P1.36 RESPONSE OF PLANT GROWTH TO SURFACE WATER BALANCE DURING A SUMMER DRY PERIOD IN CENTRAL EURASIAN STEPPE

Yoshihhiro Iijima*[1], Tsuneo Kawaragi[2], Takehiko Ito[3], Kanat Akshalov [4],
Atsushi Tsunekawa[3], Masato Shinoda[2]
[1] Hydrological Observational Research Program, FORSGC, Yokohama, Japan,
[2] Department of Geography, Tokyo Metropolitan Univ., Tokyo, Japan
[3] Faculty of Agriculture and Life sciences, Univ. of Tokyo, Tokyo, Japan
[4] Barayef Kazakh Grain Farming Research Institute, Shortandy, Kazakhstan

1. INTRODUCTION

Grasslands are located in the arid and semi-arid climate area and are one of the most widespread terrestrial ecosystems in the world. These regions are also sensitive to human- and/or climate-induced land degradation (desertification) mostly due to less water resources. According to model predictions (IPCC, 2001), it is likely that in most of arid and semi-arid areas water deficits will increase. In addition, interannual variability in above-ground net primary productivity (ANPP) in grasslands is greater and more strongly correlated with precipitation than any other ecosystems (Knapp and Smith, 2001). Improved knowledge of large-scale climatic and environmental factors regulating local water balance and plant growth associated with carbon fluxes is required to deal with issues of sustainability of the grassland ecosystems that will respond to the possible future climate change.

The short- and long-term productivity has potential to be intimately linked to the local water balance. In mid-latitude semi-arid grasslands, water is the primary factor limiting plant growth (Suzuki et al., 2000, Knapp and Smith, 2001). Water resources for plant growth in grasslands of the Central Eurasia comprise snow-melt water in the spring and rainfall during the growing season (Suzuki et al., 2000; Suzuki et al., 2003).

The Kazakhstan steppe is well-known as one of the largest granary in the Eurasian Continent. Soil fertility in this region is rich and can potentially produce high yield of crops. However, since hydro-climatic conditions are generally severe due to a small amount of precipitation with frequent occurrence of drought, water deficit is a major abiotic stress in this region. Therefore, crops are cultivated using not only rainfall during the growing season, but spring snowmelt water (Morgounv., et al, 2001). In the Central Eurasian semiarid region, snow disappearance timing is early to middle April (Shinoda et al., 2001) and the effect of snowmelt water on soil moisture was clearly observed during May (Shinoda, 2001). This timing coincides with the period when evapotranspiration exceeds precipitation likely due to the wet soil conditions (Ueda et al., 2003). This quasi-periodic water availability determines similar patterns of water use and limitations of growth among dominant species of natural grass and crops of the region. In the other words, ecosystem water balances in this grassland easily change due to altered precipitation and evaporation patterns. In particular, the occurrence of a drought has severe, negative effects not only on short-term plant production, but also on longer-term production (Briggs and Knapp, 1995; Haddad et al., 2002) and plant diversity (Tilman and El Haddi, 1992).

In order to evaluate the impact of hydro-climatic conditions on the local surface energy balance and plant growth on seasonal and annual time scales, inter-seasonal measurements of the surface energy balance components and plant biomass were conducted since 2002 at natural grassland in north part of Kazakhstan. We focused on the responses of evapotranspiration and above- and below-ground biomasses to soil moisture content, during the development of a summer dry period.

2. METHOD

Meteorological observation and biomass measurements were carried out from 1 May to 1 November, 2002 at the natural grassland in Shortandy (51.3 N, 71.2 E, 427 m) in the northern part of Republic of Kazakhstan. The surface conditions of the site are mostly flat. This area is entirely cultivated for wheat, sugar beets and a variety of other crops because of the highly productive soil.

Surface heat budget was observed using the Bowen ratio-energy balance (BREB) method, installing a Bowen ratio system. Other supporting climatic variables, such as wind speed and direction, precipitation, incoming and reflected short-wave radiation, photosynthetically active radiation (PAR), and volumetric soil moisture content were also measured.

* *corresponding author address*: Yoshihiro Iijima, Frontier Observational Research System for Global Change (FORSGC), 3173-25 Showa-machi, Kanazawa-ku, Yokohama, Japan 256-0001;
e-mail: yiijima@jamstec.go.jp

In order to estimate above- and below-ground biomass in the grassland, 4 sites of 1x1 m quadrate were set in 2 week interval from early May to mid-October, 2002. In the first site, plant coverage, height, above-ground alive and dead biomasses separately measured in each species. In addition, below-ground biomass down to 20 cm depth was also measured. In other three sites, measurements of coverage, height, above-ground alive and dead biomasses were identified between dominant grass (*Stipa Capillata*) and other species.

3. RESULTS AND DISCUSSION

3.1 *Climatological Variation in Water Balance*

Using long term climatological data observed in Shortandy during 1964 to 1986, we focused on water resources during cold season affecting the soil moisture in given spring.

Figure 1 shows averaged annual variations in soil moisture in layers from the surface to 1m depth. Soil moisture in all layers reached maximum in spring (late April), and in shallow layer (up to 20cm depth) gradually decreased until late June. After July, soil moisture in all layers simultaneously and abruptly decreased and reached minimum in early September. This drying period is recognized as summer dry season. Then, soil moisture in the shallow layer (20cm depth) came to be refilled with autumn rainfall.

Three water resources affecting soil moisture in spring are defined here as rainfall in previous autumn (W_{aut}), snowmelt water (W_{snow}), and rainfall between snowmelt and the beginning of plant growth (W_{spr}). W_{aut} and W_{spr} are total rain amounts during autumn and spring, respectively, when pentad air temperature is between 0°C and 5°C. W_{snow} is maximum snow water equivalent during a month from snow melt pentad.

Figure 2 demonstrates interannual variations in those three water resources and soil moisture content in given spring. The sum of three resources well correlated to the given spring soil moisture (Fig. 2d). W_{aut} and W_{snow} reaches 40 % of contribution and W_{aut} is most correlated. Four years exceeding 150 mm in total were caused due to large precipitation at one pentad or large amount of snow. That is, some part of water was likely removed as run off.

3.2 Climatological Variation in Water Balance

Seasonal variations in energy balance and hydro-climatic factors (daily precipitation and soil moisture) showed characteristic transition of water balance during the growing season (Fig. 3). Soil moisture at the depth of 20 cm (Fig. 3a) exhibits a remarkable difference before and after mid-July in conjunction with the frequency and intensity of

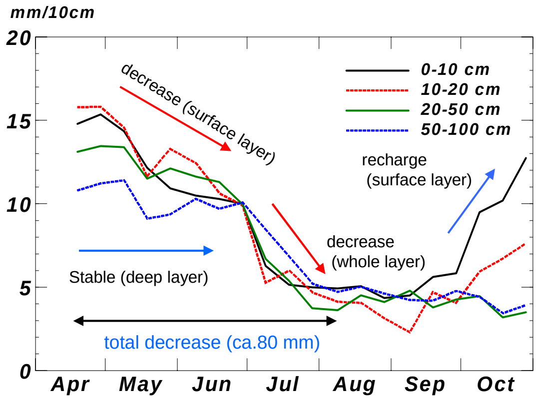

Figure 1. Seasonal variation in 10-day plant-available volumetric soil moisture (the difference from wilting point) for four layers of 0-10 cm, 10-20cm, 20-50cm, and 50-100cm at a wheat field of the Kazakhstan Research Institute of Grain Farming. The values were averaged over the period from 1972 to 1985.

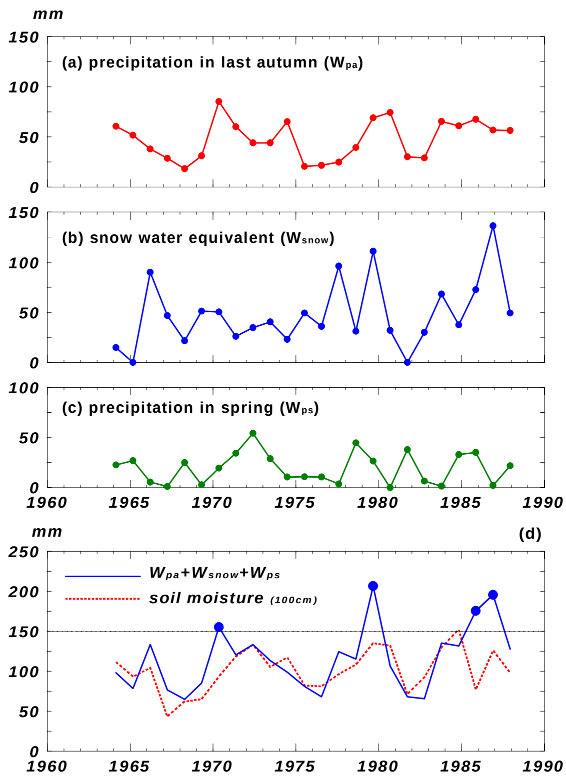

Figure 2. Interannual variation in (a) precipitation in autumn, (b) snow water equivalent, (c) precipitation in spring, and the sum of three resources and spring volumetric soil moisture.

precipitation (Fig. 3b). That is, wet conditions with more than 30% in volumetric content lasted from May to mid-July, whereas a gradual decrease began after mid-July and finally reached to the value less than 15% in late August. This seasonal pattern is similar to those for central Eurasian stations in the similar latitude (Shinoda, 2001). From May to August, net radiation (Rn) had a high value exceeding 15 MJ m^{-2} day^{-1}, and the partition of latent and sensible heat fluxes also varied corresponding with variations in the soil moisture and precipitation (Fig. 3c). During the wet season, the latent heat flux (lE) was the main partitioned components, frequently exceeding the half of the Rn. A switch in major energy component from lE to H dominated occurred in association with a soil moisture reduction after mid-July.

A decrease in soil moisture content influences the evaporative fraction lE/R_n. The evaporative fraction ranged from 0.4 to 0.8 when there was abundant soil moisture during the wet season. In contrast, when soil moisture reduced during the early stage of the summer dry period, the evaporative fraction (around 0.4) remained nearly constant. These conditions indicate that evaporative water was effectively supplied by soil moisture. Soil moisture had already stored and kept since the snowmelt season and mitigated the reduction of evaporation in accordance with progressing summer dry season at this site. Subsequently, soil moisture decreased to less than 20% during peak stage of the dry period, corresponding with abrupt decrease in the evaporative fraction to 0.1.

Continuous difference in water balance occurred between seasonally accumulated evapotranspiration and precipitation (Fig. 4). During May, evapotranspiration was active and equivalent to equilibrium evaporation, whereas the precipitation could not satisfy the evapotranspiration. The result showed that deficit in water balance between evapotranspiration and precipitation reached 40 mm during May and finally 93 mm on late August. According to Hunt et al. (2002), evapotranspiration was equivalent to 93% of precipitation over the summer at tussock grassland in New Zealand. Wever et al. (2002) also showed that the cumulative evapotranspiration balanced with cumulative precipitation based on a multiyear observation. According to seasonal course of soil moisture profile, soil moisture within the near-surface layers was substantially reduced before dry season in conjunction with plant growth. Thus, remarkable characteristic in Kazakh steppe is that the soil moisture in deeper layers compensated the deficit during summer dry period.

3.3 Response of plant growth

Above-ground alive and dead biomasses showed

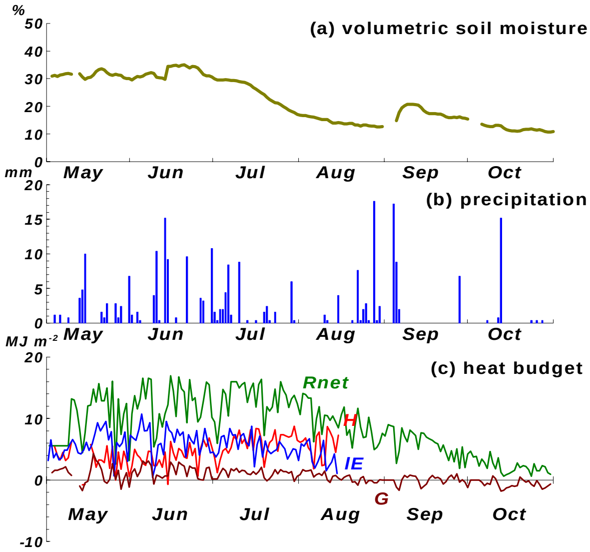

Figure 3. Seasonal variations in (a) volumetric soil water content at the 20 cm depth, (b) daily precipitation, and (c) the components of surface energy balance; net radiation (green line), sensible heat (red line), latent heat (blue line), and ground heat (brown line). W_{fc} and W_{wp} respectively mean reference values of field capacity (35.6%) and wilting point (17.8%) measured at wheat field by Kazakhstan Research Institute of Grain Farming.

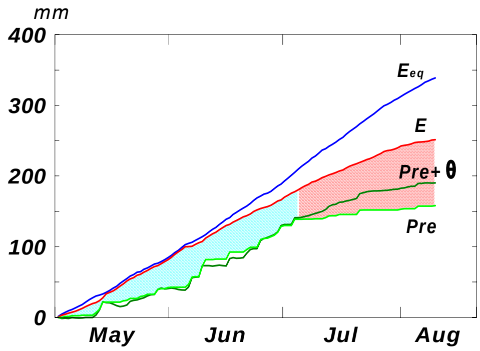

Figure 4. Cumulative precipitation (green line), evaporation (E, red line), and equilibrium evaporation (Eeq, blue line) during the observational period. Pre+θ (black line) denotes the sum of cumulative precipitation and soil moisture reduction in the top 20 cm layer of a dense root system. The average θ in the layer was assumed to be the value for 20 cm depth.

characteristic seasonal variations due to the occurrence of the summer dry period (Fig. 5). Additional indices of plant growth, namely PAR albedo and vegetation height, are also shown. As measured as NDVI (normalized difference vegetation index), the PAR albedo also indicates a phenological change in vegetation activity. PAR albedo also indicates a phenological change in vegetation activity. PAR albedo decreased rapidly and reached to the minimum value (7%) at early June (Fig. 5a). Since the vegetation cover is high (70% of the surface) at the site, PAR albedo, that is, greenness of the surface showed a quick response to simultaneous sprouting of plants. Above-ground alive biomass consistently increased until the beginning of the dry period. Dead fraction of the above-ground biomass inversely decreased. During the summer dry period, alive biomass exhibited a gradual decrease, and dead biomass turned to increase. After mid-September, increasing trend of dead biomass indicated a transition to the senescence. The peak of vegetation height showed a large delay comparing with greenness and biomass variations.

During the wet season, active plant growth produced high transpiration. Subsequently, evaporative fraction (lE/R_n) was somewhat stable (0.4), until soil moisture reduced to the wilting point during the early stage of the dry period. The mature plant was likely to tap deeper sources of soil moisture during the early stage of the drought. After the reduction of soil moisture, the transpiration was substantially weakened. Thus, the abrupt reduction in transpiration during the peak stage of the dry period implied changes in physiological response of both above- and below-ground structure to the very dry soil.

Consequently, it appeared that the response to the soil moisture variation was quite different between the above- and below-ground biomasses (Fig. 6). The growth ratio of above-ground alive biomass is positively correlated with soil moisture content (Fig. 6a), while the growth ratio naturally depends on the different phenological stages of growth and senescence. In contrast, the below-ground biomass temporally decreased during the summer dry period, while it increased again as the dry conditions progressed (Fig. 6b). The growth ratio of above-ground alive biomass is positively correlated with soil moisture content. In contrast, the below ground biomass did not show a significant correlation with soil moisture, whereas it grew even under the summer dry conditions. In brief, it implies that during dry period, the assimilation of plants could not sustain above-ground alive biomass, but a major portion of the assimilation was allocated to the below-ground biomass.

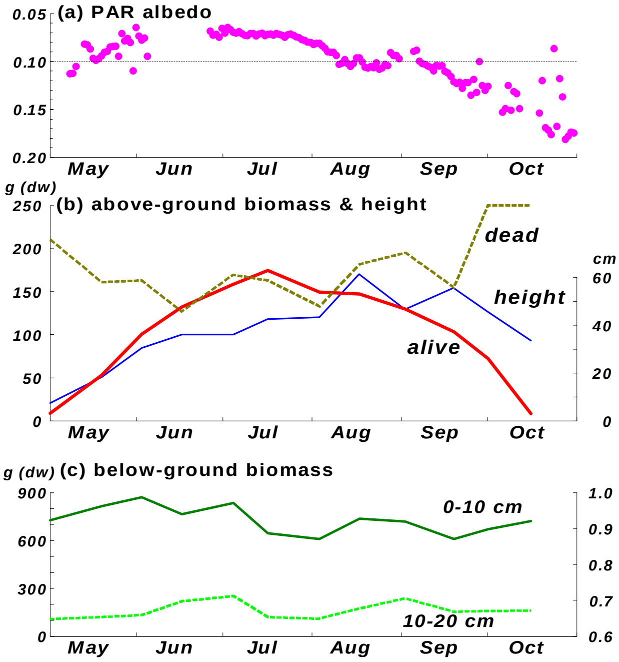

Figure 5. Seasonal variation in (a) PAR albedo, (b) above-ground alive (red line) and dead (brown line) biomass and grass height (blue line) of plant community, and (c) below-ground biomass (green lines). Note that the y-axis of (a) is upside down.

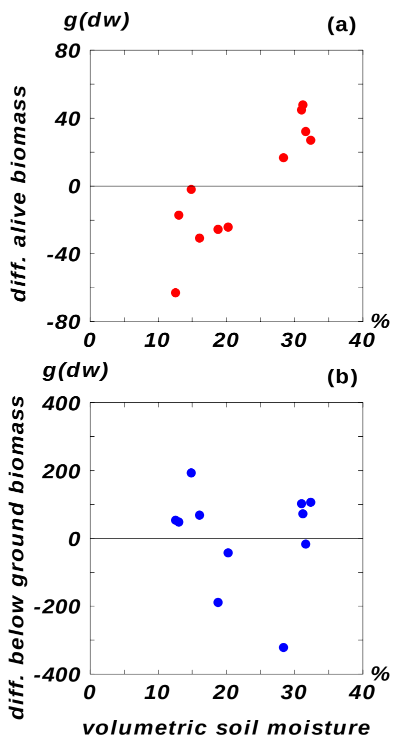

Figure 6. Relationship between soil moisture content and growth ratio (g $m^{-2}day^{-1}$) of (a) above ground alive biomass and (b) below ground biomass

4. CONCLUSION

Seasonal variations in surface energy/water balance and plant biomass over grassland were explored during the growing season of 2002. In this year there was a less precipitation period from mid-July to mid-August. Plant growth measured as PAR albedo and above-ground alive biomass was enhanced, being associated with high soil moisture content (from May to mid-July). After mid-July, soil moisture rapidly decreased, and the grasses turned to be withered. The evaporative fraction (lE/Rn) was high (exceeding 60%) during the wet season (from May to mid-July), while it reached to the minimum level (20%) as the soil moisture was reduced. Taking the high vegetation cover (exceeding 70%) and abundant dead biomass into account, most part of the evaporative water comprised transpiration through the dominant grasses.

The present study demonstrated the strong influence of soil moisture on the growth of natural grassland in the Kazakhstan steppe. Soil moisture added due to the spring snowmelt was used for evapotranspiration, compensating the lack in precipitation during the summer. Interannual soil moisture anomalies at the initial stage of the growing season, due to the combined contribution of autumn precipitation, snowmelt water, and spring precipitation, should be related to the plant growth during each phenological stage of the grassland. In addition to the soil moisture variability, interannual frequency and intensity of summer drought may cause not only water stress on plant growth but also hydro-climatic feedback through evaporation processes over the grassland. The feedback on the atmosphere should be examined through the analyses of the large-scale atmospheric moisture budget (Ueda et al., 2003). Although observation of carbon dioxide flux was not performed, our observational evidence of water balance and plant growth, which are closely related to the carbon cycle, is believed to fill the gap of our knowledge of ecosystem dynamics in the Central Eurasia where observational investigations have been rare.

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