Analyses of Accumulation of Silica in the Growth of Two Tropical Forages using Simple Equations

Shimojo, Masataka
Laboratory of Animal Feed Science, Faculty of Agriculture, Kyushu University

Bungo, Takashi
Laboratory of Animal Feed Science, Faculty of Agriculture, Kyushu University

Tobisa, Manabu
Laboratory of Animal Feed Science, Faculty of Agriculture, Kyushu University

Imura, Yoshimi
Laboratory of Animal Feed Science, Faculty of Agriculture, Kyushu University

他

https://doi.org/10.5109/24285

出版情報：九州大学大学院農学研究院紀要. 43 (3/4), pp.395-401, 1999-02. Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **43** (3・4), 395–401 (1999)

Analyses of Accumulation of Silica in the Growth of Two Tropical Forages using Simple Equations

Masataka Shimojo, Takashi Bungo, Manabu Tobisa, Yoshimi Imura, Naoki Koga, Tao Shao, Muhammad Yunus, Yutaka Nakano*, Ichiro Goto, Mitsuhiro Furuse and Yasuhisa Masuda**

Laboratory of Animal Feed Science, Faculty of Agriculture, Kyushu University, Fukuoka 812–8581, Japan
(*Received October 30, 1998 and accepted November 6, 1998*)

The present study was conducted, using simple equations, to analyze the accumulation rate of silica [ARSi], that of minerals [ARM] and silica content changes with growth of Rhodes grass [Rg] and Greenleaf desmodium [Gd]. The following two equations were suggested for analyses:

$$\mathrm{ARSi} = \frac{1}{W}\cdot\frac{d(Si)}{dt} = \left(\frac{1}{W}\cdot\frac{dM}{dt}\right)\cdot\frac{d(Si)}{dM}, \qquad \text{(A)}$$

$$\text{Changes in silica content} = \frac{1}{1000}\cdot\left(\frac{(Si)_2}{W_2}-\frac{(Si)_1}{W_1}\right)$$
$$= \left(1-\frac{W_1}{W_2}\right)\cdot\left\{\frac{1}{1000}\cdot\left(\frac{\overline{\mathrm{ARSi}}}{\overline{\mathrm{RGR}}}-\frac{(Si)_1}{W_1}\right)\right\}, \qquad \text{(B)}$$

where W=forage dry weight (g/m^2), Si=amount of silica in the forage (mg/m^2), M=amount of minerals in the forage (mg/m^2), $(1/W)\cdot(d(Si)/dt)$=ARSi, $(1/W)\cdot(dM/dt)$=ARM, $(d(Si)/dM)$=accumulation of silica per unit accumulation of M[ASiAM], $\overline{\mathrm{RGR}}$=mean relative growth rate [RGR] of forages over the interval t_1 to t_2, $\overline{\mathrm{ARSi}}$=mean ARSi over the interval t_1 to t_2, $(1-W_1/W_2)$=forage growth index [FG index], $\{\overline{\mathrm{ARSi}}/\overline{\mathrm{RGR}}-(Si)_1/W_1\}/1000$=an index for forage growth dependent silica accumulation [FGDSiA index].

Analyses using equation (A) suggested that Rg showed a higher selection of silica in the accumulation of minerals, when compared with Gd. Analyses using equation (B) suggested that Rg showed less active silica accumulation than forage growth, in contrast to more active silica accumulation than forage growth in Gd. It was suggested that the present methods accounted analytically for the accumulation characteristics of silica and its content changes with growth of forages.

INTRODUCTION

Silica, as well as other minerals, is absorbed from soil by plant roots, and the absorbed silica is deposited on plant fibers (Jones and Handreck, 1967). It is reported that silica depresses forage digestibility (Smith and Nelson, 1975; Smith and Urquhart, 1975; Van Soest, 1982; Shimojo and Goto, 1985, 1989; Minson, 1990). The content of silica is lower than that of lignin unless forages are grown on soil rich in silica or under water–logging

* Kyushu University Farm, Fukuoka 811–2307
** University of the Air, Fukuoka Study Center, Fukuoka 812–0016

condition like a paddy field. In many cases, therefore, the depression of forage digestibility by silica seems to be smaller than that by lignin. This is why we have so far taken up lignification only in the analysis, using simple equations, of the formation of indigestible materials with growth of forages (Shimojo *et al.*, 1995, 1997a, b, 1998a, d, g, h, i, 1999a, b, c).

It is considered of interest to apply simple equations to analyses of the absorption and accumulation of silica with growth of forages. Tobisa *et al.* (1997) analyzed, using the equation suggested by Hunt (1990), the absorption of some minerals by the root of *Aeschynomene americana* cv. Glenn when grown under the water–logging condition. To the analysis of the accumulation of silica, simple equations, which were suggested to the analysis of the accumulation of digestible materials (Shimojo *et al.*, 1998b, f, h, 1999a, b, c) and that of crude protein (Shimojo *et al.*, 1998c, e) with forage growth, might be expected to be applied, if modified appropriately.

The present study was designed to suggest simple equations to analyses of the accumulation of silica and its content changes with growth of forages, followed by applying them to two tropical forages, a grass and a forage legume.

EQUATIONS FOR ANALYZING ACCUMULATION OF SILICA AND ITS CONTENT CHANGES WITH FORAGE GROWTH

An equation suggested to the analysis of silica accumulation

An equation for describing silica accumulation rate per unit dry weight of the forage [ARSi] with its growth is suggested as follows:

$$\mathrm{ARSi} = \frac{1}{W} \cdot \frac{d(Si)}{dt} \qquad (1)$$

where W=forage dry weight (g/m^2), Si=amount of silica in the forage (mg/m^2).

Silica is actually absorbed by plants as a part of minerals, therefore, equation (1) is rewritten as follows:

$$\mathrm{ARSi} = \frac{1}{W} \cdot \frac{d(Si)}{dt} = \left(\frac{1}{W} \cdot \frac{dM}{dt}\right) \cdot \frac{d(Si)}{dM}, \qquad (2)$$

where M=amount of minerals in the forage (mg/m^2), $(1/W) \cdot (dM/dt)$=accumulation rate of minerals per unit W [ARM], $d(Si)/dM$=accumulation of silica per unit accumulation of M [ASiAM].

Mean value over the interval t_1 to t_2 for each of ARSi, ARM and ASiAM is approximately as follows:

$$\overline{\mathrm{ARSi}} = \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1} \cdot \frac{(Si)_2 - (Si)_1}{t_2 - t_1}, \quad (3)$$

$$\overline{\mathrm{ARM}} = \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1} \cdot \frac{M_2 - M_1}{t_2 - t_1}, \quad (4)$$

$$\overline{\mathrm{ASiAM}} = \frac{(Si)_2 - (Si)_1}{M_2 - M_1}, \quad (5)$$

where e=the base of natural logarithm.

An equation suggested to the analysis of silica content changes

An equation for describing changes in silica content with forage growth is suggested as follows:

$$\text{Chages in silica content} = \frac{1}{1000}\cdot\left(\frac{(Si)_2}{W_2}-\frac{(Si)_1}{W_1}\right)$$
$$=\left(1-\frac{W_1}{W_2}\right)\cdot\left\{\frac{1}{1000}\cdot\left(\frac{\overline{\text{ARSi}}}{\overline{\text{RGR}}}-\frac{(Si)_1}{W_1}\right)\right\}, \qquad (6)$$

where $\overline{\text{ARSi}}$=mean ARSi over the interval t_1 to t_2, RGR=forage relative growth rate $[(1/W)\cdot(dW/dt)]$, $\overline{\text{RGR}}$=mean RGR over the interval t_1 to t_2, $(1-W_1/W_2)$=forage growth index [FG index], $\{\overline{\text{ARSi}}/\overline{\text{RGR}}-(Si)_1/W_1\}/1000$=an index for forage growth dependent silica accumulation [FGDSiA index].

$\overline{\text{RGR}}$ is approximately as follows:

$$\overline{\text{RGR}}=\frac{\log_e W_2-\log_e W_1}{t_2-t_1}. \qquad (7)$$

Equation (6) is given according to the following procedures:

$$\frac{(Si)_2}{W_2}-\frac{(Si)_1}{W_1}=\frac{(Si)_1+\Delta Si}{W_1+\Delta W}-\frac{(Si)_1}{W_1}$$
$$=\frac{\Delta Si}{W_1+\Delta W}-\frac{(Si)_1\cdot\Delta W}{W_1\cdot(W_1+\Delta W)}$$
$$=\frac{\Delta Si}{W_2}-\frac{(Si)_1\cdot\Delta W}{W_1\cdot W_2}$$
$$=\frac{\Delta W}{W_2}\cdot\left(\frac{\Delta Si}{\Delta W}-\frac{(Si)_1}{W_1}\right). \qquad (8)$$

Then, the ratio of ARSi to RGR is taken up as follows:

$$\frac{\text{ARSi}}{\text{RGR}}=\frac{\frac{1}{W}\cdot\frac{d(Si)}{dt}}{\frac{1}{W}\cdot\frac{dW}{dt}}$$
$$=\frac{d(Si)}{dW}. \qquad (9)$$

Thus, the following relation is suggested,

$$\frac{\Delta Si}{\Delta W}=\frac{\overline{\text{ARSi}}}{\overline{\text{RGR}}}. \qquad (10)$$

Inserting equation (10) into equation (8) gives

$$\frac{(Si)_2}{W_2}-\frac{(Si)_1}{W_1}=\frac{\Delta W}{W_2}\cdot\left(\frac{\overline{\text{ARSi}}}{\overline{\text{RGR}}}-\frac{(Si)_1}{W_1}\right)$$

$$= \frac{W_2 - W_1}{W_2} \cdot \left(\frac{\overline{\text{ARSi}}}{\overline{\text{RGR}}} - \frac{(Si)_1}{W_1} \right)$$

$$= \left(1 - \frac{W_1}{W_2} \right) \cdot \left(\frac{\overline{\text{ARSi}}}{\overline{\text{RGR}}} - \frac{(Si)_1}{W_1} \right). \tag{11}$$

Dividing equation (11) by 1000 gives equation (6).

AN APPLICATION OF SUGGESTED EQUATIONS TO TWO TROPICAL FORAGES

Forages

Two tropical forages are Rhodes grass (*Chloris gayana* Kunth) and Greenleaf desmodium (*Desmodium intortum* (Mill.) Urb.) which were cut at 35 and 63 days of regrowth with a compound fertilizer ($N:P_2O_5:K_2O$=14:14:14%) dressed at a rate of 1.0 kg/a for each element immediately after the first cut and discard. Forage dry weight was determined by drying at 70°C for 48 hr, minerals were determined by combustion at 600°C for 3 hr, and silica was determined using the method of Goering and Van Soest (1970).

Characteristics of Rhodes grass [Rg] and Greenleaf desmodium [Gd] are shown in Table 1. The silica content in forage (g/g) was higher in Rg than in Gd at both days of regrowth (0.0156 versus 0.0024 at 35 days, 0.0123 versus 0.0032 at 63 days). This is in agreement with the review article on forage silica by Wilson (1982) that grasses generally contain higher amount of silica than forage legumes. Mineral content in forage (g/g) is higher in Rg than in Gd at both days of regrowth (0.1146 versus 0.0841 at 35 days, 0.0798 versus 0.0705 at 63 days), but the content difference between Rg and Gd decreased with growth of them. Silica concentration in minerals (g/g) is higher in Rg than in Gd at both

Table 1. Characteristics of Rhodes grass [Rg] and Greenleaf desmodium [Gd].

Forages	Rg		Gd	
Regrowth(days)	35	63	35	63
Forage dry weight: W(g/m^2)	225.56	515.00	190.00	315.28
Silica amount in forage: Si(g/m^2)	3.51	6.36	0.46	1.00
ditto: Si(mg/m^2)	3510.0	6360.0	460.0	1000.0
Silica content in forage(g/g)	0.0156	0.0123	0.0024	0.0032
Mineral amount in forage: M(g/m^2)	25.85	41.10	15.98	22.23
ditto: M(mg/m^2)	25850.0	41100.0	15980.0	22230.0
Mineral content in forage(g/g)	0.1146	0.0798	0.0841	0.0705
Silica concentration in minerals(g/g)	0.1358	0.1547	0.0288	0.0450

Silica: determined using the method of Goering and Van Soest (1970).
Minerals: determined as crude ash by the combustion of forages at 600°C for 3 hr.

days of regrowth (0.1358 versus 0.0288 at 35 days, 0.1547 versus 0.0450 at 63 days), and the concentration increased with growth in both Rg and Gd.

Accumulation of silica with growth of Rg and Gd

The accumulation of silica in Rg and Dg analyzed using ARSi, ARM and ASiAM over the interval of 28 days of regrowth are shown in Table 2a. $\overline{\text{ARSi}}$ was higher in Rg than in Gd (0.2903 versus 0.0780), and this was due to both higher $\overline{\text{ARM}}$ (1.5535) and $\overline{\text{ASiAM}}$ (0.1869) in Rg compared with those (0.9023 and 0.0864, respectively) in Gd. The ratio of Rg to Gd in ARSi (3.7240) was higher than that in $\overline{\text{ARM}}$ (1.7217), suggesting that Rg showed a higher selection of silica in the accumulation of minerals, when compared with Gd. This resulted in the ratio of Rg to Gd in $\overline{\text{ASiAM}}$ to be 2.1630. It is suggested that the present method accounts analytically for how silica and minerals accumulate with growth of forages and how the accumulation of them shows differences between forages.

Changes in silica content with growth of Rg and Gd

Changes in silica content analyzed using FG index and FGDSiA index over the interval of 28 days are shown in Table 2b. The change in silica content was −0.0032 for Rg

Table 2. Analyses of the accumulation of silica and changes in its content with growth of Rhodes grass [Rg] and Greenleaf desmodium [Gd].

a) Analysis of the accumulation of silica with growth of Rg and Gd.

Forages Interval(days)	Rg 28	Gd 28	Rg/Gd
$\overline{\text{ARSi}}$ (mg/g/day)	0.2903	0.0780	3.7240
$\overline{\text{ARM}}$ (mg/g/day)	1.5535	0.9023	1.7217
$\overline{\text{ASiAM}}$ (mg/mg)	0.1869	0.0864	2.1630

ARSi=accumulation rate of silica per unit *W*, ARM=accumulation rate of minerals per unit *W*, ASiAM=accumulation of silica per unit accumulation of minerals.

b) Analysis of changes in silica content with growth of Rg and Gd.

Forages Interval(days)	Rg 28	Gd 28	Rg/Gd
Silica content changes	−0.0032	0.0008	−4.2782
FG index	0.5620	0.3974	1.4144
FGDSiA index	−0.0057	0.0019	−3.0248

FG index=an index for forage growth, FGDSiA index=an index for forage growth dependent silica accumulation.

and 0.0008 for Gd. The negative value in Rg was due to its negative FGDSiA index (−0.0057). The difference in silica content change was mainly due to the difference in FGDSiA index (−0.0057 versus 0.0019), because the difference in FG index between the two forages (0.5620 versus 0.3974) was not so large as that of FGDSiA index.

The negative FGDSiA index in Rg (−0.0057) is related to the fact that $\overline{ARSi/RGR}$ is lower than $(Si)_i/W_i$, namely silica accumulation is less active than forage growth. This may cause a slight reduction in the content of silica during the growth of Rg (−0.0032). In contrast, the positive FGDSiA index in Gd (0.0019) brings about a slight increase in silica content (0.0008) through more active silica accumulation than forage growth. It is suggested that the present method accounts analytically for how silica accumulation is related to forage growth and how this relationship shows differences between forages.

Conclusions

Equations suggested in the present study might give some information about analyses of accumulation of silica, that of minerals and changes in silica content with growth of forages. There is a necessity for examining the present method by applying it to various forages grown under different conditions.

ACKNOWLEDGEMENTS

We wish to thank Mr. Yasukatsu Yano for his skilled technical assistance in the present study.

REFERENCES

Goering, H. K. and P. J. Van Soest 1970 Forage fiber analyses. *Agriculture Handbook (U.S.D.A.)*, **No. 379**: 1–20

Hunt, R. 1990 Compounded growth rates. *In* "Basic Growth Analysis", Unwin Hyman Ltd., London, pp. 55–72

Jones, L. H. P. and K. A. Handreck 1967 Silica in soils, plants, and animals. *Advan.Agron.*, **19**: 107–148

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

Shimojo, M. and I. Goto 1985 Effect of soluble silica on digestion of forage with rumen fluid of goat and cellulase. *Jpn. J. Zootech. Sci.*, **56**: 20–24 (in Japanese with English summary)

Shimojo, M. and I. Goto 1989 Effect of sodium silicate on forage digestion with rumen fluid of goats or cellulase using culture solutions adjusted for pH. *Anim. Feed Sci. Technol.*, **24**: 173–177

Shimojo, M., Y. Masuda, T. Bungo, T. Kawamura and I. Goto 1995 Analytical expression for formation of indigestible materials and increase in dry matter indigestibility with growth of some tropical grasses. *J. Fac. Agr., Kyushu Univ.*, **40**: 179–188

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, Y. Nakano, I. Goto and Y. Masuda 1997a An analysis of digestibility change with growth of forage. *In* "Present and future of rumen research", *Proc. First Joint Symp. Japan and Korea on Rumen Metab. Physiol.*, P-11

Shimojo, M., Y. Imura, M. Tobisa, N. Koga, T. Bungo, Y. Nakano, T. Nishihira, I. Goto and Y. Masuda 1997b Formation of indigestible materials and increase in dry matter indigestibility in the growth of two tropical forages. *J. Fac. Agr., Kyushu Univ.*, **42**: 95–99

Shimojo, M., Y. Imura, T. Bungo, M. Tobisa, N. Koga, S. Tao, M. Yunus, Z. Yin, Y. Nakano, I. Goto and Y. Masuda 1998a Formation of indigestible materials from digestible materials and photosynthates in the growth of Rhodes grass (*Chloris gayana* Kunth). *J. Fac. Agr., Kyushu Univ.*, **42**: 355–360

Shimojo, M., T. Bungo, M. Tobisa, Y. Imura, N. Koga, S. Tao, M. Yunus, Z. Yin, Y. Nakano, I. Goto and Y.

Masuda 1998b 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. M. Tobisa, Y. Imura, T. Bungo, N. Koga, S. Tao, M. Yunus, Z. Yin, I. Goto, Y. Nakano and Y. Masuda 1998c Analyses of accumulation of crude protein and decrease in its content in the growth of *Chloris gayana* Kunth and *Desmodium intortum* (Mill.) Urb. *J. Fac. Agr., Kyushu Univ.*, **42**: 377–381

Shimojo, M., T. Bungo, M. Tobisa, Y. Imura, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998d Analyses of formation of indigestible materials and increase in dry matter indigestibility with growth of two tropical forages. *Proc. 8th World Conf. Anim. Prod.*, Seoul, Korea, **Vol. II**: 508–509

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998e Analyses of accumulation of crude protein and decrease in its content with growth of Rhodes grass. *Proc. 8th World Conf. Anim. Prod.*, Seoul, Korea, **Vol. II**: 512–513

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, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998g Some aspects on the analysis of the formation of indigestible materials with growth of forages. *Proc. 8th World Conf. Anim. Prod.*, Seoul, Korea, **Vol. II**: 518–519

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998h Accumulation rate of digestiblematerials 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, M. Tobisa, Y. Imura, N. Koga, S. Tao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1998i An application of growth analysis method to simple correlation analysis between dry matter indigestibility and lignin content with growth of a forage. *J. Fac. Agr., Kyushu Univ.*, **43**: 127–136

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**: in press

Shimojo, M., T. Bungo, Y. Imura, M. Tobisa, N. Koga, T. Shao, M. Yunus, Y. Nakano, I. Goto, M. Furuse and Y. Masuda 1999b 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**: in press

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

Smith, G. S. and A. B. Nelson 1975 Effects of sodium silicate added to rumen cultures on forage digestion, with interactions of glucose, urea and minerals. *J. Anim. Sci.*, **41**: 891–899

Smith, G. S. and N. S. Urquhart 1975 Effect of sodium silicate added to rumen cultures on digestion of siliceous forages. *J. Anim. Sci.*, **41**: 882–890

Tobisa, M., M. Shimojo, Y. Masuda and I. Goto 1997 Effects of waterlogging treatment on the contents of cell wall constituents and minerals in *Aeschynomene americana* cv. Glenn. *Grassld. Sci.*, **43**: 298–305 (in Japanese with English summary)

Van Soest, P. J. 1982 Nutritional quality. *In* "Nutritional Ecology of the Ruminant", Cornell University Press, New York, pp. 23–74

Wilson, J. R. 1982 Environmental and nutritional factors affecting herbage quality. *In* "Nutritional Limits to Animal Production from Pastures", ed. by J. B. Hacker, CAB International, Farnham Royal, U. K., pp. 111–131