An Intersection of Ruminant Production and Forage Production

Shimojo, Masataka
Laboratory of Animal Feed Science, Division of Animal Science, Department of Animal and Marine Bioresource Science, Faculty of Agriculture, Kyushu University

Ikeda, Kentaro
Laboratory of Animal Feed Science, Division of Animal and Marine Bioresource Science, Department of Animal and Marine Bioresource Science, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University

Asano, Yoki
Laboratory of Animal Feed Science, Division of Animal and Marine Bioresource Science, Department of Animal and Marine Bioresource Science, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University

Ishikawa, Reiko
Research Fellow of the Japan Society for the Promotion of Science

他

https://doi.org/10.5109/24445

出版情報：九州大学大学院農学研究院紀要. 46 (2), pp.321-329, 2002-02-28. Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **46** (2), 321–329 (2002)

An Intersection of Ruminant Production and Forage Production

Masataka SHIMOJO*, Kentaro IKEDA[1], Yoki ASANO[1], Reiko ISHIWAKA[2], Manabu TOBISA, Tao SHAO[3], Noriko OHBA[4], Hiroyuki SATO[1], Yukiko MATSUFUJI[1], Yasukatsu YANO[5] and Yasuhisa MASUDA

Laboratory of Animal Feed Science, Division of Animal Science, Department of Animal and Marine Bioresource Science, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
(*Received October 31, 2001 and accepted November 20, 2001*)

The concept of intersection was introduced into relationships between forage production and ruminant production by premising the equality in the amount between forage yield (kg/a) and cumulative forage intake (kg/head). Some relationships were given through the mutual transformation of two units (kg/a↔kg/head) at the intersection. (i) There was a relation of ruminant growth period (d_R) to forage yield (kg/a) through daily intake (kg/a/d_R), and forage growth period (d_F) was related to cumulative forage intake (kg/head) through the unit (kg/head/d_F) that was shown for both forage growth rate and rough estimate of assimilation rate. (ii) The animal (head) was related to the field (a) through the unit (a/head) shown for each of feed efficiency, forage digestibility and the ratio of the amount of animal excreta to forage yield, this ratio showed the return of excreta to the field. (iii) The intersection led to either of forage and ruminant production analyses. (iv) When entering the ruminant production analysis from the forage production analysis, there was a pair appearance of feed efficiency and feed conversion, followed by its pair disappearance. The present study suggested field–forage–ruminant relationships.

INTRODUCTION

In the ruminant production from meadows or pastures, field–forage–ruminant relationships (soil–plant–animal relationships) are of great importance to the cycling of nutrient elements (Whitehead, 2000a). This is also associated with sustainable systems of ruminant production (Mannetje, 1994; Peel and Lloveras, 1994; Spedding, 1995). In some actual management systems, however, there is a disconnection in the relationships, where forage–ruminant relationships (ruminant production) and field–forage relationships (forage production) are considered two different things. This often causes one–way flow of nutrients from soils, through forages, to ruminants, a problem that animal excreta are not returned to fields from which forages were produced.

In our previous reports forage–ruminant relationships were investigated from some

1) Laboratory of Animal Feed Science, Division of Animal Science, Department of Animal and Marine Bioresource Science, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University
2) Research Fellow of the Japan Society for the Promotion of Science
3) Visiting Research Scientist from the People's Republic of China
4) Research Student, School of Agriculture, Kyushu University
5) Technical Specialist, School of Agriculture, Kyushu University
* Corresponding Author (E–mail: mshimojo@agr.kyushu–u.ac.jp)

different aspects using simple analytic equations (Shimojo *et al.*, 1998a, b, c, d, e, f, 1999a, b, c, d, 2000a). Analytic approaches might be expected to describe the return of animal excreta to fields if a new concept is introduced in order to form close relationships between fields, forages and ruminants.

The present study was designed to form field–forage–ruminant relationships by introducing a concept of intersection of ruminant production and forage production, where these two were treated equally to relate animals to fields.

CONSTRUCTING AN INTERSECTION

The concept of an intersection

At an intersection of road A and road B one stands on both roads, and can walk along either road by taking turns at the intersection. This is based on something equal or something common at the intersection of both roads.

An intersection of ruminant and forage production

An intersection of ruminant production and forage production is, when constructed using the amount of forage, described, for example, like Case A.

[Case A] The forage produced from the field with the area of one are was cut and fed to an animal, followed by the complete consumption. This shows the equality in the amount between cumulative forage intake (I) and forage yield (Y). Thus,

$$I\ (\mathrm{kg/head}) = Y\ (\mathrm{kg/a})\ . \tag{1}$$

The premise (1) suggests that interchanging the animal (head) and the field (a) does not alter the amount of forage (kg). However, this does not always apply to actual cases, where there is a need of making modifications as shown in the following cases.

[Case B] When the forage produced from the field with the area of one are was completely eaten by five animals, they are regarded as one group of animals and kg/head is replaced by kg/group in the premise (1).

[Case C] When an animal completely consumed the forage produced from the field with the area of three ares, the field is regarded as one zone of the field and kg/a is replaced by kg/zone in the premise (1).

[Case D] When the forage produced from the field with the area of one are was fed to an animal but a part of the offered forage was left uneaten, there is a replacement of [I (kg/head)=Y (kg/a)] with [I (kg/head)=$m \cdot Y$ (kg/a), where $m < 1$.] in the premise (1).
Actual cases are given as the combination of above cases, where the number of animals and the area of field take various values.

Items used for analyses of ruminant and forage production

The following items are used for analyzing ruminant production.

t_R: a certain period of growth of an animal (days: d_R).

I: cumulative forage intake over the period of d_R (kg/head).

G: body weight gain over the period of d_R (kg/head).

The following items are used for forage production analyses.

t_F: growth period of the forage (days: d_F),

A: mean leaf area over the period of d_F for the whole forage in the field with the area of one are [$=(A_1+A_2)/2$], where, for example, A_1=leaf area of the whole forage in the early growth stage when the plant height is 10 cm, A_2=leaf area of the whole forage at the later stage when cut for hay at the height of 10 cm above the ground. A is also regarded as mean leaf area index. A is a very rough value with a lack of accuracy in forage production analyses, but introduced forcedly this time in order to make a rough estimate of assimilation rate of the whole forage.

Y: yield of the whole forage harvested from the field with the area of one are (kg/a).

Then, analytic equations for ruminant production and those for forage production will be constructed with an intersection of them.

RUMINANT PRODUCTION ANALYSIS WITH AN INTERSECTION FOR ENTERING RORAGE PRODUCTION ANALYSIS

The daily gain of a ruminant animal is described as the product of daily forage intake and feed efficiency. Thus,

$$\frac{G}{t_R}=\frac{I}{t_R}\cdot\frac{G}{I}, \tag{2}$$

where G/t_R=daily gain (kg/head/d_R), I/t_R=daily forage intake (kg/head/d_R), G/I=feed efficiency.

The digestible part of intake is more closely related to body weight gain than intake is. Replacing I in the second term of the right–hand side of equation (2) with the digestible forage intake [DI (kg/head)] gives

$$\frac{G}{t_R}=\frac{I}{t_R}\cdot\frac{G}{DI}\cdot\frac{DI}{I}. \tag{3}$$

G/DI is regarded as modified feed efficiency. DI/I shows forage digestibility that is naturally introduced in order to keep the equality between both sides of equation (3) even after replacing I with DI. Poppi *et al.* (2000) stated the importance of the interaction of intake, passage and digestibility to animal production. This is also suggested in equation (3): G/t_R as animal production, I as intake, I/t_R as daily intake that is influenced by passage of digesta, DI/I as digestibility.

Replacing I (kg/head) in equation (2) with Y (kg/a) according to the premise (1) gives

$$\frac{G}{t_R}=\frac{Y}{t_R}\cdot\frac{G}{Y}, \tag{4}$$

where Y/t_R=daily forage intake (kg/a/d_R), G/Y=feed efficiency (a/head).

Daily forage intake (Y/t_R), which undergoes the unit transformation from kg/head/d_R into kg/a/d_R, relates the animal growth period (d_R) to the forage yield (kg/a). Feed efficiency (G/Y), that has a unit (a/head) obtained from dividing G (kg/head) by Y (kg/a), relates the animal (head) to the field (a). G/Y is considered a kind of coefficient for estimating the animal production efficiency from the field in terms of feed efficiency. This interpretation is hided at the back of the ordinary comprehension of feed efficiency, and comes out into the open this time to show close relationships between fields and ruminants through the forage as a mediator.

The indigestible part of intake is excreted in feces. Feces, together with urine, form animal excreta. Replacing Y in the second term of the right-hand side of equation (4) with the amount of animal excreta [E (kg/head)] gives

$$\frac{G}{t_R}=\frac{Y}{t_R}\cdot\frac{G}{E}\cdot\frac{E}{Y}. \tag{5}$$

G/E is the ratio of body weight gain to the amount of excreta, showing that the ruminant production always goes together with the production of excreta. E/Y, that is naturally introduced to keep both sides of equation (5) equal, shows the ratio of the amount of animal excreta to the forage yield. Thus, E/Y relates, through undergoing the unit transformation [(kg/head)/(kg/a)→(a/head)], the animal (head) to the field (a). This is interpreted as follows: the forage relates the field to the animal by removing nutrients from the soil to the animal, and the excreta relate the animal to the field through returning feces and urine to the field (Pain, 2000; Whitehead, 2000a, b). Therefore, E/Y is considered a kind of coefficient for estimating the nutrient recycling between fields and ruminants via forage production and excreta return.

Replacing E with DI in equation (5) gives

$$\frac{G}{t_R}=\frac{Y}{t_R}\cdot\frac{G}{DI}\cdot\frac{DI}{Y}. \tag{6}$$

DI/Y is considered another description of forage digestibility with a unit (a/head) that is obtained from (kg/head)/(kg/a) in DI/Y, and thus relates the animal (head) to the field (a). DI/Y is considered a kind of coefficient for estimating the digestible dry matter production efficiency from the field in terms of forage digestibility. This interpretation, that is hided at the back of the ordinary comprehension of forage digestibility, comes out into the open this time to show field–ruminant relationships through digestible dry matter accumulated in the forage (Shimojo *et al.*, 1998a, d, f, 1999c, d).

The forage yield (Y) is rewritten as follows,

$$Y=\left\{\frac{1}{A}\cdot\frac{Y}{t_F}\right\}\cdot A\cdot t_F, \tag{7}$$

where A=mean leaf area over the period of d_F for the whole forage in the field with the area of one are, t_F=growth period of the forage (d_F: days), $(1/A)\cdot(Y/t_F)$=rough estimate of assimilation rate (kg/a/d_F).

Inserting equation (7) into equation (4) gives

$$\frac{G}{t_R}=\frac{\left\{\frac{1}{A}\cdot\frac{Y}{t_F}\right\}\cdot A\cdot t_F}{t_R}\cdot\frac{G}{\left\{\frac{1}{A}\cdot\frac{Y}{t_F}\right\}\cdot A\cdot t_F}, \tag{8}$$

G/t_R=daily gain, $\{(1/A)\cdot(Y/t_F)\cdot A\cdot t_F\}/t_R$=daily forage intake,

$G/\{(1/A)\cdot(Y/t_F)\cdot A\cdot t_F\}$=feed efficiency.
Changing the form of equation from (2), through (4), into (8) shows that there is an entrance to the forage production analysis from both daily intake and feed efficiency in the ruminant production analysis. This is due to the intersection that is constructed by replacing I (kg/head) with Y (kg/a) according to the premise (1). The right–hand side of equation (8) shows that both daily intake and feed efficiency in the animal are supported by forage production, suggesting an aspect of the heterotrophic characteristic of ruminant animals.

FORAGE PRODUCTION ANALYSIS WITH AN INTERSECTION FOR ENTERING RUMINANT PRODUCTION ANALYSIS

The absolute growth rate of the forage is described as the product of rough estimate of assimilation rate and mean leaf area. Thus,

$$\frac{Y}{t_F}=\left\{\frac{1}{A}\cdot\frac{Y}{t_F}\right\}\cdot A\,, \tag{9}$$

Y/t_F=absolute growth rate (kg/a/d_F), A=mean leaf area over the period of d_F for the whole forage in the field with the area of one are, $(1/A)\cdot(Y/t_F)$=rough estimate of assimilation rate (kg/a/d_F).

Replacing Y (kg/a) in equation (9) with I (kg/head) according to the premise (1) gives

$$\frac{I}{t_F}=\left\{\frac{1}{A}\cdot\frac{I}{t_F}\right\}\cdot A\,, \tag{10}$$

where I/t_F=absolute growth rate (kg/head/d_F), $(1/A)\cdot(I/t_F)$=rough estimate of assimilation rate (kg/head/d_F).
Both absolute growth rate (I/t_F) and rough estimate of assimilation rate $[(1/A)\cdot(I/t_F)]$ undergo the unit transformation from kg/a/d_F into kg/head/d_F, and thus relate forage growth period (d_R) to cumulative forage intake by the animal (kg/head).

The cumulative forage intake (I) is rewritten as follows:

$$I=\frac{I}{t_R}\cdot\frac{G}{I}\cdot\frac{I}{G}\cdot t_R\,, \tag{11}$$

where I/t_R=daily forage intake, G/I=feed efficiency, I/G=feed conversion that appears newly here, t_R=a certain period of growth of the animal, the product of (I/t_R) and (G/I) is G/t_R and this is equation (2) analyzing the ruminant growth.

Inserting equation (11) into equation (10) gives

$$\frac{\dfrac{I}{t_R}\cdot\dfrac{G}{I}\cdot\dfrac{I}{G}\cdot t_R}{t_F}=\left[\frac{1}{A}\cdot\frac{\dfrac{I}{t_R}\cdot\dfrac{G}{I}\cdot\dfrac{I}{G}\cdot t_R}{t_F}\right]\cdot A\,. \tag{12}$$

Changing the form of equation from (9), through (10), into (12) shows that there is an entrance to the ruminant production analysis from both absolute growth rate and rough estimate of assimilation rate in the forage production analysis. This is caused by the intersection constructed by replacing Y (kg/a) with I (kg/head). I/G, that is naturally introduced to keep the equality between both sides of equation (12), is feed conversion as already shown in equation (11). It is another feature of equations (11) and (12) to give a pair appearance of G/I (feed efficiency) and I/G (feed conversion). This is, however, followed by a pair disappearance of them because of a reciprocal relationship $[(G/I) \cdot (I/G)=1]$. This might be one of the reasons why either G/I or I/G is usually used to evaluate feed–animal relationships. Feed efficiency and feed conversion are also given by interconvertible relationships between forage production analysis and ruminant production analysis (Shimojo *et al.*, 2000a). In the right–hand side of equation (12), leaf area (A) exists alone in the second term and A takes the form supporting the ruminant production in the first term. This suggests an aspect of the autotrophic characteristic of forage plants.

FIELD–FORAGE–RUMINANT RELATIONSHIPS

The mutual transformation between two units (kg/head↔kg/a) resulted in relating the ruminant (head) to the field (a) [equations (4), (5) and (6)], because the amount was equal between forage yield (kg/a) and cumulative forage intake (kg/head) as shown in the premise (1). This constructed an intersection of ruminant and forage production, from which point one was allowed to enter either of their analyses [equations (8) and (12)].

These results are associated with a kind of symmetric treatment of forage and ruminant production, which was also shown in different ways in our previous reports (Shimojo *et al.*, 1998b, e, 1999a, b, 2000a). The present treatment may lead to a series of interpretation as shown in the following three. (α) Forages are produced from the field to feed ruminant animals. (β) The removing of nutrients from the soil is followed by the compensation to recover the soil condition, where excreta from the animals eating forages are returned to the field and in addition fertilizer application is needed if there is still a shortage of nutrients. (γ) This is followed by the next production of forages. In the actual management forages are produced in parallel with the production of animals. Thus, there occurs the following continuation, which supports human life (Shimojo *et al.*, 2000b, c).

$$\text{Forage production} \rightarrow \text{ruminant production} \rightarrow \text{forage production} \rightarrow \cdots\cdots . \quad (13)$$

This is associated with sustainable systems for ruminant agriculture based on self–supplying forages, as shown in field–forage–ruminant relationships obtained through forage production and excreta return [equations (4), (5) and (6)]. The sustainable system gives a quantitative limitation to the amount of animal excreta that can be returned to the field, otherwise there occurs an environmental pollution as well as harmful effects on soils and plants (Wadman *et al.*, 1987; Pain, 2000). Therefore, systems suggested from the continuous relationships (13) are roughly divided into the following three groups. (i) The system with low levels of external inputs: an example for it is given by the extensive ruminant production from permanent grasslands (Wilkins, 2000). (ii)

The system with high levels of external inputs to produce forages of high digestibility and dry matter: an example for it is given by the intensive ruminant production from meadows, especially from harvested temperate forages whose nutritive value is higher than that of tropical forages (Minson, 1990a, b). (iii) The system with a link to other fields for producing food crops for human consumption in order to transfer an excess amount of animal excreta over acceptable limitation: an example for it is given by producing ruminants from some species of tropical forage crops whose yields are very high (Hanna and Torres–Cardona, 2001) but digestibility coefficients are lower compared with temperate forages (Minson, 1990a). It is likely also in the system (ii) that an excess amount of animal excreta is taken out from forage fields to manure other fields for grain crop production. Improving forage digestibility contributes to not only increasing animal production but also reducing the amount of feces excreted, provided that the rate of improvement is higher in digestibility than in yield of forages. This is the tactics indispensable to forage breeding programs, especially for tropical forages (Bray and Hutton, 1976) and also for species of high yields.

There are cases where ruminants are produced from the combination system of grazing and harvesting (Horrocks and Vallentine, 1999). Sustainable systems are likely to be related to grazing systems, because there arises a shift to extensive systems (Peel and Lloveras, 1994) which are related to nature conservation (Nösberger *et al.*, 1994).

CONCLUSIONS

A symmetry–like treatment of forage and ruminant production, which was given by introducing an intersection of them, was consequently related to the traditional and important way of ruminant agriculture, namely ' it is the soil that produces animals through forage production.' The present study may give an example of conceptual approaches to constructing sustainable systems for ruminant agriculture based on field–forage–ruminant relationships.

REFERENCES

Bray, R. A. and E. M. Hutton 1976 Plant breeding and genetics. *In* "Tropical Pasture Research: Principles and Methods", ed. by N. H. Shaw and W. W. Bryan, CAB, Oxford, pp. 338–353

Hanna, W. W. and S. Torres–Cardona 2001 *Pennisetums* and *Sorghums* in an integrated feeding system in the tropics. *In* "Tropical Forage Plants: Development and Use", ed. by A. Sotomayor–Ríos and W. D. Pitman, CRC Press LLC, Boca Raton, pp. 193–200

Horrocks, R. D. and J. F. Vallentine 1999 Feeding harvested forages. *In* "Harvested Forages", Academic Press, San Diego, pp. 75–85

Mannetje, L 't. 1994 Towards sustainable grassland management in The Netherlands. *In* "Grassland and Society", ed. by L. 't Mannetje and J. Frame, Wageningen Pers, Wageningen, pp. 3–18

Minson, D. J. 1990a Digestible energy of forage. *In* "Forage in Ruminant Nutrition", Academic Press, Inc., San Diego, pp. 85–149

Minson, D. J. 1990b Protein. *In* "Forage in Ruminant Nutrition", Academic Press, Inc., San Diego, pp. 162–207

Nösberger, J., J. Lehmann, B. Jeangros, W. Dietl, W. Kessler, P. Bassetti and J. Mitchley. 1994 Grassland production systems and nature conservation. *In* "Grassland and Society", ed. by L. 't Mannetje and J. Frame, Wageningen Pers, Wageningen, pp. 255–265

Pain, B. F. 2000 Control and utilization of livestock manures. *In* "Grass: Its Production & Utilization (3rd ed.)", ed. by A. Hopkins, Blackwell Science Ltd., Oxford, pp. 343–364

Peel, S. and J. Lloveras 1994 New targets for sustainable forage production and utilization. *In* "Grassland and Society", ed. by L. 't Mannetje and J. Frame, Wageningen Pers, Wageningen, pp. 35–47

Poppi, D. P., J. France and S. R. Mclennan 2000 Intake, passage and digestibility. *In* "Feeding Systems and Feed Evaluation Models", ed. by M. K. Theodorou and J. France, CABI Publishing, Oxon, pp. 35–52

Shimojo, M., T. Bungo, M. Tobisa, Y. Imura, N. Koga, S. Tao, M. Yunus, Z. Yin, Y. Nakano, I. Goto and Y. Masuda 1998a Accumulation of digestible materials and decrease in dry matter digestibility in the growth of two tropical grasses. *J. Fac. Agr., Kyushu Univ.*, **42**: 365–372

Shimojo, M., T. Bungo, M. Tobisa, Y. Imura, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y.Masuda 1998b A hypothetic equation from which growth analysis equations of forages and ruminants are derived as special cases. *J. Fac. Agr., Kyushu Univ.*, **43**: 103–109

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y.Masuda 1998c Mean leaf area of the canopy for light interception by forages and mean retention time of feed in the rumen for feed ingestion by ruminants as investigated using simple models. *J. Fac. Agr., Kyushu Univ.*, **43**: 111–118

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998d Accumulation rate of digestible materials and formation rate of indigestible materials in the description of relative growth rate of forages. *J. Fac. Agr., Kyushu Univ.*, **43**: 119–126

Shimojo, M., T. Bungo, N. Koga, Y. Imura, M. Tobisa, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998e An equation with a potential for describing relative growth rate of forages and of ruminants using related component factors. *Proc. 8th World Conf.Anim.Prod.*, Seoul, Korea, **Vol.II**: 510–511

Shimojo, M., T.Bungo, S. Tao, Y. Imura, M. Tobisa, N. Koga, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998f Analyses of accumulation of digestible materials and decrease in dry matter digestibility with growth of Rhodes grass. *Proc. 8th World Conf. Anim. Prod.*, Seoul, Korea, **Vol.II**: 516–517

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, T. Shao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1999a Two different–type equations of relative growth analysis for both forages and ruminants and deriving of them from a hypothetic equation. *J. Fac. Agr., Kyushu Univ.*, **43**: 355–364

Shimojo, M., T. Bungo, M. Tobisa, Y. Imura, N. Koga, T. Shao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1999b Net assimilation rate of forages and forage intake of ruminants as related using a hypothetic equation suggested to growth analysis of both forages and ruminants. *J. Fac. Agr., Kyushu Univ.*, **43**: 365–371

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, T. Shao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1999c Accumulation of digestible materials with growth of forages and digestion of forage dry matter by *in vitro* incubation with rumen fluid and pepsin. *J. Fac. Agr., Kyushu Univ.*, **43**: 373–382

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, T. Shao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1999d Forage growth analysis, forage digestion analysis and ruminant growth analysis as related using simple equations. *J. Fac. Agr., Kyushu Univ.*, **43**: 383–393

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, M. Furuse, Y. Masuda, Y. Yano, Y. Nakano, T. Shao, M. Yunus and I. Goto 2000a Contrastive or interconvertible relationships between forage and ruminant growth analysis equations –A simple description using a symmetry–like characteristic–. *J. Fac. Agr., Kyushu Univ.*, **44**: 279–285

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, M. Furuse, Y. Masuda, Y. Yano, Y. Nakano, T. Shao, M. Yunus and I. Goto 2000b Basic dividing of foods between ruminants and humans when based on the production of forages or grain crops, or both –A simple analytic description–. *J. Fac. Agr., Kyushu Univ.*, **44**: 287–292

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, M. Furuse, Y. Masuda, Y. Yano, Y. Nakano, T. Shao, M. Yunus and I. Goto 2000c Basic avoidance of food competition among ruminants, non–ruminants and humans –A simple analytic description–. *J .Fac. Agr., Kyushu Univ.*, **44**: 293–297

Spedding, C. R. W. 1995 Sustainability in animal production systems. *Anim. Sci.*, **61**: 1–8

Wadman, W. P., C. M. J. Sluijsmans and L. C. N. de la Lande Cremer 1987 Value of animal manures: changes in perception. *In* "Animal Manure on Grassland and Fodder Crops. Fertilizer or Waste ?", ed. by H. G.Van Der Meer, R. J. Unwin, T. A. Van Dijk and G. C. Ennik, Martinus Nijhoff Publishers, Dordrecht, pp. 1–16

Whitehead, D. C. 2000a Introduction. *In* "Nutrient Elements in Grassland: Soil–Plant–Animal Relationships", CABI Publishing, Oxon, pp. 1–14

Whitehead, D. C. 2000b Nutrient elements in soils. *In* "Nutrient Elements in Grassland: Soil–Plant–Animal Relationships", CABI Publishing, Oxon, pp. 15–40

Wilkins, R. J. 2000 Forages and their role in animal systems. *In* "Forage Evaluation in Ruminant Nutrition", ed. by D. I. Givens, E. Owen, R. F. E. Axford and H. M. Omed, CABI Publishing, Oxon, pp. 1–14