A SYSTEM MODEL FOR SHORT AND LONG TERM PREDICTION
OF GRAZING PASTURE PRODUCTIVITY

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SUMMARY

It is very important for pasture managements to be able to forecast the short term productivity of pasture, and to clarify the conditions under which high and stable pasture productivity can be maintained for long term. In the predictions for the period from Mar. to Nov. in 1982, gain in animal body weight and grass production were well estimated. And using results of long term simulations computed under the assumptions of various grazing pressures an optimal grazing intensity was determined.

1. Introduction

Studies of grassland ecosystem require so large area, even in an experiment, that it is impossible to conduct any replication experiment in most cases as is usual with crop experiments. Moreover, a grassland ecosystem is usually made up of many environmental and biological factors, which constitute to production in the ecosystem, and the interactions between them are complicatedly entangled with each other. For these reasons, it has not been easy to build

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reproductive experiments but introduction of the system concept, high speed computers and ecosystem ecology studies applied to grassland research in the latter half of 1960's provided a way to the future course in grassland research. In system approaches for grassland ecology, each pasture is recongnized as a system, functions in the system are expressed by a system model, and this model is exposed to computer simulations for hypothetical comparisons of productivity between different livestock production systems or in the search for a pasture system having the highest potential productivity.

The system approach to pasture ecosystem and simulation studies based on the system model have been carried out for the following purposes: (1) To clarify various functions and interactions between functions which affect the pasture productivity. (2) To forecast short term productivity of pasture, i.e. productivity for a year or for one season, and to make decisions for short term pasture management, such as grazing intensity and amount of fertilizer to apply. (3) To clarify the conditions under which high and stable pasture productivity can be maintained for long terms, e.g. 10 years or more, because pasture plants are perennial and because ideally land should be utilized for many years continuously. (4) To compare efficiencies of various livestock production systems, and to decide what system or what combination of systems is best. In the following sections, a system model of grazing pasture built for purposes (1) to (3) will be discussed. More details will be presented by Shiyomi et al.(in preparation).

2. A grazing pasture system model

In a grazing pasture, solar energy is patially fixed

by pasture plants, some parts of these plants are consumed by animals, and some portion of the plants consumed is fixed as energy in animal bodies(Akiyama et. al, 1982). Escaping portions of energy from these fixations are accumulated in the soil via feces or dispersed into the atmosphere as heat from animals. Residual portions of plants change into standing dead material and then into litter, and finally accumulate in the soil. The system of energy flow in a grazing pasture from sun to animals or soil is shown in Figure 1. In this figure, the amounts of energy accumulated in the system are denoted by flags or rectangles; directions of energy flow are indicated by arrows; and external effects including environmental and artificial effects on the energy flow are denoted by elipses, and these effects work at the points shown by broken arrows. Bows pointed at by broken arrows indicate valves for regulating energy flow. For example, leaf area index(LAI) affects the amount of energy flow from sun to plants, that is, in a manner of speaking, if the valve is opened, LAI becomes larger and then the amount of energy fixed in plants increases.

The amounts of energy in 8 different states in a pasture, shown in Figure 1, are as follows: portion available to animals(available herbage) V_1 , unavailable herbage V_2 , below-ground plant portions V_3 , standing dead material V_4 , litter accumulated on the ground surface (litter) V_5 , herbage consumed by cattle V_6 , total body weight of cattle V_7 , and amount of feces V_8 . All these are measured in calorific values. These amounts in 8 states are called 'state variables' hereafter, and change with time t . Changes in these variables can be formulated into a set of differential equations in the following form.

$$\dot{V}_1 = f_{01}Q_0 + f_{21}V_2 + f_{31}V_3 - (f_{12} + f_{14} + f_{19})V_1 - F_{16}$$

Figure 1. Compartment model of energy flow on a grazing pasture(see text).

$$\begin{aligned}
\dot{V}_2 &= f_{02}Q_0 + f_{21}V_1 + f_{32}V_3 - (f_{12} + f_{23} + f_{24} + f_{29})V_2 \\
\dot{V}_3 &= f_{23}V_2 - (f_{31} + f_{32} + f_{39} + f_{310})V_3 \\
\dot{V}_4 &= f_{14}V_1 + f_{24}V_2 - f_{45}V_5 \\
\dot{V}_5 &= f_{45}V_4 - f_{510}V_5 \\
\dot{V}_6 &= F_{16} \\
\dot{V}_7 &= f_{67}F_{16}h_1 - F_{79}h_2 \\
\dot{V}_8 &= f_{68}F_{16} - f_{810}V_8, \text{ if there are cattle in the given} \\
&\quad \text{block,} \\
&= -f_{810}V_8, \text{ if there are no cattle in the block,}
\end{aligned} \tag{1}$$

where $\dot{V}$ denotes dV/dt . In Eq. 1, the unit for these variables, except V_7 , is kcal/m^2 and the unit for V_7 is kcal/ha . Coefficients in Eq. 1, f_{ij} 's, denote energy flow rate or speed from state i to another state j , and generally they are also functions of time t . They change with season and every environmental change. These coefficients are called 'rate variables' hereafter. Q_0 is the global solar radiation arrived at the pasture, and it is expressed by a sine function of time t . Rate variables f_{01} and f_{02} are efficiencies of solar energy to V_1 and V_2 , respectively. Rate f_{i9} 's are coefficients concerning energy losses from V_i by respiration, and f_{i10} 's are coefficients concerning energy transfer from V_i to soil. F_{16} is the amount of energy taken in by grazing, and F_{79} is the amount of energy loss by respiration of cattle. Parameters h_1 and h_2 are constants concerning the area of the grazing pasture and the number of individual cattle, respectively. Q_0 and f_{ij} 's are either functions of days starting from Mar. 1 or air-temperature. Explanations about rate variables are omitted in this paper. Refer Shiyomi et.al(in preparation).

3. Simulations

1) Short term prediction of grazing pasture productivity

When the condition of the pasture on Mar. 1 and the total body weight of the cattle on the pasture at the beginning of the grazing period were given and pasture productivity was calculated using Eq. 1, where normal meteorological conditions measured at National Grassland Research Institute, which indicate average for 30 years, were used in calculations, results are obtained as in Figure 2A. It is obvious from Figure 2A that the predicted animal production are rather lower than the actual observation. As air-temperatures from late May to middle June were considerably higher than temperatures in the normal year, it is assumed that plant growth during period was much accelerated. Parameter values were therefore changed as follows: (1) the amount of energy transfer from below-ground to above-ground plant portions between May 20 and June 19 was increased to 1.5 times the original; (2) digestibility of herbage between April 19 and May 20 was increased from 0.65 to 0.71; and (3) if (dry matter weight of herbage per ha)/(total body weight of animals) was less than 0.1, each of the individual cattle consumed an amount of dry herbage corresponding to 2.2% of their individual body weight; otherwise 2.5%. These revision greatly improved simulated results as shown in Figures 2B and C. This model will be used for predicting pasture productivity at the same experiment site in 1983.

2) Long term prediction for grazing pasture productivity

Any pasture has to be maintained for a long period, for example, 10 years or more. For this reason, unless

Figure 2. (see the next page).

Figure 2. Prediction for a experimental pasture in 1982. A. Prediction calculated by using the initial values for the spring of 1982 and the meteorological data for a normal year: original; B. Calculation where the amount of energy transfer from under-ground portions to above-ground portions between May 20 and June 19 was increased to 1.5 times the original; C. Calculation where digestibility of herbage between Apr. 19 and May 20 was increased from 0.65 to 0.71, furthermore. G: above-ground biomass exposed to grazing, N: above-ground biomass in protected cages.

b1: below-ground biomass, observed
b2: " , predicted
b3: " , calculated
a1: above-ground biomass, observed
a2: " , predicted
a3: " , calculated
t1: total body weight of cattle, observed
t2: " , predicted
t3: " , calculated

changes in pasture productivity for various agricultural actions are adequately predicted, non-effective or excessive investments may be made for pasture or the pasture may be wasted. This preliminary work shows the possibility for long term predictions of grassland productivity using a system model and its simulations.

The model is a mimic of the experimental pasture in National Grassland Research Institute. In this model, a pasture of 2 ha is divided into 4 equal blocks, a herd, whose total body weight on April 15 is 1450kg, is released to graze on one of the blocks, the herd is moved on these 4 blocks according to a previously determined rotation shedule from April to Nov. every year. In the calculations, mean air-temperature in the normal year was utilized. The simulated result is shown in Figure 3a and it is called 'standard'. A course of annual and seasonal changes over a 10 year period, i.e. for 3650 days, is shown in this figure, and the trends between years are very similar as a natural consequence. The simulated results roughly approximate the actual results observed in the National Grassland Research Institute for 8 years, that is, the above-ground and below-ground plant biomasses attain peaks around May and June (300g and 600g dry weight/m², respectively) in both cases. Per-capita daily weight gain is 0.32kg live weight and total gain weight per herd for a year, which is made up of 9 young individuals, is 586kg live weight.

It was assumed, in the above calculations, that 9 individual cattle were put out to graze; but now, let us assume the next step 18 young individuals are grazed on the same pasture for 10 years. What is the result? This calculation is shown in Figure 5b, and indicates a decrease in plant biomass, especially in below-ground biomass when

Figure 3. Simulations of pasture productivity under 3 different grazing intensities over a 10 year period. a. Standard where the total body weight of cattle was 1540 kg/9 capita/ 2 ha and meteorological conditions are for a normal year; b. Calculation under conditions where grazing intensity is raised to twice that of standard; c. Calculation under condition where the grazing intensity is raised to 3 times that of standard. a*: under-ground plant biomass, b*: per-capita body weight of cattle, c*: above-ground plant biomass, d*: standing dead material, e*: surface litter.

compared to the results with only 9 individuals. But the increase in animal body weight with time does not change from the results produced by the 9 individuals, that is, per-capita daily gain remains at 0.32kg and total gain is 1171kg per year, which is just twice the result with the 9 individuals.

What changes would occur when grazing intensity on the same pasture is raised to 3 times standard? The calculated result is shown in Figure 3c, indicating a shortage of herbage for grazing animals. In this calculation, per-capita daily gain is 0.03kg and total gain is 342kg for a herd constituted of 27 individuals.

From this series of 3 simulations shown in Figure 3, it is obvious that optimal herd size is between 18 and 27 individuals. Now, per-capita daily gain and total gain per year calculated for various herd size are shown in Figure 4.

Figure 4. Decision for an optimal grazing intensity, assuming that the number of individuals shown in this figure graze for 203 days starting from Apr. 15, where the weight of each individual is 171.1 kg on that day. Real line: changes in total weight gain for various grazing intensities; dotted line: changes in per-capita daily weight gain under various grazing intensities.

In this calculation, 0.32kg in per-capita daily gain can be maintained up to a herd size of 19.5/2 ha, and maximum total gain per year can be attained at a herd size of 18.7/2 ha under the meteorological conditions of the normal year. In this way, an optimal herd size can be estimated.

4. Conclusions

The following conclusions are derived from the present work.

(1) The model utilized in this study originates from the Okubo's(1977) Zoysia grassland ecosystem model in Iwate Prefecture and its modification by Shiyomi et. al(1982). It becomes clear in this study that the model once established is widely applicable for grassland under various conditions such as might exist in different districts and with different compositions of grass species if adequate modifications are made on the model.

(2) As shown in this work, long term and short term predictions of pasture productivity can be realized by a system model and its simulations. These predictions can efficiently offer desirable techniques for managing grassland and grazing animals since it will be possible to forecast for pasture where grazing conditions, such as grazing intensity and fertilizer application, are varied.

(3) Continuous improvement of the system model are required for exact predictions. Especially, changes in pasture productivity brought on by fertilizer application, supplemental feeding when the amount of available herbage is not sufficient, and the role of decomposers in the soil have to be incorporated into the model.

(4) It is very important to obtain reliable long term meteorological predictions extending over several

months in order to calculate an exact prediction in pasture productivity, but it is not easy to predict long term weather conditions at the present time.

(5) It is widely expected that grazing techniques will be developed using computer simulations for increasing efficiency in utilizing solar energy.

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