Process-based modelling of the nutritive value of forages: a review

P. Korhonen [1], P. Virkajärvi [1], G. Bellocchi [2], Y. Curnel [3], L. Wu [4], G. Jégo [5], T. Persson [6], M. Höglind [6], M. Van Oijen [7], A.-M. Gustavsson[8], R.P. Kipling[9], A. Rotz[10], T. Palosuo[1], P. Calanca[11]

[1] ***Green Technology, Natural Resources Institute Finland (Luke), Halolantie 31A, FI-71750 Maaninka, Finland***
[2] *INRA, France*
[3] *Walloon Agricuandltural Research Center, Belgium*
[4] *Rothamsted Research, UK*
[5] *Agriculture and Agrifood Canada, Quebec, Canada*
[6] *Norwegian Institute of Bioeconomy Research (NIBIO), Norway*
[7] *Centre for Ecology and Hydrology, UK*
[8] *Swedish University of Agricultural Sciences, Sweden*
[9] *Aberystwyth University, UK*
[10] *U.S. Department of Agriculture, Agricultural Research Service, USA*
[11] *Agroscope, Institute for Sustainability Sciences ISS, Switzerland*

MACSUR Science Conference
May 22-24 2017

Luke
NATURAL RESOURCES INSTITUTE FINLAND

Aims

This study reviews and compares alternative modelling approaches for simulating forage nutritive value.

It is intended to

1) provide model users with essential information for choosing a proper fit-for-purpose grassland models that include nutritive value
2) give model developers feedback that is helpful in improving the models
3) promote the development of state-of-the-art model assessment

Modelling of nutritional variables required to predict animal performance is recognized as one of the fifteen main challenges for modelling European grasslands in Kipling et al. 2016 –review*

**Kipling et al. 2016: Key challenges and priorities for modelling European grasslands under climate change. Science of the Total Environment 566-567: 851-864.*

Models

The focus on process-based/mechanistic/biophysical models with approaches applicable for European grasslands:

- BASGRA
- CATIMO
- IFSM
- MCPy
- ModVege
- PaSim
- QUAL
- SPACSYS
- STICS

These models cover swards cut for silage or hay, grazed swards, monocultures and mixtures, permanent grasslands and leys kept for less than five years.

Model structures

BASGRA
CATIMO
IFSM
MCPy
ModVege
PaSim
QUAL
SPACSYS
STICS

The chosen grassland models work on

- field scale
- daily time step

Most of the chosen models are open access and have editable script → model modifications possible for users

Only a couple of the models have modular structure → possibly laborious to implement parts from one model to other models

Some of the models use functional groups to distinct differently developing parts of the canopy (IFSM, ModVege, PASIM, SPACSYS)

Grasslands have characteristics that are not included in most arable cropping systems

- Short or long-term perenniality
  - over-wintering
  - carry-on effects
- Recovery from repeated defoliation
  - cutting or grazing possible at any developmental stage
- Harvested biomass is comprised of all above–ground biomass
  - canopy exists in a dynamic state → harvest time determines nutritive value of yield
- Interaction between animals and vegetation

Many variables are used for describing forage nutritive value

Energy variables	Digestibility variables	Protein variables
ME: metabolisable energy **NEL**: net energy of lactation **NEM**: net energy of maintenance **FME**: fermentable metabolisable energy **FEm**: feed unit for milk production (Norwegian) **GE:** Gross energy **DE:** Digestible energy …	**CWC**: cell wall content/concentration **CWD**: cell wall digestibility **IVCWD**: in vitro cell wall digestibility **NDF**: neutral detergent fiber **NDS**: neutral detergent solubles **dNDF**: in vitro digestibility of NDF **iNDF**: indigestible NDF **pdNDF**: potentially digestible NDF **OMD**: organic matter digestibility **DOM**: digestible organic matter **IVOMD**: in vitro organic matter digestibility **IVTD**: in vitro true digestibility of dry matter **TDN**: total digestible nutrients **D-value**: concentration of digestible organic matter in DM …	**N concentration** **CP**: crude protein **DCP**: digestible crude protein **RDP**: rumen digestible protein **ERDP**: effective rumen degradable protein **ADIP**: acid detergent insoluble protein **DUP**: digestible undegradable crude protein content **ADIN**: acid-detergent insoluble nitrogen **NDIN:** neutral detergent insoluble nitrogen **SP:** water soluble crude protein …

Which of these are considered in current models?

Has something useful been left out?

Processes affecting nutritive value of grassland

Scale	Factors affecting nutritive value	Related variables possibly used in models
Vegetation	Proportions of different plant species	- Species composition - Functional traits
Plant	Proportions of different plant organs	- Leaf:stem-ratio - Phenology - Senescence
Tissue	Proportions of different plant tissues	NA
Cell	Proportion of cell walls and cell solubles	- NDF
Cell wall	Cell wall components (lignin, cellulose, hemicellulose, pectins)	dNDF, iNDF, IVTD, OMD

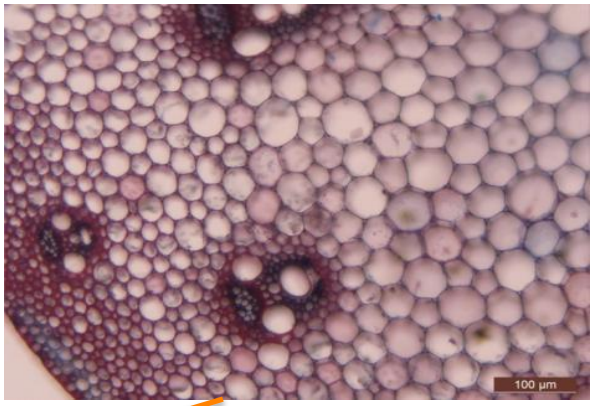
Cell wall content and digestibility

- Neutral detergent fiber (NDF) – the amount of fibrous component of plant material including cellulose, hemicellulose and lignin

- NDF digestibility is affected by cell wall composition (amount and structure of lignin, cellulose, hemicellulose and pectins)
  - Lignification the primary factor inhibiting cell wall degradability

- The digestible proportion of NDF is often described using
  - digestibility of NDF (dNDF)
  - indigestible NDF (iNDF)

Photograph:
P. Korhonen & A.Kärkönen



Red color =
lignin (safranin)

Cell wall content and digestibility

- NDF concentration of forage dry matter is the most commonly used variable to describe cell wall development in models
  - simulated in 6 out of 9 models (BASGRA, CATIMO, IFSM, PASIM, QUAL, STICS)

- Digestibility of NDF is simulated in models as
  - indigestible NDF: iNDF (IFSM)
  - non-digestible NDF: NDFnd (PASIM)
  - digestible NDF: dNDF (BASGRA, CATIMO, (STICS))

Digestibility of forage biomass

- Digestibility of forage can be presented using different variables, e.g.
  - dry matter digestibility (DMD)
  - organic matter digestibility (OMD)
  - amount of digestible organic matter in DM (D-value)
  - total digestible nutrients (TDN)

- Digestibility can be measured *in vitro, in sacco/in situ* or *in vivo*
  - *In vitro* –values commonly used and are also mostly used in model

Digestibility of forage biomass

- Development of digestibility changes during the annual growth cycle (e.g. vernalized spring yield vs. autumn yield)
  - differences between the yields not fully taken into account in all reviewed models

- Forage digestibility variables simulated in the models:
  - In Vitro True Digetibility: IVTD (CATIMO, IFSM, QUAL)
  - Organic matter digestibility: OMD (ModVege, PASIM, QUAL)
  - Total digestible nutrients: TDN (IFSM)

Energy value of forage

- The most often used values to describe energy content of forage in practice are
  - metabolizable energy (ME), often expressed as forage ME concentration (e.g. MJ kg^{-1} DM)
  - net energy for production, e.g. net energy for lactation (MJ kg^{-1} DM NEL).
- Energy value of forage is simulated in the models as
  - net energy for lactation or maintenance, NEL/NEM (IFSM and PASIM)
  - net energy for milk production (VEM) (MCPy)
  - metabolisable energy, ME (QUAL, IFSM)
- Information of animal performance (animal digestion model) often needed in models for variables describing energy in relation to performance

Protein and non–protein N

- Nitrogen concentration of forage is commonly simulated in grassland models (here in 7 out of 9 models)
- Other N-related variables that describe nutritive value are less commonly included. However,
  - crude protein (CP) can be calculated based on N concentration (calculated in 5 out of 9 models - usually 6.25 times N concentration)
  - MCPy simulates also DVE (the amount of protein digestible and available in the small intestine).
- The indicators of forage protein value are typically estimated based on digestibility and CP of forage

What next?

The final publication is in progress – will include:

- descriptions of different modelling approaches
- reasoning if we should include more variables in the models or develop the existing ones further
- up-to-date information of what is possible and realistic with the current models regarding NV modelling
- model information gathered in an easy-to-compare way to support decisions in choosing suitable models for use
- a review of what model couplings have already been made and what could be possible

Thank you!

Luke
NATURAL RESOURCES
INSTITUTE FINLAND


Luke
NATURAL RESOURCES
INSTITUTE FINLAND