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SUMMARY OF DOCTORAL THESIS

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Title: Estimation of pasture productivity in Mongolian grasslands: Field survey and Model simulation

モンゴル草原における牧草生産力の推定：
現地調査およびモデルシミュレーション

Mongolia is a country of nomadic livestock husbandry and its economy is dependent on livestock products. Natural grasslands are the main source of forage for these animals, and grassland productivity is strongly influenced by the country's dry, continental climate. The production of natural grassland is regulated by many factors, such as soil moisture, temperature, solar radiation, soil nutrient availability, and grassland utilization and management. Of these, soil moisture is the most critical and limiting factor determining the efficiency of plant radiation utilization and vegetation productivity in the country. A drying trend has recently been observed in soil moisture, further limiting pasture growth. This background emphasizes the importance of gathering accurate and timely information about pasture productivity for livestock survival. However, direct measurements can be difficult to gather, especially in remote areas of a large country like Mongolia. It is therefore essential to develop and validate models against observed measurements to estimate pasture productivity widely. The main aims of this thesis were to quantify input parameters (PAR/SR: the ratio of photosynthetically active radiation to solar radiation; and RUE: radiation use efficiency) of Production Efficiency Model (PEM) and to examine the suitability of PEM modified using the quantified parameters to estimate pasture productivity in the following vegetation zones: desert steppe, dry steppe, steppe, and forest steppe. A list of the main findings from this study given below:

First, the relationships between aboveground biomass (AGB) and precipitation were revealed. In this analysis, datasets for 15 sites were used, spanning the years 1986–2005. The results demonstrated that cumulative precipitation during the growth period had the highest significant correlation with AGB. When considered on a monthly basis, these data showed that precipitation in June had the most significant impact on AGB in forest steppe, whilst precipitation in July was most significant in desert steppe and steppe zones. Moreover, at the desert steppe sites, where conditions are relatively dry, precipitation was strongly correlated with AGB, independent of event size, and even small precipitation events (≤ 5 mm) significantly affected AGB. Conversely, in the steppe and forest steppe zones, where conditions are relatively wet, AGB did not alter at small precipitation events, whereas large precipitation events (≥ 5.1 mm) tended to contribute to plant growth. This result suggests that more frequent and small precipitation events do not benefit vegetation growth in steppe and forest steppe zones. The results of this study provide an important contribution to experimental studies on

the water requirements of natural grassland.

Second, the input parameter of PAR/SR for the PEM was quantified at Bayan Unjuul. The lowest monthly ratio occurred in April and December (0.42), while the highest ratio occurred in July (0.459). The annual mean was 0.434, which is lower than that reported in many previous studies due to drier conditions in the region. During the growth period (April–September), the ratio was 0.438 and this was used in the PEM to estimate aboveground net primary productivity (ANPP). The variation of PAR/SR is largely attributed to differences in sky condition (clearness index) and water vapor in the atmosphere (water vapor pressure). A significant and negative correlation was found between the clearness index and PAR/SR (r = -0.36, $p < 0.05$), while a significant and positive correlation was found between water vapor pressure and PAR/SR (r = 0.48, $p < 0.05$). These findings are consistent with previous studies. This is the first time that PAR/SR, a key input parameter for radiation-based models, has been determined for Mongolia.

Third, to quantify RUE, AGB and above and below-canopy PAR were measured at Bayan Unjuul under different conditions of soil water and air temperature during the growing season of two years. A wide range of RUE (0.23–1.06 g AGB/MJ intercepted PAR (IPAR)) was found in negative correlation with soil water and low temperature stresses. Compared with the temperature stress, the water stress was a strong down-regulator on RUE, verifying that drought is a major concern for radiation utilization in the study area. The maximum RUE was 2.34±0.16 g AGB/MJ IPAR by excluding the effects of water and temperature stresses, and this was used in the model to estimate ANPP. This is the first study to provide the important model parameter of RUE for natural grassland in Mongolia under various levels of seasonally varying water and temperature conditions.

Fourth, the PEM (using the quantified parameters) was used to estimate pasture productivity at four sites in distinct vegetation zones of Mongolia: Mandalgovi (desert steppe), Bayan Unjuul (dry steppe), Darkhan (steppe), and Bulgan (forest steppe). Simulation results demonstrated that the highest ANPP of 68.2 g carbon (C)/m^2 and the lowest ANPP of 6.9 g C/m^2 over the growing season (April–September) occurred at Darkhan and Mandalgovi, respectively. Moreover, a comparison of the effect of temperature and water stresses on pasture productivity indicated that water stress was a stronger down-regulator of ANPP. The comparison between measurements and the simulation indicated that simulated ANPP was similar to measured AGB for Mandalgovi and Bayan Unjuul, whereas simulated ANPP tended to overestimate actual AGB for Darkhan and Bulgan.

This thesis represented advances in the field observation and in modeling of pasture productivity in the semi-arid region of Mongolia. This is the first attempt to estimate pasture productivity in the country by applying quantified parameters to the PEM. The model has the advantages of using a simple calculation method which does not require the complex eco-physiological parameters. The model results demonstrate that the parameterized PEM was applicable to dry regions, whereas further model modification is needed for relatively wetter and colder regions.

In the future, advanced technology such as remotely sensed data and Geographical Information Systems should be used alongside this model to represent the spatial distribution of pasture productivity in dry regions. This approach will generate valuable information on feed availability and the efficient management of livestock grazing, which is of great use to herders and decision-makers.