Grassland Management Models

By MASAE SHIYOMI*

Ecology Division, National Grassland Research Institute
(Nishinasuno, Tochigi, 329-27 Japan)

Introduction

Grasslands in Japan are of two types, i.e., (1) natural grasslands composed of, for example, dwarf bamboo, *Miscanthus*, *Zoysia* and understory forest plants and (2) artificial grasslands established by reclamation and seeding improved grasses and legumes. Artificial grasslands are usually managed by agricultural techniques, but natural grasslands have been utilized and maintained for ages by so-called ecological management. The ecological management is universal because most of earth's grasslands are of the natural type. Since a team headed by the late Prof. van Dyne started constructing models for managing the Great Plains grasslands in Colorado, many models have been established for managing natural grasslands in various countries including Japan, especially in the course of the International Biological Programme (IBP). The largest-scale example is a system model, called ELM, constructed by the Colorado University Team led by Innis[4]. It is equipped with 9 submodels: producer, plant phenology, insect consumer, decomposer, mammalian consumer, temperature, water, nitrogen and phosphorous.

Attempts at grassland management using such system models have been extended from natural grasslands to artificial grasslands, and these models are intended to be used for estimation and control of energy and matter flow. Although grassland management by system models has not fully developed, the model development for grassland management will be reviewed in the present paper. Due to limited space available, only the outlines are presented. Most mathematical procedures are omitted in this paper.

Energy flow model

In the 1970s a Grassland Team of the IBP and the Ecology Division of the National Grassland Research Institute (NGRI) in Japan started modeling studies of energy flow in grazing grasslands. First, Okubo et al.[7] developed an energy flow system model of *Zoysia japonica* natural grassland on Nanashigure-yama, where they measured energy and matter flow for two years. Okubo's concept is shown in Fig. 1-a as a compartment model. Each compartment is expressed by a rectangle and v_i indicates the amount of energy stored in the i-th compartment. The increment or decrement of energy in each of the compartments at any given instant is determined by differences between inflow and outflow. This can be mathematically formulated by a set of 8 differential equations, i.e., an instantaneous change in the amount of energy in the i-th compartment, v_i, is expressed by dv_i/dt. Results obtained from simulations using this model are shown in Fig. 1-b which indicates two cases: with and without grazing cattle. This management difference caused different seasonal changes of herbage biomass.

Shiyomi et al.[13] constructed, an improved model of artificial grasslands with improved grasses and legumes on the basis of Okubo's model. This model is also a compartment model as shown in Fig. 2, and can be written as a set of differential equations. In this

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Present address:

* Plant Ecology Division, National Institute of Agro-Environmental Sciences (Tsukuba, Ibaraki, 305 Japan)

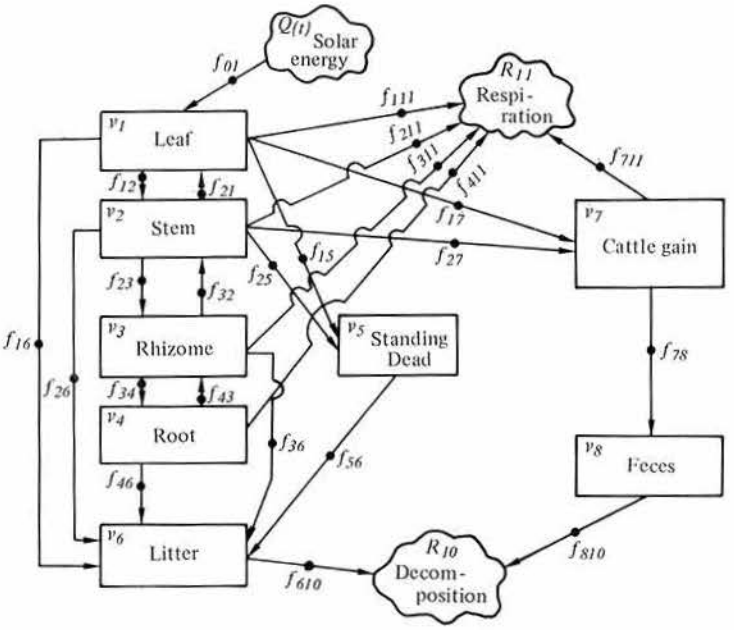

Fig. 1-a. Compartment model for *Zoysia japonica* grassland at Nanashigure-yama, Iwate, by Okubo et al.[7], showing energy flow from the sun to grassland
Rectangles and cloud-like shapes denote state variables and source-sinks, respectively.

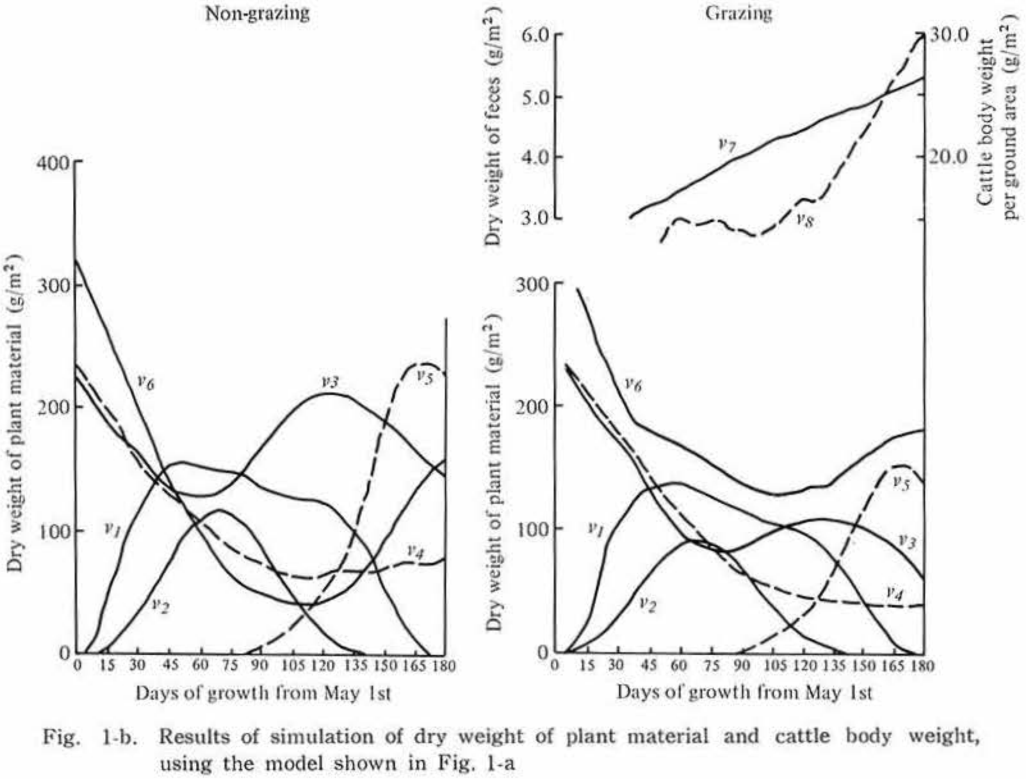

Fig. 1-b. Results of simulation of dry weight of plant material and cattle body weight, using the model shown in Fig. 1-a

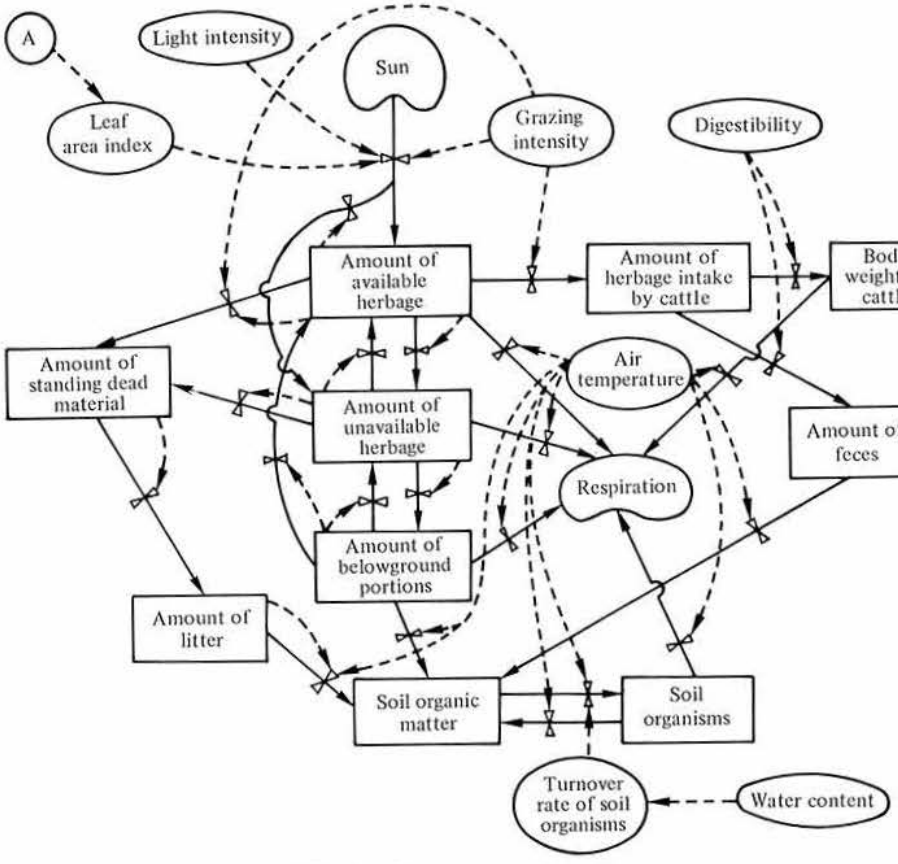

Fig. 2. Compartment model describing energy flow for an artificial grassland by Shiyomi et al.[13]
Solid and broken lines denote energy and information flows, respectively. Rectangles, cloud-like shapes and ellipses denote state variables, source-sinks, and rate variables, respectively.
Ⓐ indicates relationship with nitrogen flow in Fig. 4.

model, solar energy flows to herbage, and it runs from herbage to cattle by feeding and some portion of it is accumulated in cattle bodies. According to Akiyama et al.[1] and Takahashi et al.[15,16], annual solar energy at NGRI is about 10^{10} kcal/ha, its accumulation in plants is about 5×10^7 kcal/ha/yr, and its accumulation in cattle bodies is about 10^6 kcal/ha/yr. Other portions of energy contained in herbage flow to belowground plant parts or dead materials and litter. These flows are influenced by various environmental and artificial factors expressed as ellipses in the figure. For example, the amount of energy lost by plant and livestock respiration is influenced by the ambient air-temperature. Grazing intensity and fertilizer application, for example, are artificial factors, which can control energy flow or energy production on grassland. Arthropods may also effect energy flow on grasslands, but its effect is negligible[12], so that not shown in Fig. 2.

Recently Okubo and Jacquard[6] proposed a new model in which plants (producer), animals (consumer) and soil microorganisms (decomposer) have structures of an analogous ecological system. The concept is shown in Fig. 3.

Nitrogen flow model

In the foregoing energy flow model, grazing

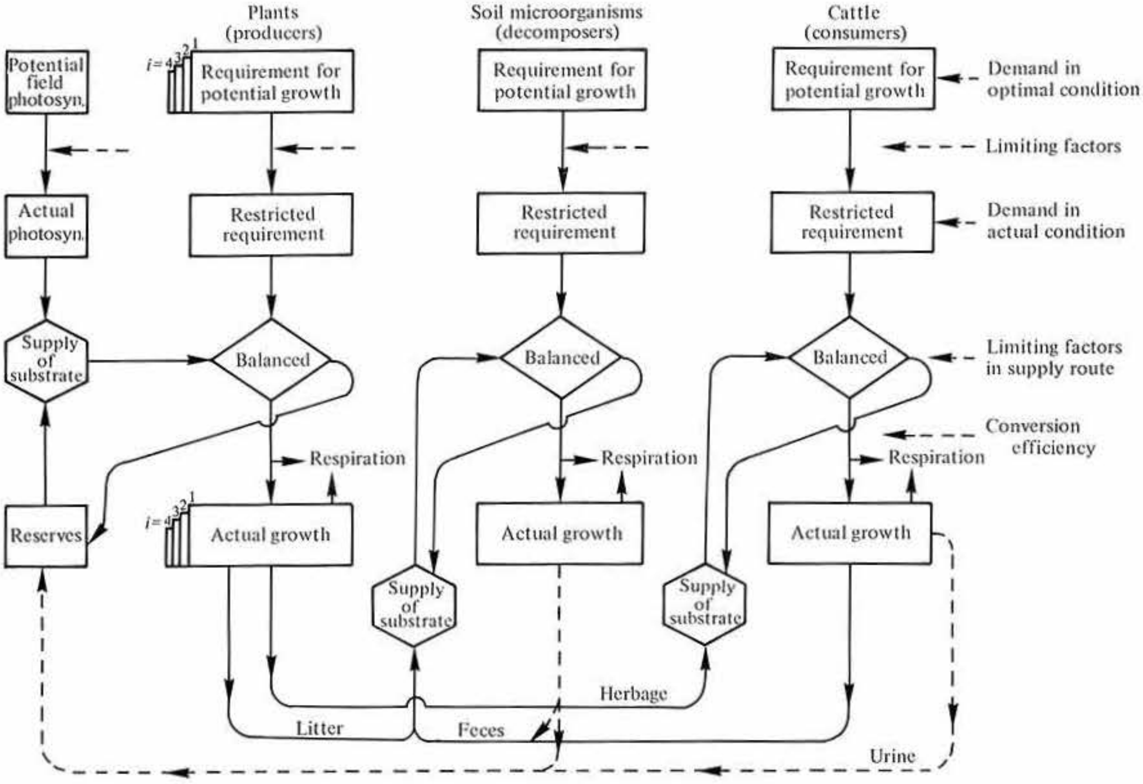

Fig. 3. Demand-supply relationship model for plant-animal-soil microorganism system by Okubo and Jacquard[6]

intensity is included as a factor of artificial grassland management. Another major factor is fertilizer application especially in intensive grassland management. Fig. 4 gives a compartment model showing nitrogen dynamics in a grassland ecosystem. Nitrogen concentration in plant aboveground parts in Fig. 4 relates to leaf area index, LAI, indicated by Ⓐ in Fig. 2, so that when nitrogen concentration in leaf tissue increases, LAI increases. Through this effect, as nitrogen concentration in plant aboveground parts increases, photosynthesis increases. Details of this model is included in Shiyomi et al.[14], although a mathematical description is omitted here to avoid complexity.

Results of simulation, showing seasonal changes in herbage biomass and amounts of nitrogen in biomass, are shown in Fig. 5. This simulation was conducted on the assumption that meteorological and grazing conditions are similar to those at NGRI (Table 1), and began on March 1 at the early spring condition. Fig. 5(A) mimics actual grazing pasture at NGRI, where cattle are grazed from mid-April to early-November, and 27 kg N/ha is applied both in May and August, while Fig. 5(B) shows a case of applying a total of 216 kg N/ha by split application (4 times). Herbage biomass peaks in May or June in both cases. The zigzagged seasonal herbage biomass changes are caused by grazing in the simulation of an actual rotation grazing schedule at NGRI. Comparison of (A) and (B) shows that herbage and animal production on grassland varies with different management.

Energy and nitrogen budgets obtained from analogous simulations as mentioned above are shown in Table 2. The amount of photo-

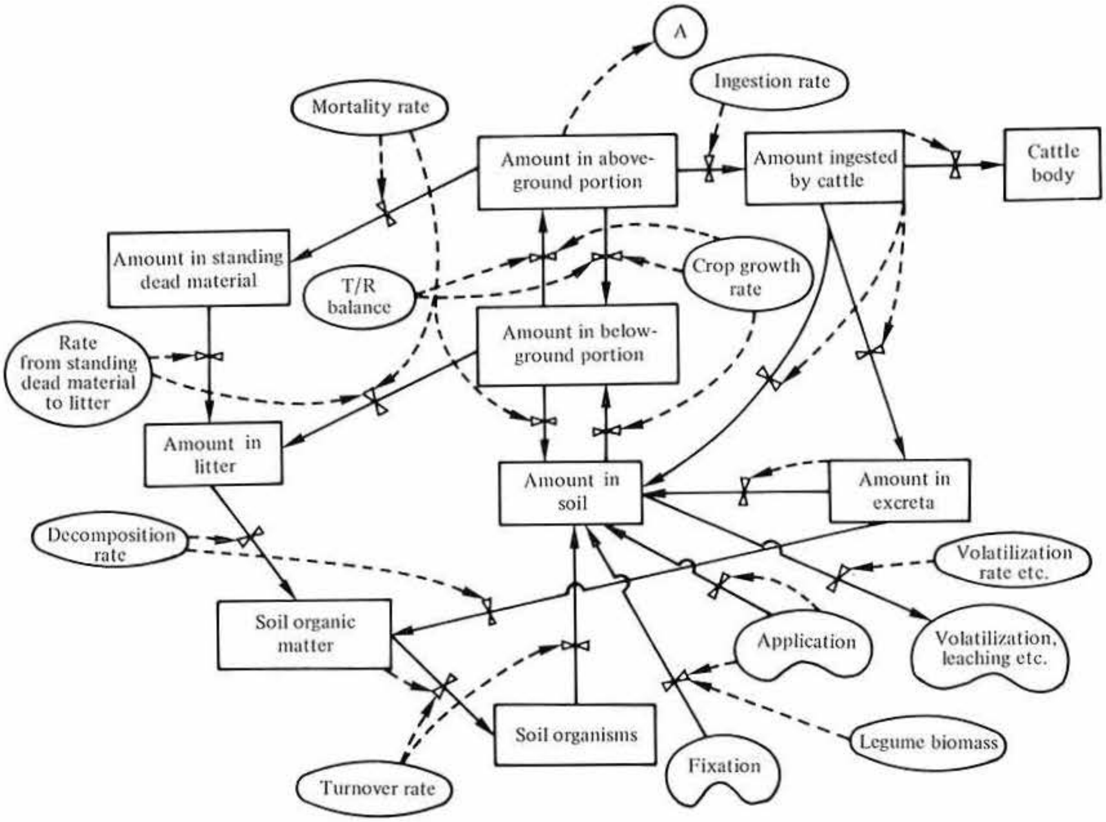

Fig. 4. Compartment model describing nitrogen flow for an artificial grassland by Shiyomi et al.[14]
Solid and broken lines denote nitrogen and information flows, respectively.
Rectangles, cloud-like shapes and ellipses denote state variables, source-sinks, and rate variables, respectively.
Ⓐ indicates relationship with energy flow in Fig. 2.

synthesized energy and its accumulation in cattle bodies increases with the quadruple rate of N application, but not proportional to N applied. N absorption by plants increases from 189 kg N/ha to 354 kg N/ha by the quadruple N application, but N accumulation in cattle bodies increases only from 14 kg N/ha to 15 kg N/ha. In this simulation, the total annual cattle live weight gain could be calculated as 422.5 kg/ha and 455 kg/ha for the low and high rates of N application, respectively. From this result, the efficiency of N application was calculated. The increase of 1 kg N/ha/yr brings about 0.2 kg/ha/yr of cattle live weight increase. This efficiency is unexpectedly low, and suggests the importance of harmony between the amount of herbage and grazing intensity on grassland.

The increase in total body weight at various stocking rates was calculated under the same conditions as given in Fig. 5(A) except for stocking rate, and the result is shown in Fig. 6. It is obviously shown that an optimal stocking rate can be estimated at 1400 kg/ha of total cattle live body weight at the beginning of the grazing season under normal meteorological conditions. It may be best to recommend only 70–80% of this value, because varying meteorological conditions may cause a level of plant production lower than that of the normal year.

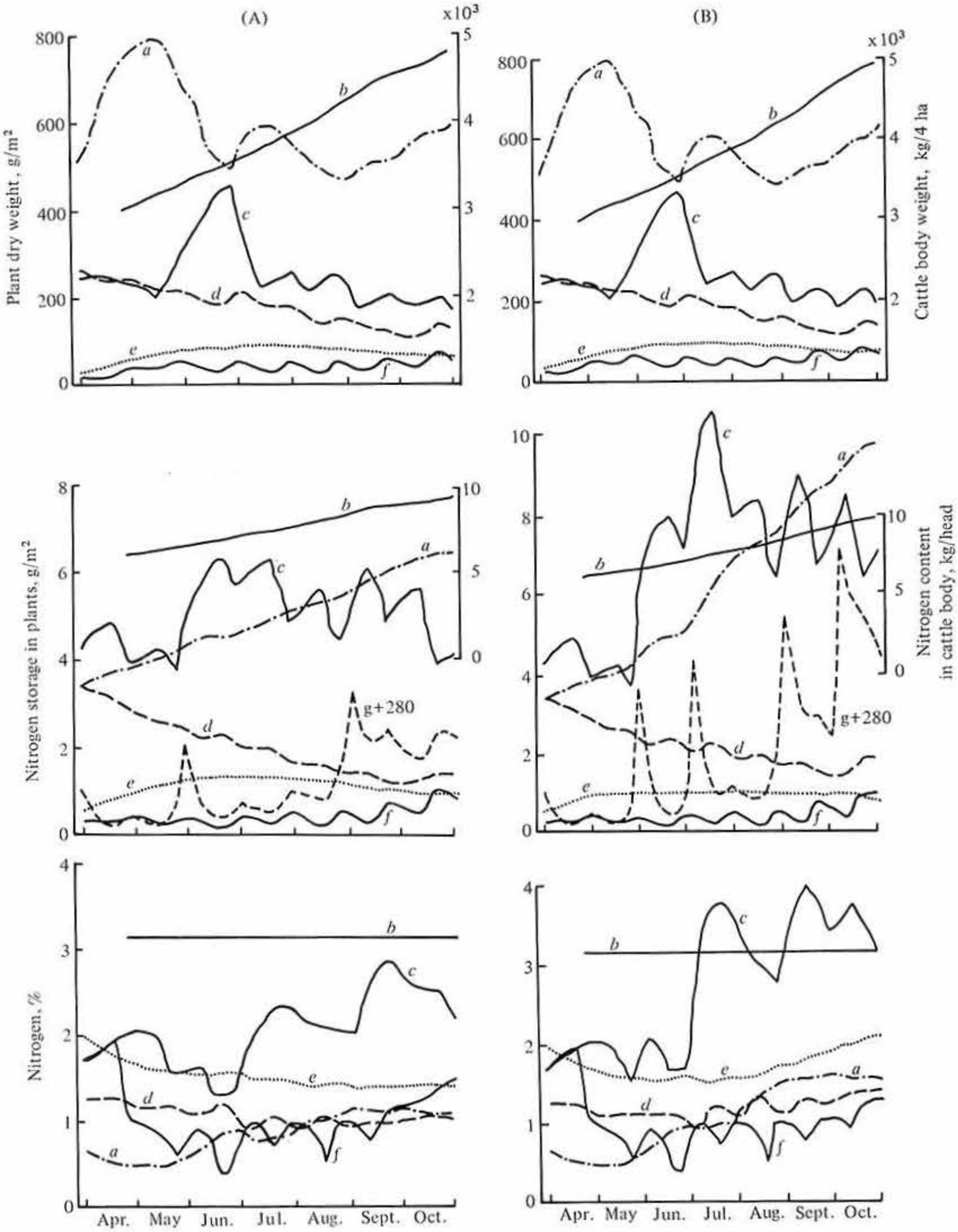

Fig. 5. Simulation of seasonal changes in herbage and cattle body weight and nitrogen storage in rotational grazing by Shiyomi et al.[14]

A : Nitrogen fertilizer (27 kg N/ha) was applied in both May and August,

B : Nitrogen fertilizer (54 kg N/ha) was applied in May, June, August and October, respectively.

a : Belowground parts, *b* : Cattle body weight, *c* : Aboveground herbage biomass, *d* : Standing dead herbage material, *e* : Ground surface litter, *f* : Feces, *g* : Soil.

Table 1. Site parameters and experimental pasture condition at NGRI* for the modeling approach

Item	Explanation
Latitude	36°55′N
Longitude	139°58′E
Altitude	330m asl
Mean monthly air temperature	minimum 1.1°C (January), maximum 24.2°C (August), annual average 12.3°C
Mean monthly precipitation	minimum 40.9mm (January), maximum 255.9mm (August), annual total 1631.9mm
Daily global solar radiation	minimum 1735.5 kcal/m^2/day, maximum 3844.9 kcal/m^2/day, annual average 2681.4 kcal/m^2/day
Pasture plants	Mixture of *Agrostis alba, Poa pratensis, Trifolium repens Dactylis glomerata, Lolium perenne, Festuca arundinacea*
Yearly fertilizer application	N; 100 kg/ha, P_2O_5; 180 kg/ha, K_2O; 100 kg/ha
Grazing conditions	paddock size; 0.5 ha, number of paddocks; 4, number of cattle; 8-9, breed; young Japanese black, total inital body weight at the beginning of each grazing season (April); 1600 kg, stocking rate in mid April; 800 kg/ha, rotated between 4 paddocks in a set sequence each week from April to November

* National Grassland Research Institute.

Table 2. Annual energy and nitrogen budget on simulated pastures

Item	Annual nitrogen application per ha	
	54 kgN	216 kgN
1) Energy budget, unit: 10^4 kJ/ha		
Global solar radiation	473×10^4	473×10^4
Energy photosynthesized	98375	107451
Plant respiration	82779	90300
Accumulation in plants	−297	−436
Accumulation in standing dead material	56	76
Accumulation in litter	9473	10657
Energy ingested by cattle	6364	6854
Accumulation in cattle bodies	530	571
Heat production in cattle	3632	3912
Energy excreted	2202	2371
2) Nitrogen budget, unit: kgN/ha		
Nitrogen uptake	189	354
Accumulation in plants	2	5
Accumulation in litter	9	43
To soil	82	128
To cattle	97	178
Accumulation in cattle bodies	14	15
Nitrogen excreted	83	163

Simple structure model for forecasting grazing grassland productivity

Models introduced in the previous two sections are heavily equipped with many parameters thereby causing two defects, i.e., (1) it is not easy to give likely values to many parameters, and (2) farmers do not have adequate programs in their personal computers to analyze many differential equations.

To evade these defects, a simpler model should be developed although the level of

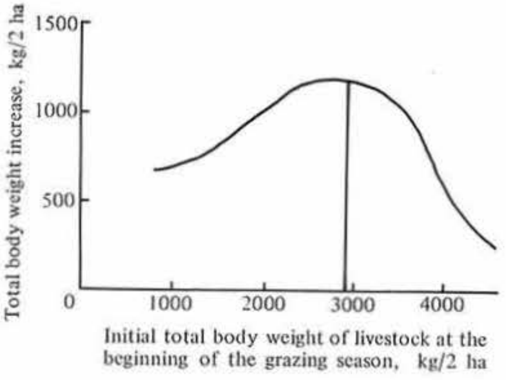

Fig. 6. Determination of the optimal stocking rate under a 30 year average meteorological condition, assuming that cattle with the total body weight indicated here graze for 203 days from April 15

mimicry to actual grassland is sacrificed to some extent. Shiyomi et al.[11] proposed a model describing herbage growth by a logistic equation. Let x, r and K be herbage biomass at time t, growth rate of herbage biomass and maximum possible herbage biomass, respectively. Then, the instantaneous growth of herbage biomass at time t as:

$$\mathrm{d}x/\mathrm{d}t=rx(1-x/K). \qquad \text{......(1)}$$

This equation cannot express seasonal changes of herbage biomass and consumption by cattle because r and K are held constant.

Now, let r take large values in the spring and autumn and small values in the summer as in actual grassland although K takes a constant. Furthermore, let cattle feed a constant amount of herbage, a, every day. Then, equation (1) will be changed as follows:

$$\mathrm{d}x/\mathrm{d}t=r(t)x(1-x/K)-a\,, \qquad \text{......(2)}$$

where $r(t)$ denotes a function of t. An example of equation (2) is given in Fig. 7(B) which shows nearly the same shape as the seasonal biomass change in Fig. 5(A). Although equations (1) and (2) are quite simple, they have still some problems: e.g., $r(t)$ must be defined in advance and $r(t)$ may change from year to year.

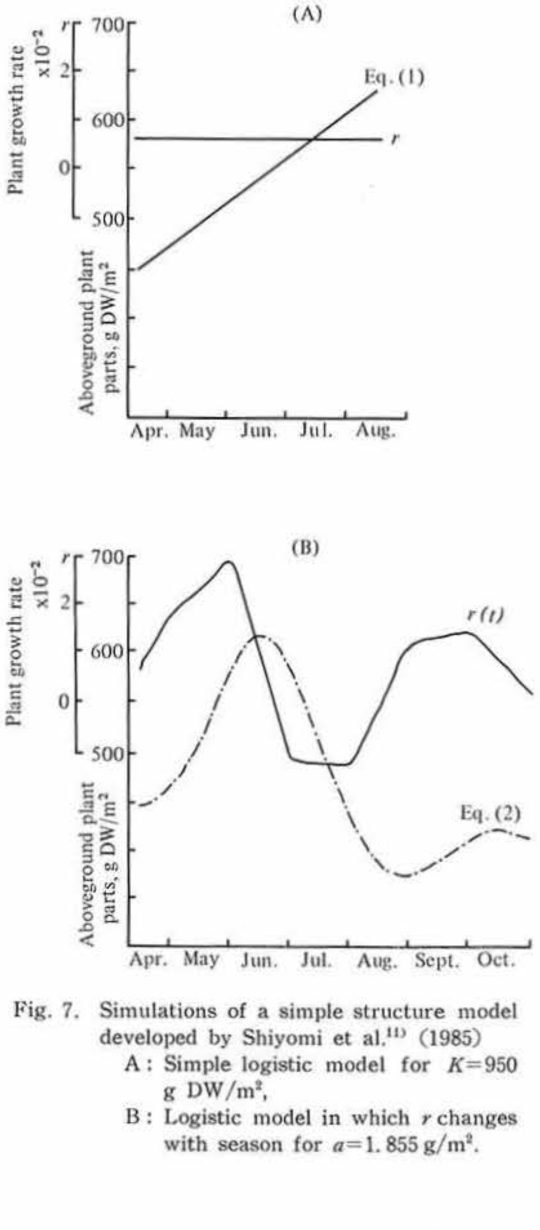

Fig. 7. Simulations of a simple structure model developed by Shiyomi et al.[11] (1985)
A: Simple logistic model for $K=950$ g DW/m²,
B: Logistic model in which r changes with season for $a=1.855$ g/m².

Grassland community model

Species composition of plants in a grassland changes seasonally and annually. For grassland maintenance and management, succession plays a very important role. For artificial grasslands, species composition at establishment must be generally ideal and it must preferably be kept constant for a long period. Furthermore, many of the natural

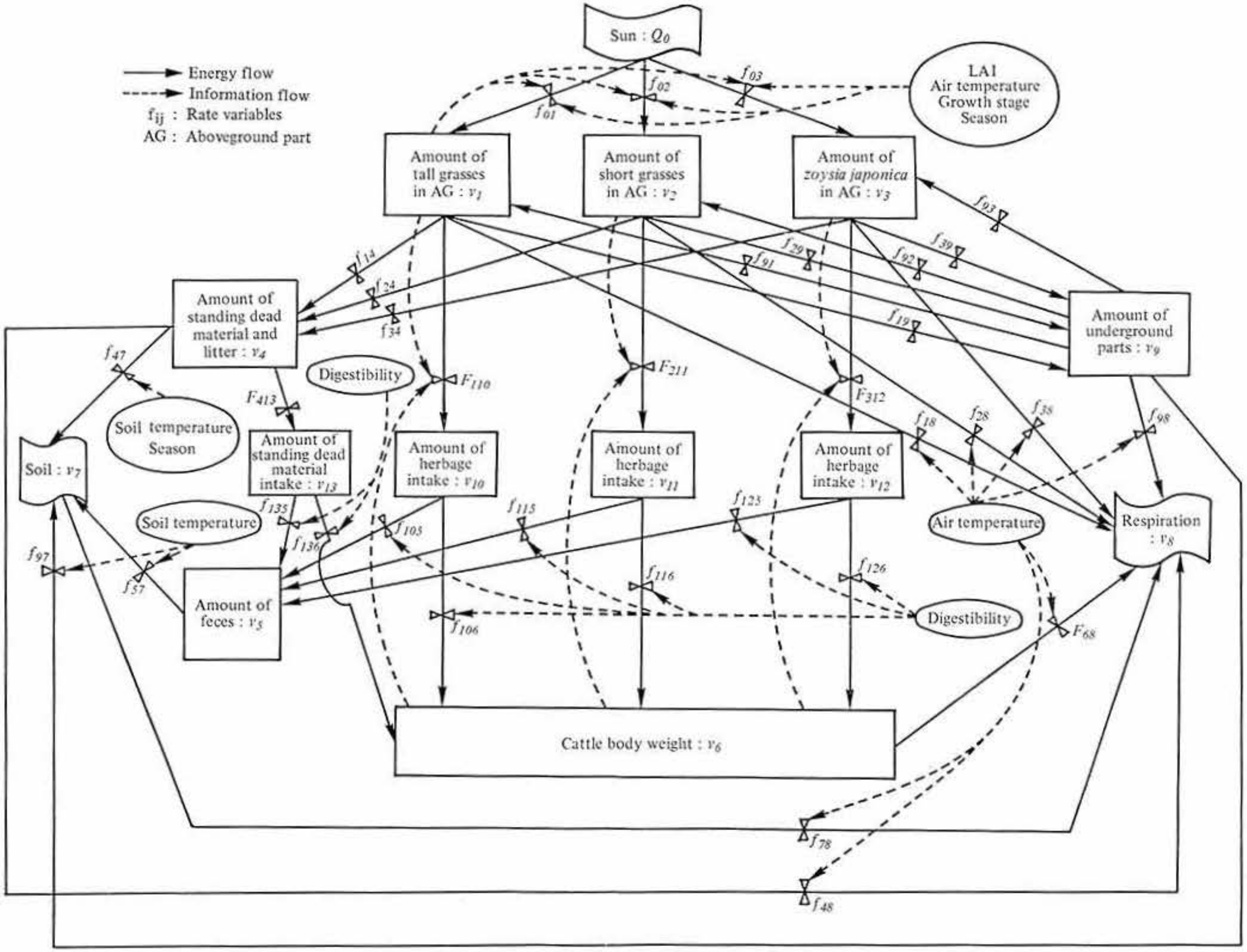

Fig. 8. Compartment model describing herbage species competition between improved short grasses, improved long grasses and *Zoysia japonica* by Koyama et al.[5]

Long grasses include orchardgrass, tall fescue and perennial ryegrass, and short grasses include Kentucky bluegrass, redtop and, for convenience sake, white clover.

grasslands in Japan exist on a line of succession between *Zoysia japonica* and *Miscanthus sinensis*, and it is very important for animal husbandry to maintain a stabilized state at a desirable proportion of these two species.

Many ideas for dealing with succession and community stability have been proposed; one example is that of Gutierrez and Willard[3]. At the 15th International Grassland Congress (Kyoto, 1985), Chinese scientists proposed succession models of various types (for example, Chen and Li[2]).

Two new models will be introduced below. Data for succession and vegetation studies are often shown by measuring cover, but the following models deal with dry weight biomass per unit area.

Koyama et al.[5] proposed a model dealing with competition between the following three plant groups: (1) improved short grasses (this group includes white clover for convenience sake), (2) improved long grasses, and (3) *Zoysia japonica*. The concept of this model is shown in Fig. 8. In this model, competition between plants for light and feeding selection for preference constitutes the focus. In a grassland where long grasses dominate, cattle feed first newly developed soft leaves and next short grasses. Leaves of *Zoysia japonica* are so hard that cattle do not like to feed them when other improved grasses are available, but *Z. japonica* is resistant to trampling. Simulations by this model can well mimic seasonal vegetation changes in actual grasslands[5] (the details are not shown due to space limitation). The most important questions in studies of plant succession are: (1) how the species composition changes with time, (2) whether or not the species composition is stable, and (3) whether or not the species composition is valuable for animal husbandry. Unfortunately, Koyama's model can not answer these questions.

Now, let us formulate a new, simple idea, which is a game between *Z. japonica* and improved grasses. Through this game, whether any of them can win or keep a stable equilibrium between them can be discerned.

Let x and y be biomasses of *Z. japonica* and improved grasses, respectively and let h and h' be amounts of *Z. japonica* and improved grasses ingested by cattle, respectively. Then the following Lotka-Volterra type competition model can be adopted:

$$\begin{aligned} dx/dt &= x(a-bx-cy)-h \\ dy/dt &= y(e-fx-gy)-h', \end{aligned} \quad \text{......(3)}$$

where a, b, c, e, f and g denote constants. In equation (3), h and h' also depend upon bio-

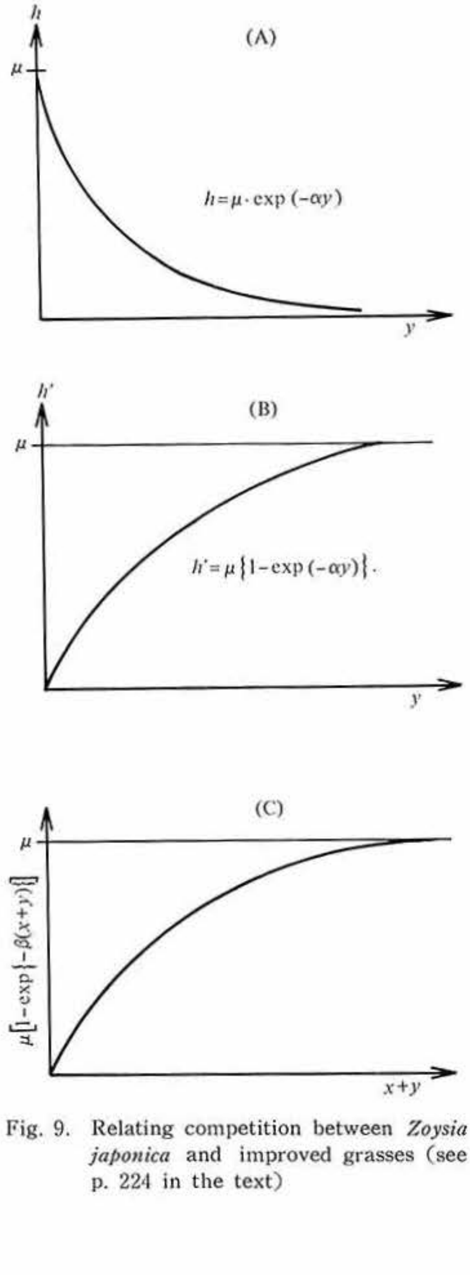

Fig. 9. Relating competition between *Zoysia japonica* and improved grasses (see p. 224 in the text)

mass of *Z. japonica* and of improved grasses because palatability for cattle is different between them. Then, let μ be the amount of herbage ingested by cattle per unit period of time, and we can take up the following two cases for h and h'. (1) When there is a sufficient amount of herbage (*Z. japonica* + improved grasses), $h + h' = \mu$ is constant and $h = \mu \cdot \exp(-\alpha y)$ where α is a positive constant (Fig. 9(A) and 9(B)), and (2) when there is insufficient herbage, μ in the foregoing equation is replaced by $\mu[1-\exp\{-\beta(x+y)\}]$, that is,

$$h=\mu[1-\exp\{-\beta(x+y)\}]\cdot\exp(-\alpha y)$$
$$h'=\mu[1-\exp\{-\beta(x+y)\}]\cdot\{1-\exp(-\alpha y)\},$$

where β denotes a positive constant (Fig. 9(C)).

Through some ingenious simulations of equation (3), we will be able to attain a desirable solution.

Table 3a. Clustering of years by their 10-day mean of air-temperture from March to October

Pattern*		1	2	3	4	5	6	Overall average
No. of years		8	4	3	9	5	13	
Year		51, 53, 66 74, 76, 79 80, 82	45, 47, 54 57	49, 70, 84	56, 58, 60 68, 69, 72 77, 81, 83	44, 63, 65 71, 78	46, 48, 50, 52 55, 59, 61, 62 64, 67, 73, 75 85	
								°C
Mar.	F	4.7	1.8	-0.1	3.2	1.8	3.5	3.1
	S	5.4	3.3	1.3	5.6	3.4	4.1	4.3
	T	5.5	6.2	2.8	7.2	5.8	5.8	5.9
Apr.	F	8.4	9.2	6.1	7.8	7.1	10.3	8.6
	S	9.3	11.1	8.4	10.7	9.5	11.4	10.4
	T	12.2	10.9	11.4	13.4	10.8	12.8	12.3
May	F	13.4	12.4	14.5	14.6	12.7	15.1	14.1
	S	14.9	14.0	15.6	14.7	16.2	15.5	15.2
	T	17.0	15.5	17.0	16.0	16.6	16.4	16.4
Jun.	F	18.4	15.7	17.0	17.9	17.9	17.9	17.7
	S	19.1	16.8	18.8	18.4	19.8	19.0	18.8
	T	20.2	18.1	18.5	19.7	21.5	19.9	19.8
Jul.	F	19.8	20.2	19.9	21.1	22.7	22.1	21.2
	S	21.1	20.5	23.8	22.6	23.5	23.8	22.7
	T	24.1	23.1	25.3	24.3	23.8	25.1	24.4
Aug.	F	23.6	24.6	24.4	25.0	25.4	24.9	24.7
	S	24.1	25.2	25.0	24.0	24.5	25.1	24.6
	T	23.2	23.9	23.5	22.1	23.8	24.0	23.4
Sept.	F	21.7	20.6	22.0	22.6	19.8	22.8	21.9
	S	19.6	21.0	20.0	20.3	19.5	20.8	20.3
	T	17.5	17.7	18.0	18.1	17.7	18.1	17.9
Oct.	F	16.4	15.2	14.8	16.3	14.9	16.6	16.0
	S	15.8	13.1	14.9	14.0	13.0	14.6	14.4
	T	13.0	12.4	11.4	12.7	13.0	12.4	12.6

* Pattern 1 : high temperatures in the 1st and 2nd 10-days of March, low in July and August and high in the 2nd and 3rd 10-days of October,

Pattern 2 : low in the 1st and 2nd 10-days of March, low from the 3rd 10-days of April to the 1st 10-days of August,

Pattern 3 : extremely low until the end of April,

Pattern 4 : a little high in March and April,

Pattern 5 : low until the 1st 10-day period of May, high from the 2nd 10-days of May to the 2nd 10-days of July and low from the 3rd 10-day period,

Pattern 6 : high throughout the whole season, especially in April, July and September.

Table 3b. Prediction of plant growth (g dry weight/m^2) corresponding to the 6 seasonal air-temperature patterns (in Table 3a) using a grazing pasture model

Pattern		1	2	3	4	5	6	Average
Mar.	1	69.5	69.5	69.5	69.5	69.5	69.5	69.5
	11	91.8	58.4	59.5	93.1	58.4	92.8	93.2
	21	111.9	62.3	44.9	113.5	64.8	114.2	114.6
	31	124.0	96.3	43.5	163.7	91.6	126.5	126.5
Apr.	10	163.8	154.1	75.2	193.6	145.4	167.8	168.7
	20	161.4	155.3	109.9	173.7	153.3	160.0	162.5
	30	152.7	150.3	129.0	155.7	150.5	150.0	152.3
May	10	184.3	185.3	175.3	183.4	185.1	181.3	183.4
	20	221.5	222.3	213.1	221.5	219.5	235.3	220.5
	30	278.5	279.7	262.8	286.2	274.3	281.1	280.5
Jun.	9	339.4	346.5	323.6	346.9	336.2	338.2	342.4
	19	407.3	422.3	391.6	416.7	402.3	405.4	411.4
	29	360.9	378.6	353.1	369.4	353.4	360.0	364.9
Jul.	9	232.6	241.3	231.2	234.5	223.7	229.0	232.4
	19	196.1	200.9	191.5	193.9	186.0	188.6	192.7
	29	180.7	185.0	174.5	178.1	173.8	173.4	177.2
Aug.	8	179.2	181.1	173.8	175.9	173.4	172.8	175.8
	18	185.3	184.0	180.6	182.6	180.1	179.3	182.0
	28	186.1	183.5	182.6	186.3	182.3	181.2	183.7
Sept.	7	169.5	169.2	167.3	169.3	169.9	165.1	168.0
	17	163.9	162.9	162.3	162.4	165.5	159.7	162.3
	27	166.8	165.0	165.0	164.8	167.4	163.1	165.0
Oct.	7	168.5	169.0	169.3	167.2	170.6	165.9	167.8
	17	156.1	160.4	158.7	157.7	161.6	156.2	157.7
	27	154.2	159.0	158.3	156.6	159.0	155.7	156.5
Nov.	6	181.1	184.4	184.8	182.7	183.8	182.5	182.8

Prediction of meteorology and grassland production

As grassland productivity is greatly affected by natural conditions, especially meteorological conditions, a precise prediction of meteorological conditions is required for an accurate prediction of grassland production.

As the long range meteorological forecast is not so precise, it can hardly be used for grassland management. As a second best method, we assumed meteorological variations which are quite likely to occur during each season, and estimated the grassland production for different meteorological patterns.

Now, an example is given. Ten-day mean air-temperatures during the plant growing season have been recorded at NGRI since 1944. The data of 42-years were classified into six different seasonal meteorological patterns (Table 3a) by k-means cluster analysis (Shiyomi[8]). In this table, patterns 2, 3 and 5 have cold winter, and patterns 4 and 5 have hot summer. For each of these patterns, seasonal changes in grassland production were simulated using the foregoing Shiyomi's model[13]. The results are shown in Table 3b. For the simulation calculation was started from March 1 when herbage biomass was 69.5 g/m^2 in dry weight. The table indicates apparent delay of herbage growth in patterns 2 and 5 which recovers by April 30, but in pattern 3 retarded herbage growth lasts until the end of July. This method, even admittedly imperfect, is better than guess-work for forecasting grassland production.

Spatial pattern model and prediction of herbage biomass

Grassland is not in a state of evenly distributed herbage, but in a mosaic state of herbage biomass. Such a spatial pattern on grassland might be caused by interactions between animals and vegetation. It was theoretically and empirically shown by Shiyomi et al.[9,10] that frequency distributions of herbage weight per unit ground area, w, under grazing conditions fit the gamma distribution:

$$\frac{w^{p-1}p^{p}}{\Gamma(p)\mu^{p}}\exp(-pw/\mu), \qquad \text{......(4)}$$

where μ and p denote the distribution mean and shape parameter, respectively. In this equation, p-value between 0 and 1 indicates a more aggregated spatial pattern than a random one, and p-value larger than 1 indicates a more even pattern than a random one. Furthermore, when $p\rightarrow\infty$, the pattern approaches completely even.

When relationships between μ and p were empirically examined, the following linearity was found in the observed data:

$$p=0.03142\mu+0.2661, \qquad \text{......(5)}$$

where μ is g dry matter/0.25 m². When average herbage biomass weight/unit ground area can be predicted, for example, by the energy flow model or simple structure model shown above, the p-value and the shape of herbage weight frequency distribution can be determined from equation (5).

On grazed grassland with improved herbage, if herbage biomass higher than 5 cm above the ground surface is less than 15 g dry weight/m², cattle can hardly feed on such herbage, while if it is more 400 g dry weight/m², it may be composed of unpalatable and hardened plant tissues or unavailable weeds. An example of changes in herbage biomass (μ) and spatial pattern (p) forecasted by using the energy flow model and equation (5) is shown in Table 4, and herbage weight frequency distribution drawn using parameters indicated in Table 4 is shown in Fig. 10. Table 5 shows predictions, obtained from Table 4, of available herbage biomass (between 15 and 400 g dry weight/m²). Although herbage biomass is abundant at the heading stage in

Table 4. Herbage biomass changes predicted and spatial pattern index changes calculated

Month・day	Herbage biomass, μ	Spatial patten index, p	Remarks	Notes for Fig. 5
Mar. 1	29.2*	1.18		a
Apr. 21	58.2	2.09	At the beginning of grazing season	b
Apr. 28	16.4	0.78	After one-week of grazing	c
Jun. 21	80.8	2.08	At the maximum biomass stage	d
Aug. 17	51.0	1.86		e
Oct. 12	11.1	0.61	At the end of grazing season	f

* g dry weight/0.25m²

Table 5. Predicted values of available herbage biomass per ha using data in Table 4

Month・day	Total herbage biomass (t)	Available biomass (t)	Unavailable biomass (t)	
			less than 15g/m²	more than 400g/m²
Mar. 1	1.16	1.03(88)*	0.11	0.02
Apr. 21	2.33	1.99(85)	0.02	0.32
Apr. 28	0.66	0.49(75)	0.14	0.03
Jun. 21	3.23	2.28(71)	0.01	0.94
Aug. 17	2.04	1.84(90)	0.03	0.17
Oct. 12	0.44	0.27(61)	0.17	0.00

* Numerals in the parentheses: percentage of available biomass to the total herbage biomass.

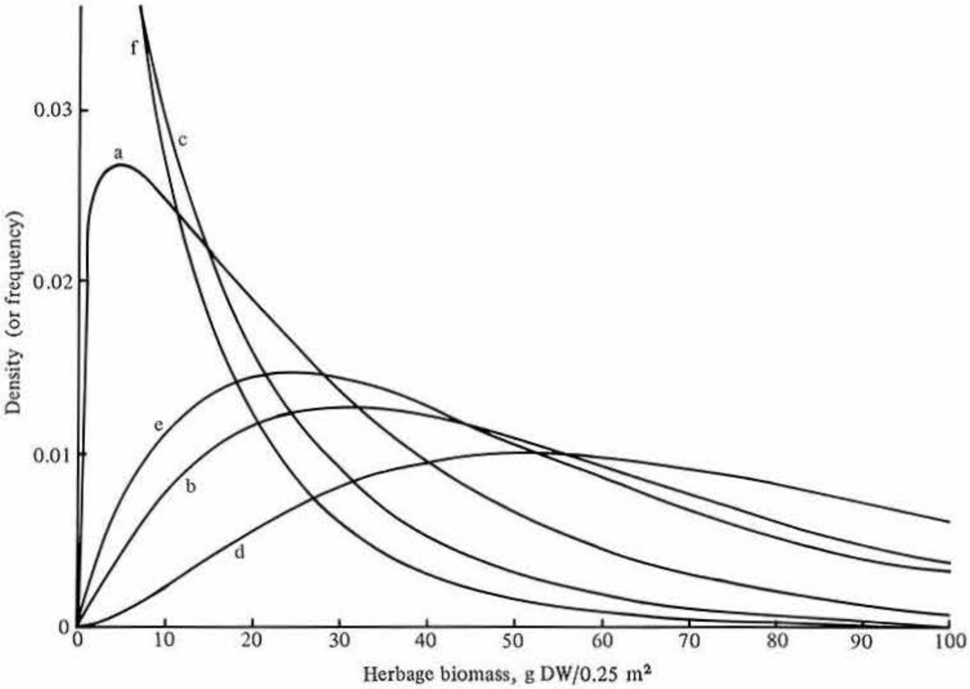

Fig. 10. Prediction of herbage biomass spatial pattern using the parameter value from Table 4 (see notes in Table 4 for a, b, ..., f)

early summer in Table 5, it is known that herbage at this stage is very hard and unpalatable. This result indicates that the grazing with skill brings about, as an indirect result, the increased amount of available herbage, and improved quality and digestibility of the herbage produced. In other words, it is desirable to graze intensively or to harvest before heading to ensure high quality.

Conclusion

As each grassland usually has a huge area, it may be impossible to produce herbage and animals by servomechanism as is done in the green house. However, the concept of servomechanism can be applied to the area-dependent agriculture in the field of an automatic measuring and forecasting system.

For example, let 10 stations equipped with biomass sensors and meteorological recorders be located in the northern part of Tochigi Prefecture and the data obtained are sent to a computer center at the Prefectural Office. Then, the computer can forecast grassland biomass using some mathematical models. The Prefectural Government can supply information to farmers or farmers' cooperatives along with information of other crops and crop pests, just like the tomorrow's weather forecast. This can, indeed, be said to be a real-time control of agriculture.

Summary

Development of grassland management models has been going on for these ten years. It started at Colorado University in the 1970s. In Japan similar studies started a little later. In the present report, the following eight models for grassland management, developed mainly at NGRI, and some examples of application to estimate grassland productivity are presented:

(1) Three 'energy flow or dry matter

budget models' by Okubo et al. (1977), by Shiyomi et al. (1982) and by Okubo and Jacquard (1985).

(2) 'A nitrogen flow model' by Shiyomi et al. (1988).

(3) 'A simple structure model' for forecasting grassland productivity by Shiyomi et al. (1985).

(4) Two 'grassland community models' for forecasting vegetation changes with time by Koyama et al. (1986) and some ideas by Shiyomi.

(5) 'A model for predicting herbage biomass available to cattle' by Shiyomi, and

(6) Relationships between meteorological pattern and grassland production.

If we can obtain real-time information concerning weather and herbage biomass from monitor stations set up in a given large area, we can predict the grassland situation and supply these prediction to farmers from time to time just like weather forecast.

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