al.* (2006) found that the ratio was only 3 or even smaller in the deeper soil in the Haibei area of Qilian Mountains [26]. In shrub areas there was no average ratio that could be compared, but it was similar to Potentilla fruticosa shrub areas [23]. Generally, under limited nutrients, the ratio of above- and below ground biomass is decreased [12]. Compared with typical grasslands, AP was very poor in our study area. As described in Table 4, AP of the first and the second soil layer was only 4.9 mg/kg and 2.6 mg/kg respectively, and AP was significantly different between these two layers. In typical grasslands the value was up to 18.5 mg/kg and 13.7 mg/kg respectively [25]. However, the values of AK and SOM in our study area were similar to others [26]. Phosphorus is therefore a limiting nutrient for plant growth in this area, and the above ground biomass was small and should be increased by fertilizer because it can increase significantly the above ground biomass but not the below ground biomass [28].

From Table 2, we found that the ratio of above- and below- ground biomass in shrub was not related to altitude, cover and species, but it was positively related to cover in grasslands, suggesting that we can improve the above ground biomass by increasing cover. In addition, cover was positively related to species (r=0.43, $p<0.01$), so maintenance of plant diversity is also important in this area establishing aboveground dominance and providing a functional heterogeneity of the community in grassland [1, 29]. In Table 3, it was found that the ratio of above- and below-ground biomass was positively related to the above compartment in shrubby areas, while in grasslands, it was significantly related to both of the two compartments, suggesting that different measures should be taken when we try to change this ratio.

Based on Table 5, we found change of the biomass allocation between above ground and below ground in shrub mainly depended on FC, and AK. We found that above: below ratios in shrub were positively related to FC, which is consistent with the results of Lei *et al.* (2011) [22]. But Lane *et al.* (1998) [30] found high shrub productivity on coarse textured soil with low water-holding capacity, so the correlation between above ground biomass of shrub and FC needs further investigation. In grassland biomass allocation was not related to the soil physicochemical properties. However, two compartments both in shrub and grassland were significantly related to some of the soil properties, suggesting that the factors impacted on it were complicated. For example, pH and SBD were negatively related to biomass in both of shrub areas and grassland, which means that reduced pH and SBD can improve biomass. AK was negatively related to above ground biomass of shrub areas, but positively to grassland, suggesting that no addition K was needed in shrub when in balanced fertilization program. AP was mainly related to biomass of grassland, so increasing P can improve above ground productivity. Table 4 showed that SOM in shrubby areas was higher than in grasslands, and there was significant difference between them at the depth of 10-20 cm ($F=5.5$, $p<0.05$), suggesting that shrub areas were more effective than grassland in sequestering carbon.

CONCLUSION

According to our study, we found that cover, pH and available P were the main factors that caused the ratio of above- and below- ground biomass to be small. Other factors not specifically studied here, such as low temperature may be another cause, because the average temperature in the study area is 0-1.2°C. The relative humidity is 60%, so aridity might not be an important factor.

Soil organic matter is the largest terrestrial store of biologically active C and N [31-32], in which C and N often accounts for 52-58% and 3.7-4.1% respectively. Our research has identified some factors (e.g. pH, cover and available P) that suggest management practices such as phosphorus fertilization that may lead to increases in carbon accumulation in soils of the Qilian mountain area.

ACKNOWLEDGEMENTS

This work was supported by National Natural Science Foundation of China (41461109), the Major Program of the Natural Science Foundation of Gansu province, China (18JR4RA002), the Key Laboratory of Ecohydrology of Inland River Basin, Chinese Academy of Science (KLERB-ZS-16-01), and Opening Fund of Key Laboratory of Land Surface Process and Climate Change in Cold and Arid Regions, CAS (LPCC2018008).

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