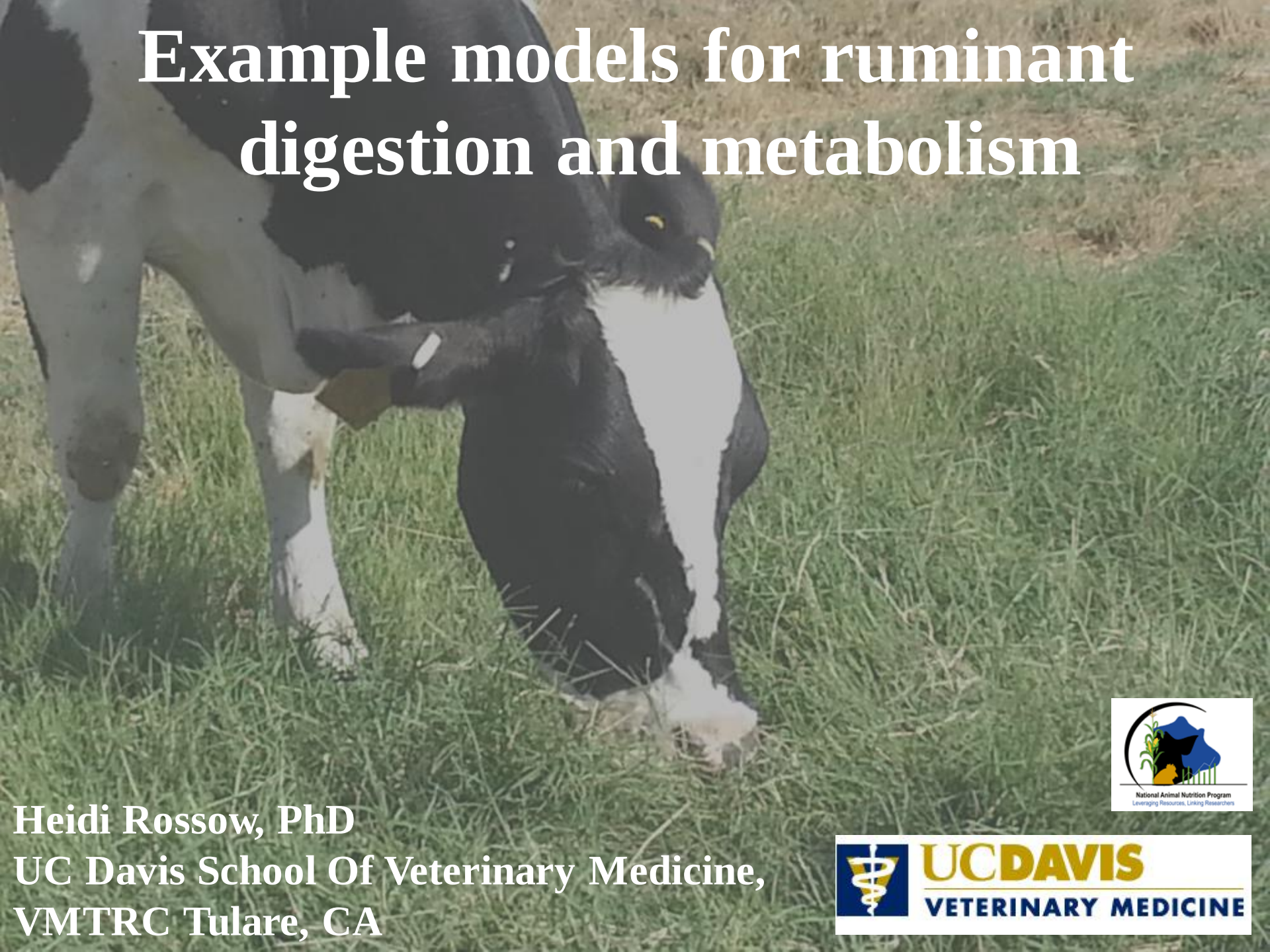
Example models for ruminant digestion and metabolism



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National Animal Nutrition Program
Leveraging Resources, Linking Researchers

UCDAVIS VETERINARY MEDICINE

Intro to Molly
Representation of milk production
Short demo using BST
Exercise

WEBSITE:
http://www.vmtrc.ucdavis.edu/laboratories/metabolic/molly.cfm

Publications:

Baldwin RL, France J, Gill M. 1987. Metabolism of the lactating cow I-III. J Dairy Research 54:77-145.

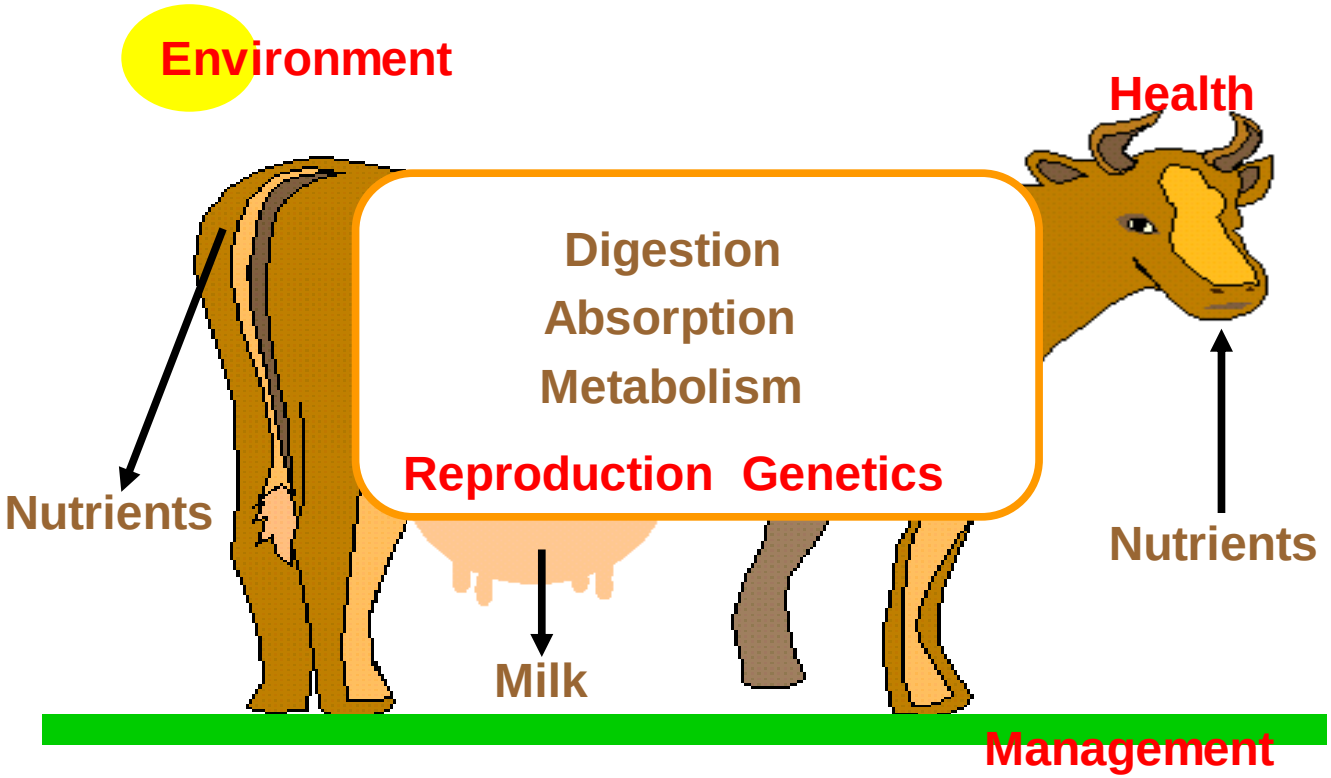
Baldwin RL. 1995. Modeling ruminant digestion and metabolism. Chapman & Hall:London.

Johnson HA, Maas JA, Calvert CC, Baldwin RL. 2008. Use of computer simulation to Teach systems approach to Nutrition and Metabolism. JAS 86:483-499

Neal & Thornley 1983 J Ag Sci Cambridge 101:389-400

OBJECTIVE

Bridge gap between basic knowledge of cow digestion and metabolism, and animal performance



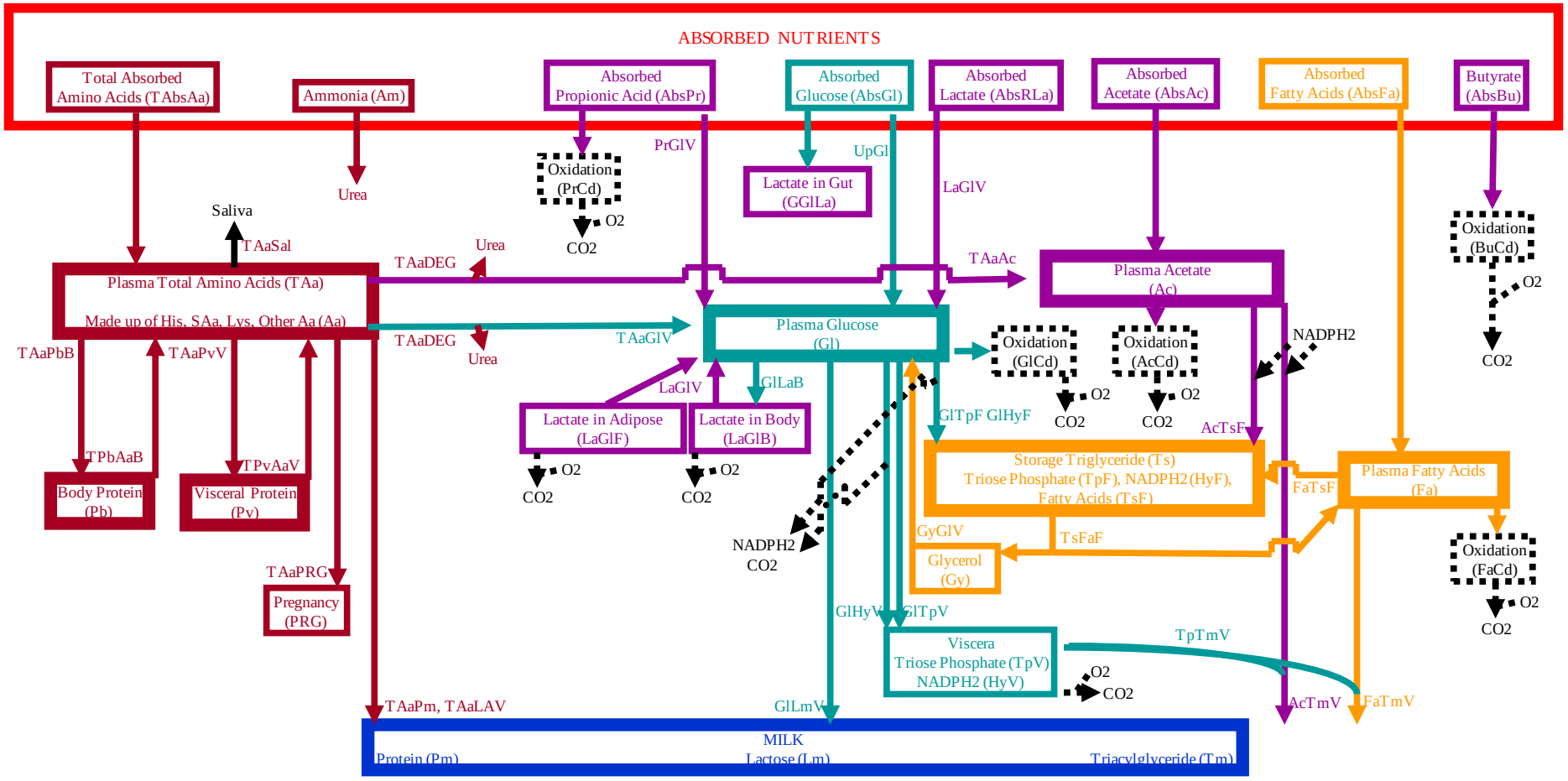
State Variables

Animal Element

Amino acids
(Lys His Met/Cys Other)
Glucose
Acetate
Fatty Acids
Adipose TG
Body Protein
Visceral Protein
Uenz
Milk lactose
Milk Protein
Milk Fat
Milk

Digestive Element

Large Particles
Small Particles
Microbes
Rumen VFAs
DMI
Soluble Ash
Cellulose
Hemicellulose
Soluble, Insoluble Protein
Soluble Carbohydrates
Alpha, Beta Hexoses


ABSORBED NUTRIENTS
Total Absorbed Amino Acids (TAbsAa)
Ammonia (Am)
Absorbed Propionic Acid (AbsPr)
Absorbed Glucose (AbsGl)
Absorbed Lactate (AbsRLa)
Absorbed Acetate (AbsAc)
Absorbed Fatty Acids (AbsFa)
Butyrate (AbsBu)
Urea
PrGlV
Oxidation (PrCd)
O2
CO2
UpGl
Lactate in Gut (GGlLa)
LaGlV
Saliva
TAaSal
Urea
TAaDEG
TAaAc
Plasma Acetate (Ac)
Oxidation (BuCd)
Plasma Total Amino Acids (TAa)
Made up of His, SAa, Lys, Other Aa (Aa)
TAaDEG
Urea
TAaGlV
Plasma Glucose (Gl)
NADPH2
Oxidation (GlCd)
Oxidation (AcCd)
TAaPbB
TAaPvV
LaGlV
GlLaB
Lactate in Adipose (LaGlF)
Lactate in Body (LaGlB)
GlTpF GlHyF
AcTsF
Storage Triglyceride (Ts)
Triose Phosphate (TpF), NADPH2 (HyF),
Fatty Acids (TsF)
FaTsF
Plasma Fatty Acids (Fa)
TPbAaB
TPvAaV
Body Protein (Pb)
Visceral Protein (Pv)
NADPH2
CO2
GyGlV
TsFaF
Glycerol (Gy)
Oxidation (FaCd)
TAaPRG
Pregnancy (PRG)
GlHyV
GlTpV
Viscera
Triose Phosphate (TpV)
NADPH2 (HyV)
TpTmV
TAaPm, TAaLAV
GlLmV
AcTmV
FaTmV
MILK
Protein (Pm)
Lactose (Lm)
Triacylglyceride (Tm)

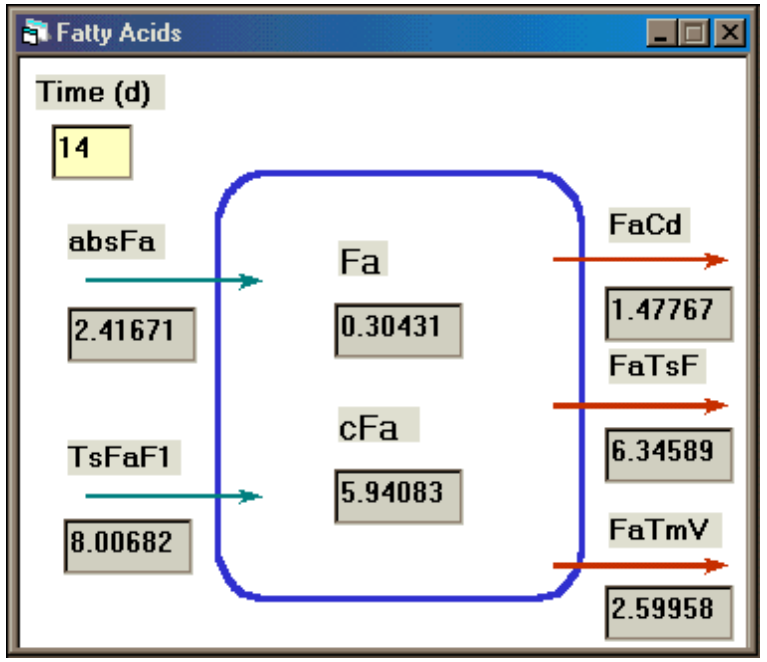
Equations

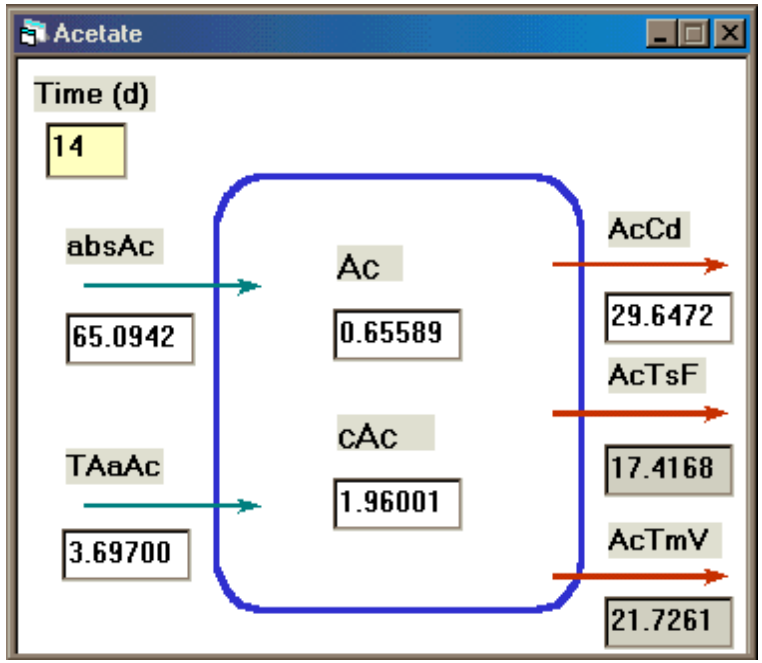
dFa/dt = absFa + TsFaF1 -FaTsf – FaTmV – FaCd

Units = Mol/d
Integrate dFa/dt = Mol Fa

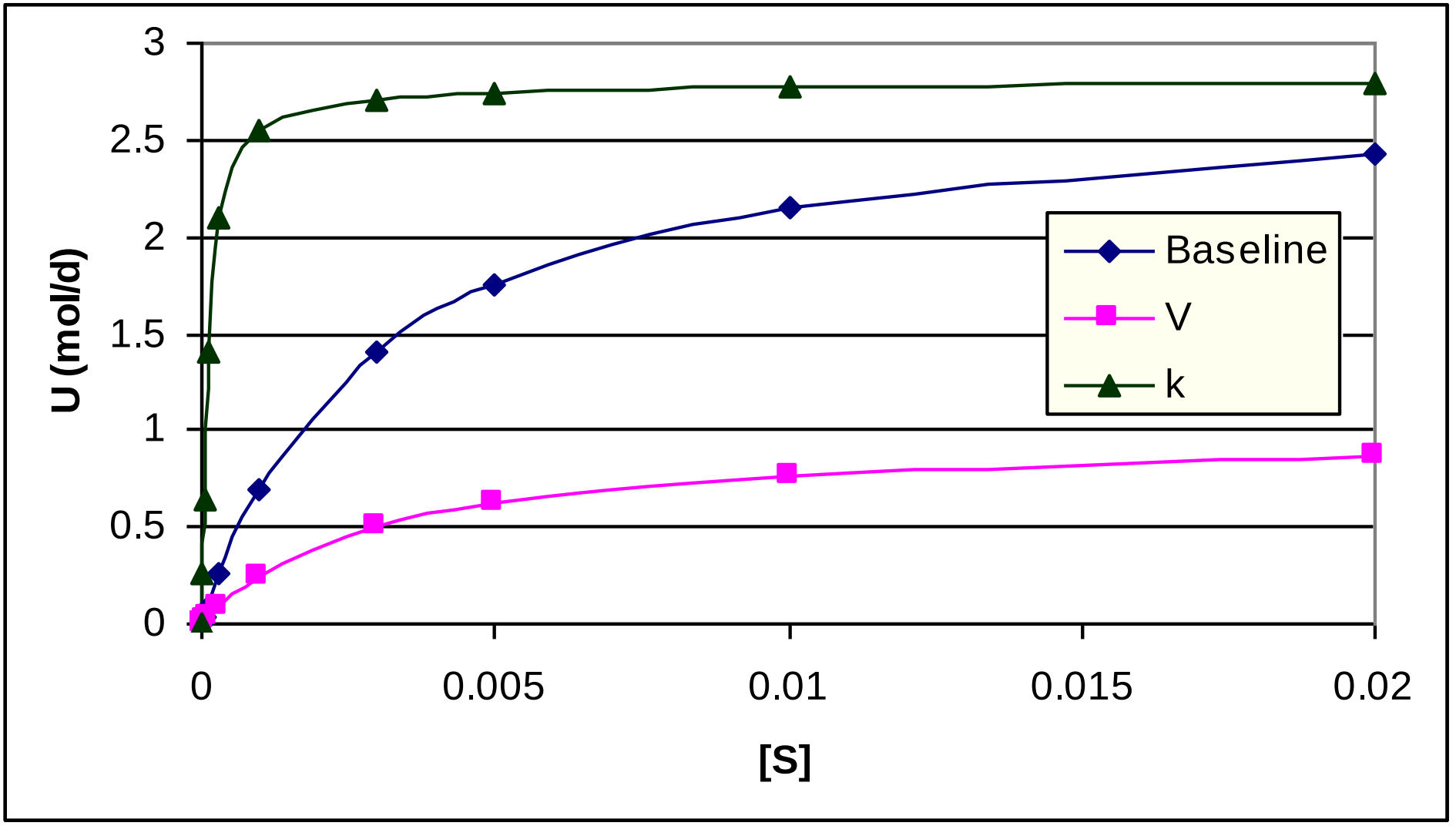
cFa = Fa / Blood volume
= Mol/L

dAc/dt = absAc + TAaAc -AcTsF – AcTmV - AcCd

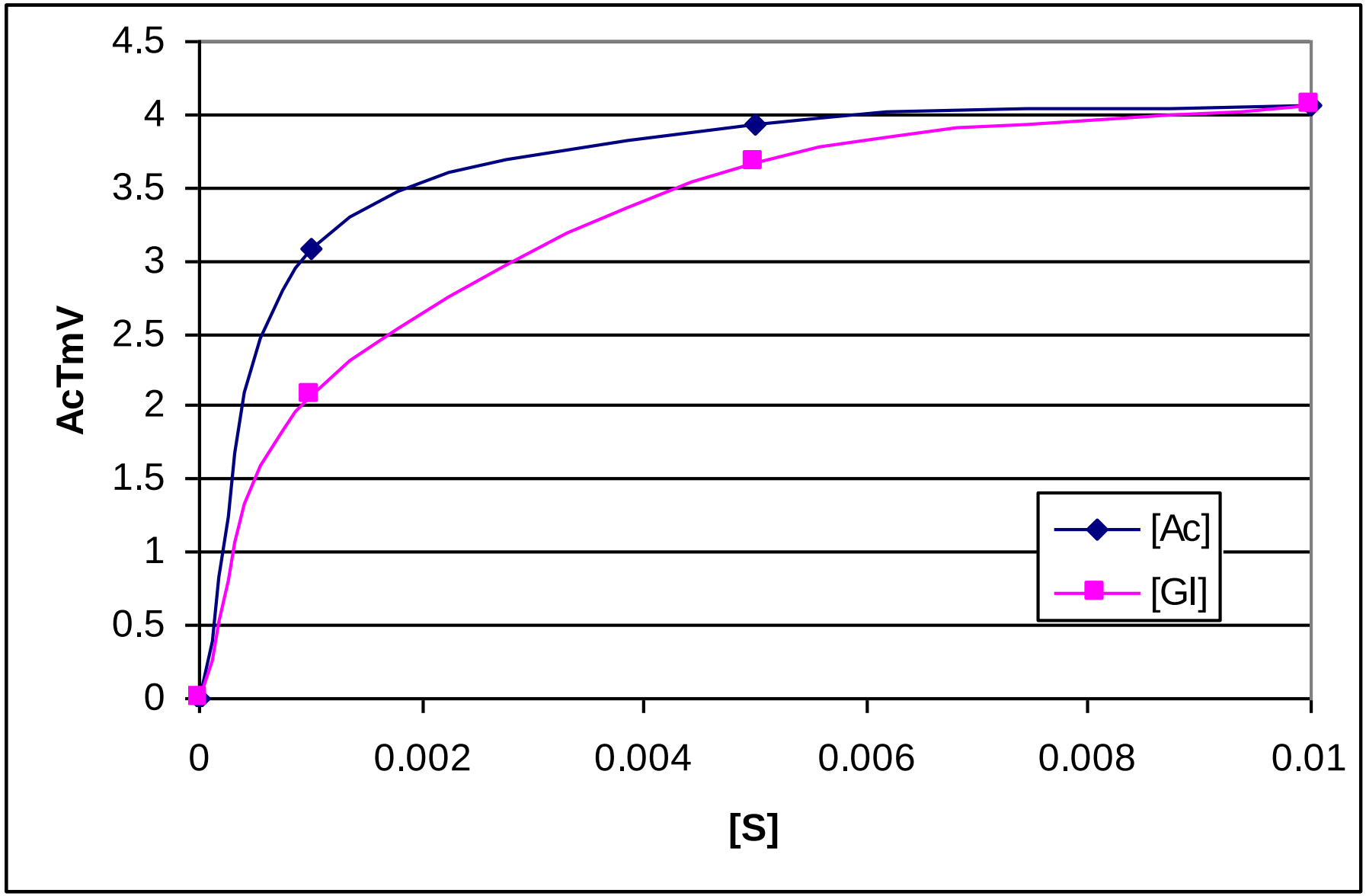




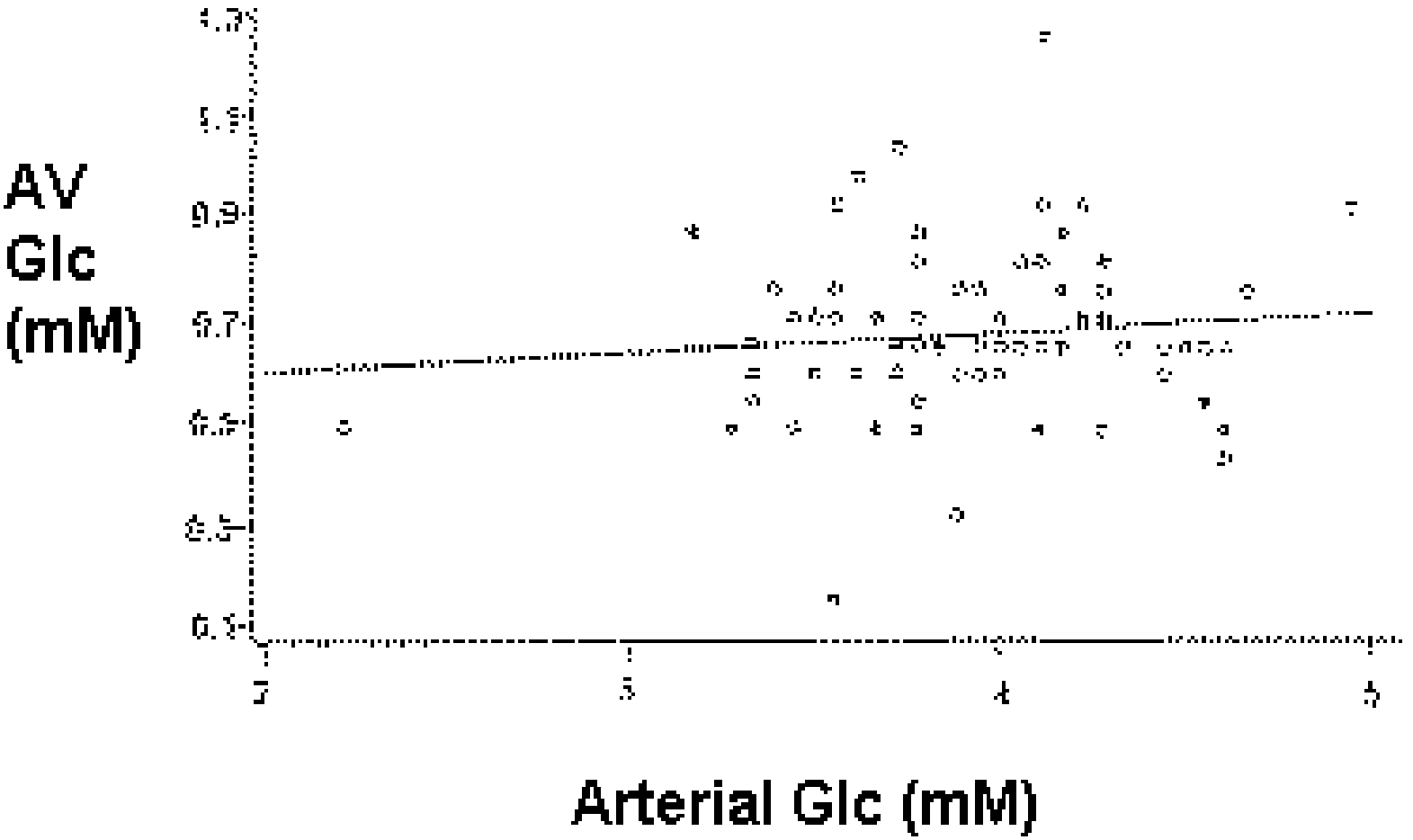
Example: U = Vm / (1 + Km/[S])



$$AcTmV = V_{AcTmV} * uenz * Kminh * INS / (1.0 + k_{AcTmV}/[Ac] + k1_{AcTm}/[Gl])$$

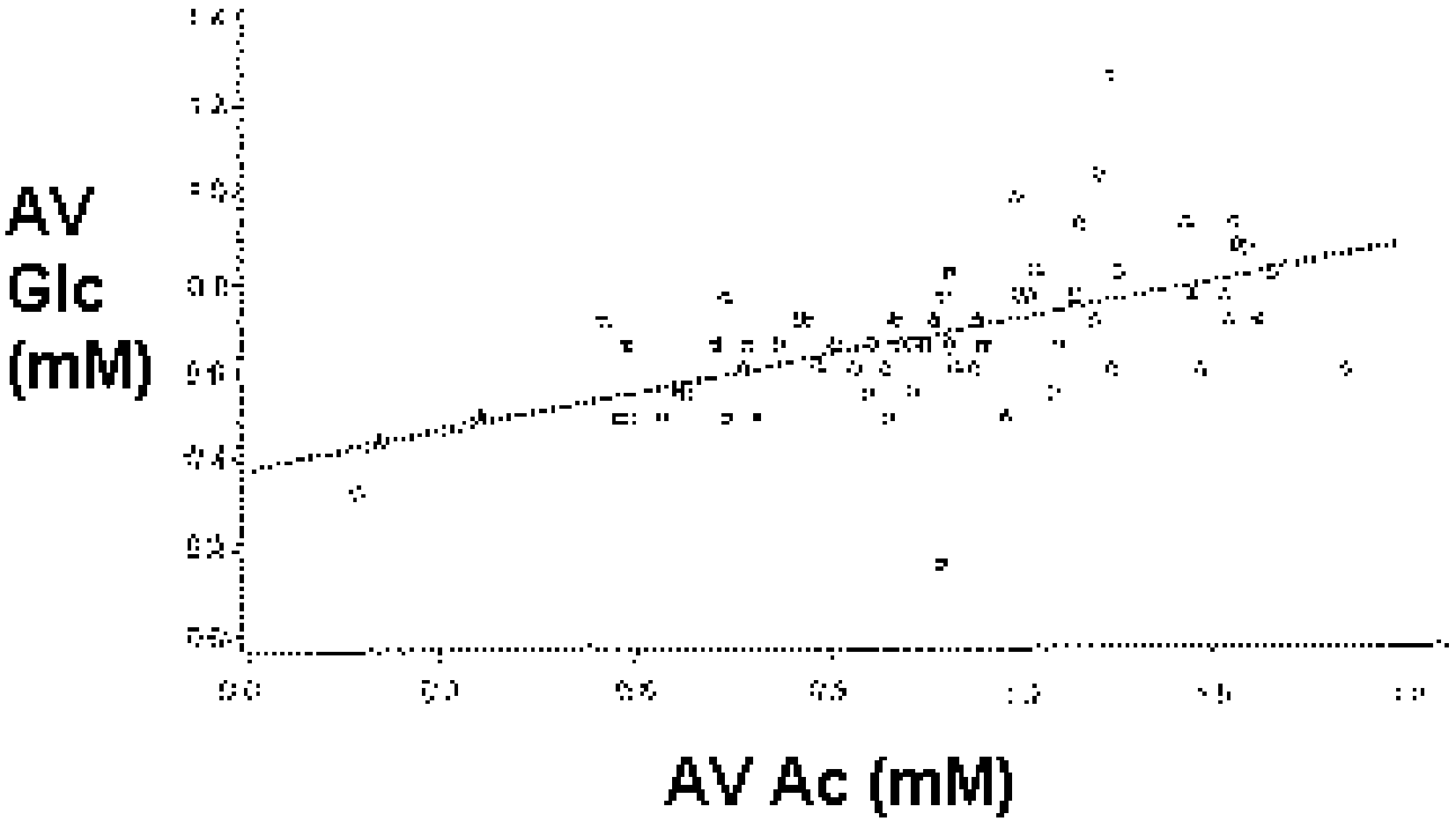


AV Difference (Mammary)



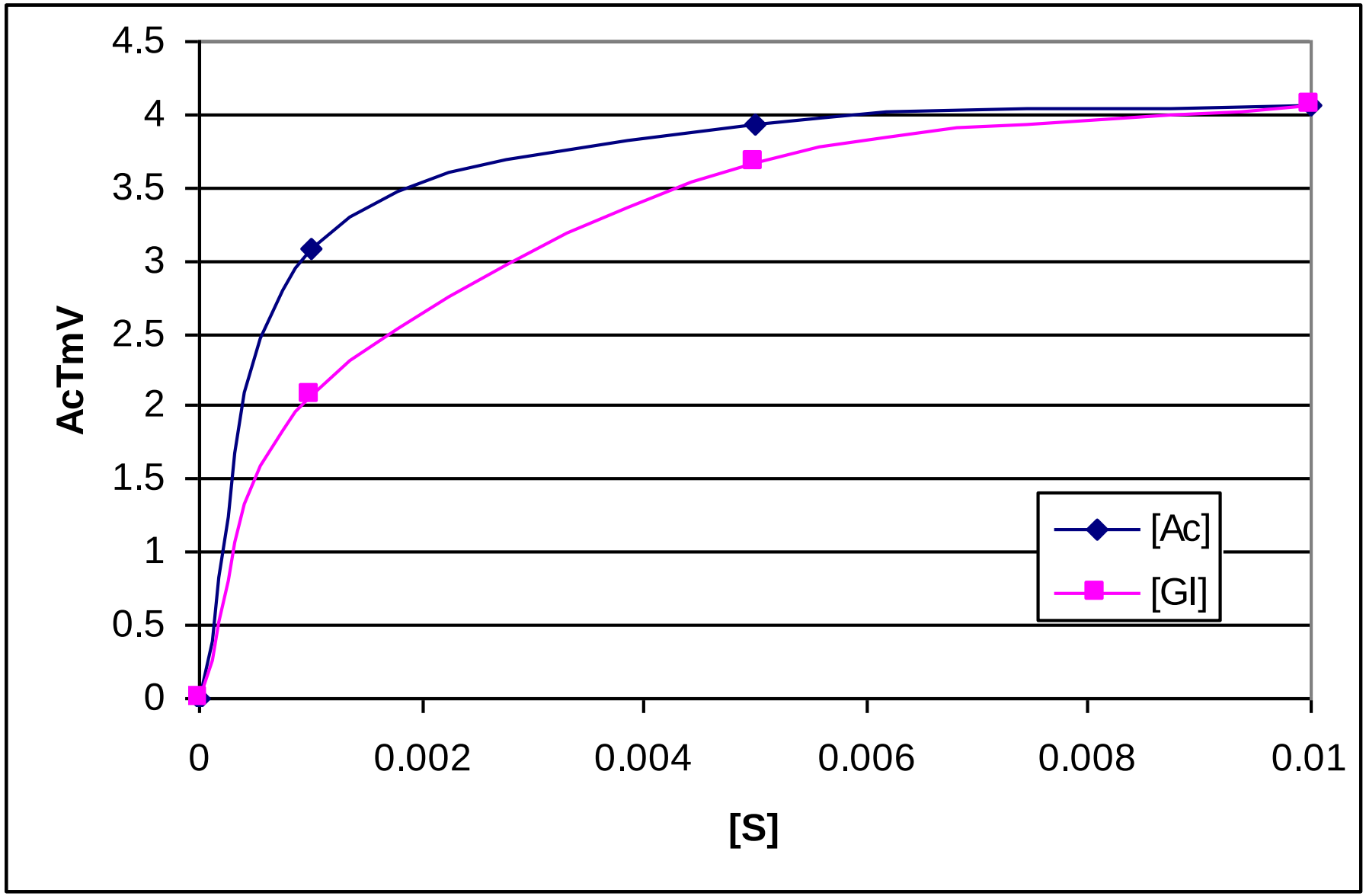
Miller et al., 1991

AV Difference (Mammary)

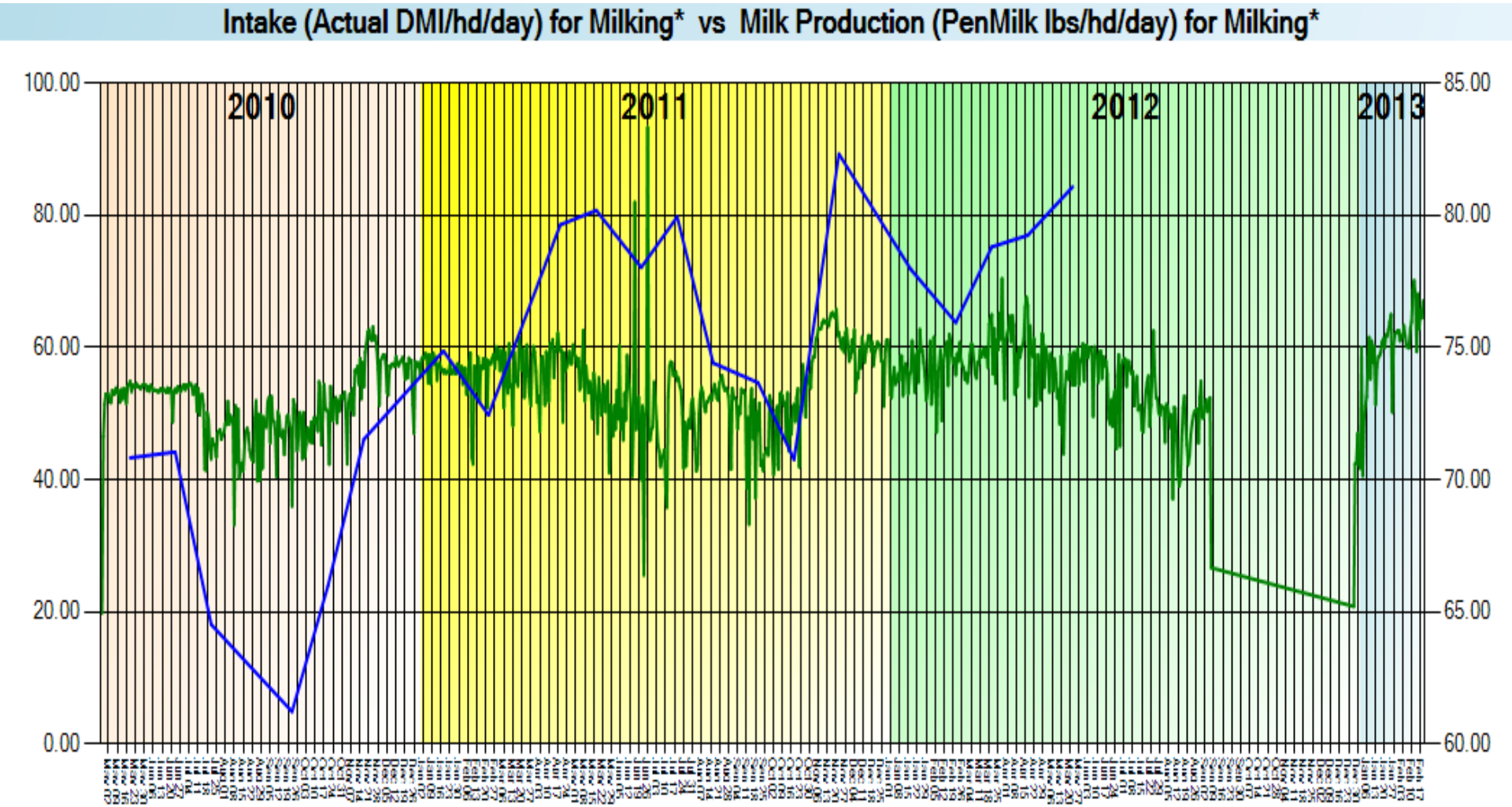


Miller et al., 1991

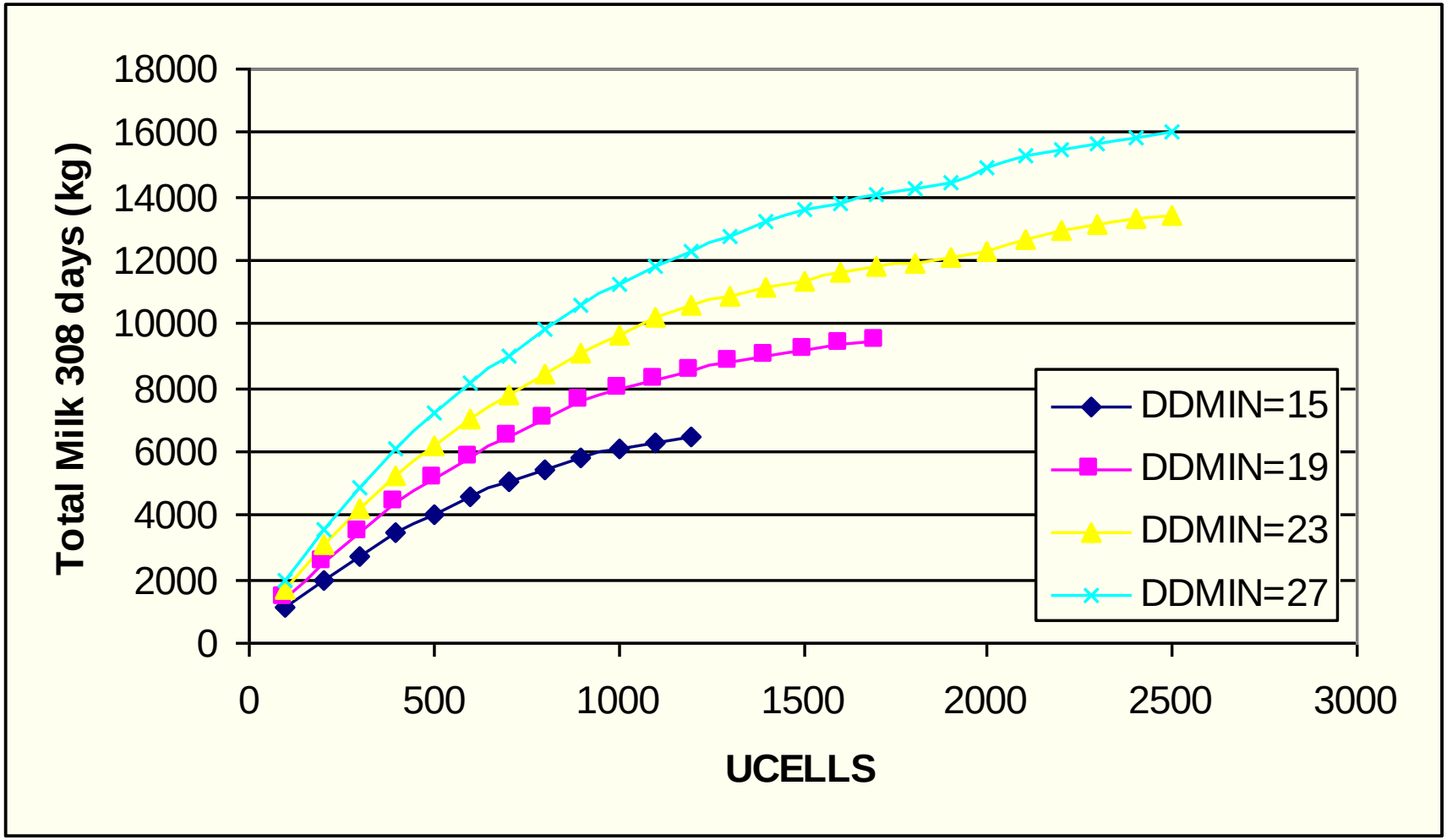
$$AcTmV = V_{AcTmV} * uenz * Kminh * INS / (1.0 + k_{AcTmV}/[Ac] + k1_{AcTm}/[Gl])$$



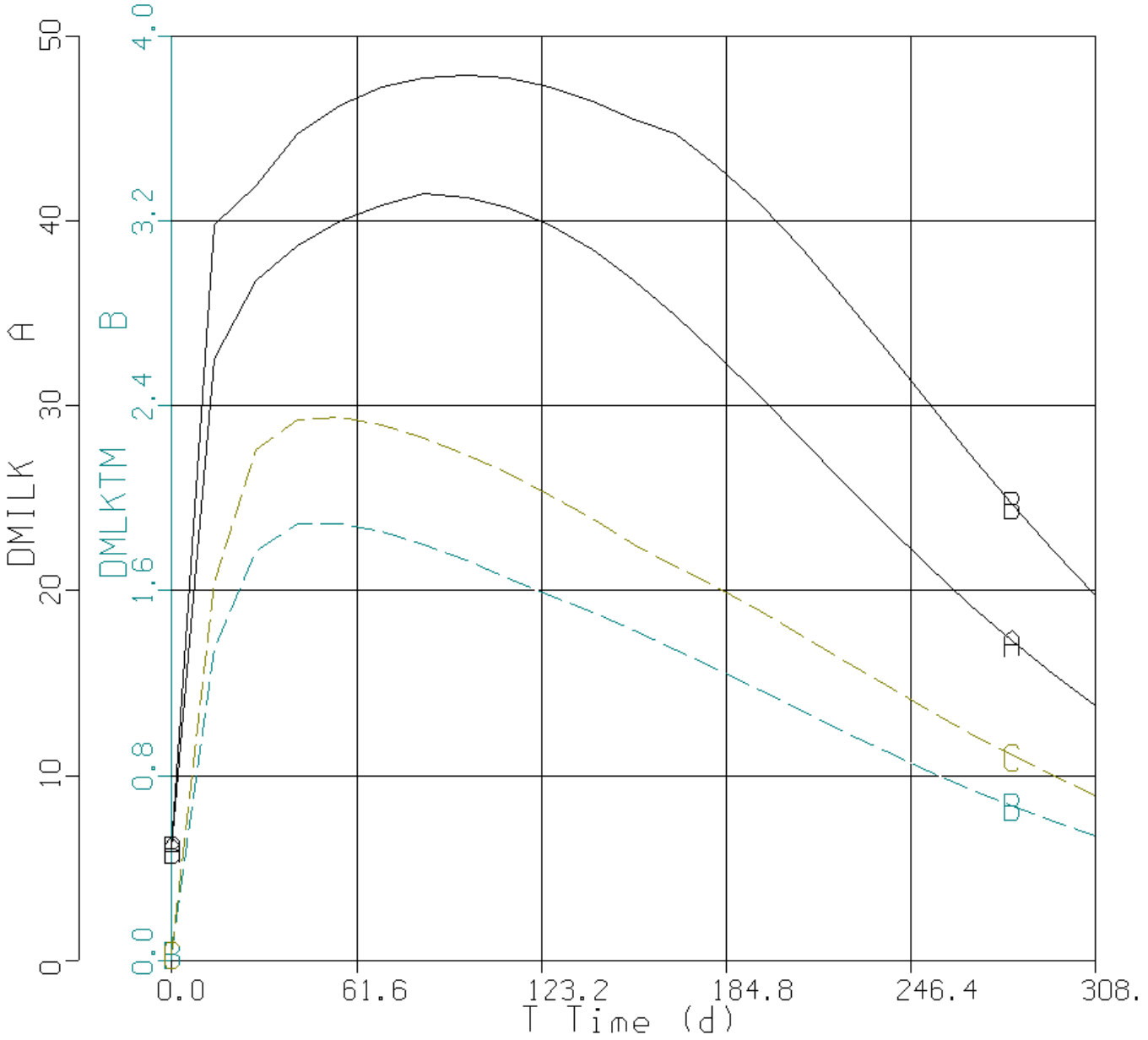
Representation of milk production



Molly Milk Production vs. DMI



Potential milk = UCELLS



Molly milk production assumptions

1. Lactose is 4.8% of milk yield

2. Lactose production is dependent on a-lactalbumin production

3. Relative proportion of milk fat from de novo (Ac) and body, diet (Fa) are 50/50

4. Milk protein yield is determined by limiting amino acid theory.

Representation of milk production

duenz = usyn - udeg

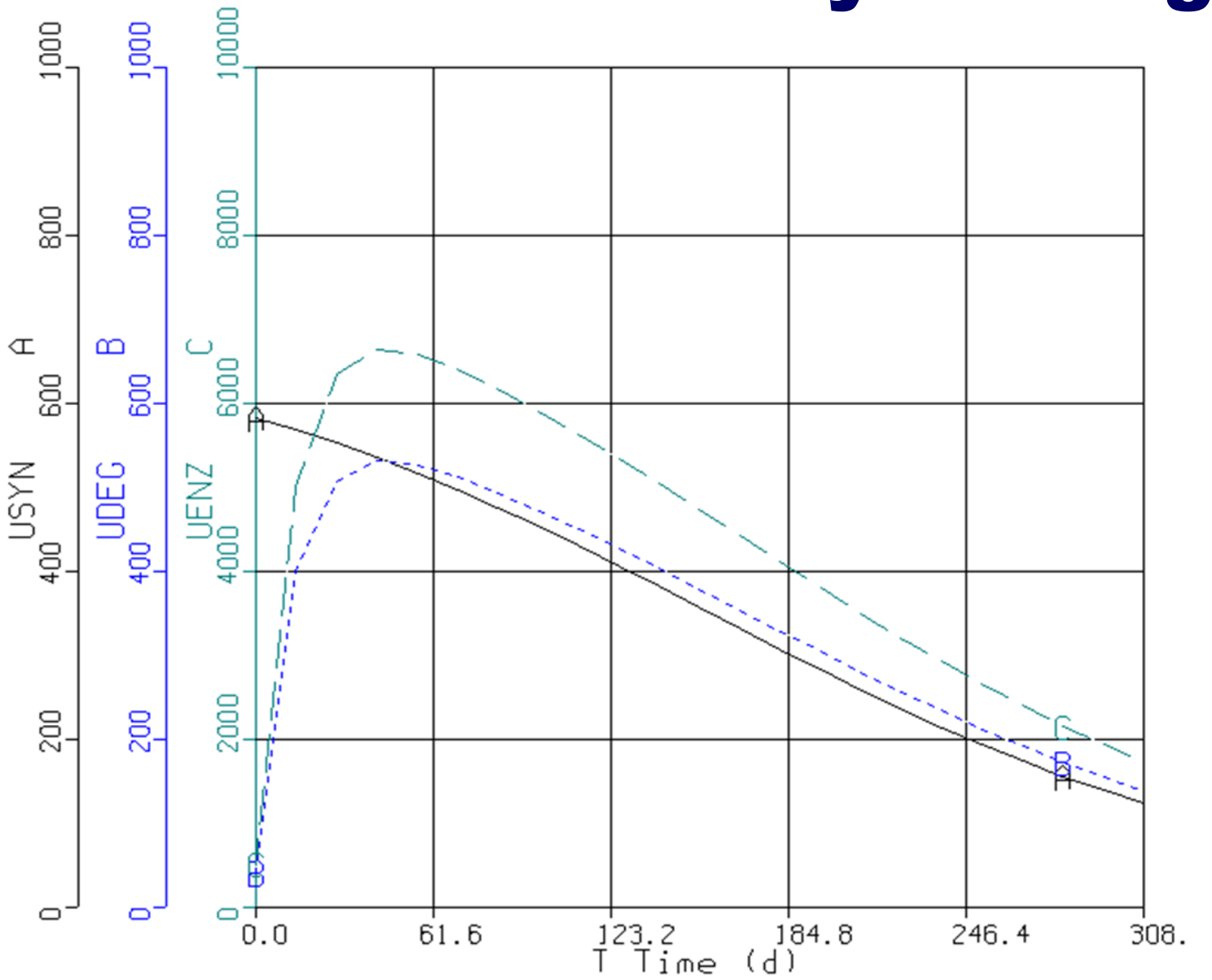
usyn = Vusyn*UCELLS*Lhor*BST/
(kusyn+Lhor*BST)

udeg = uenz*(Kudeg + KudegM*
((umave/Kmdeg)^{10}/(1+umave/Kmdeg)^{10}))

= retained milk effects
Lhor is integrated

Neal & Thornley 1983 J Ag Sci Cambridge 101:389-400

duenz = usyn - udeg



Milk Components

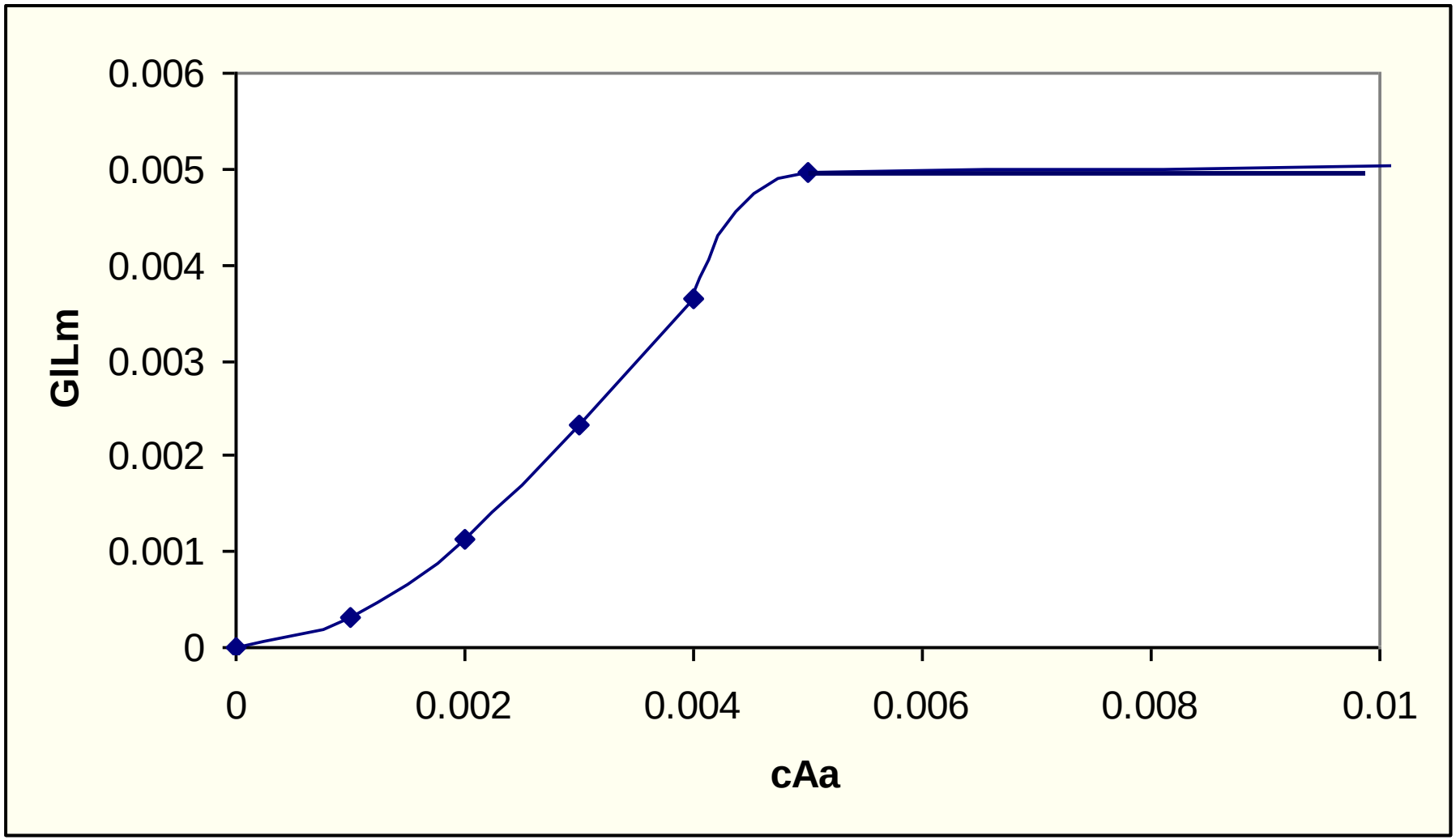
1. $GILmV = V_{GILmf} * (V_{AaLA} * uenz * kminh / (1 + ((k_{AaLA}/[Aa])^{EXP}))/fLAAa$

2. $FaTmV = V_{FaTmV} * uenz * INS * kminh / (1 + k_{FaTmV}/[Fa] + k1_{FaTm}/[GI])$

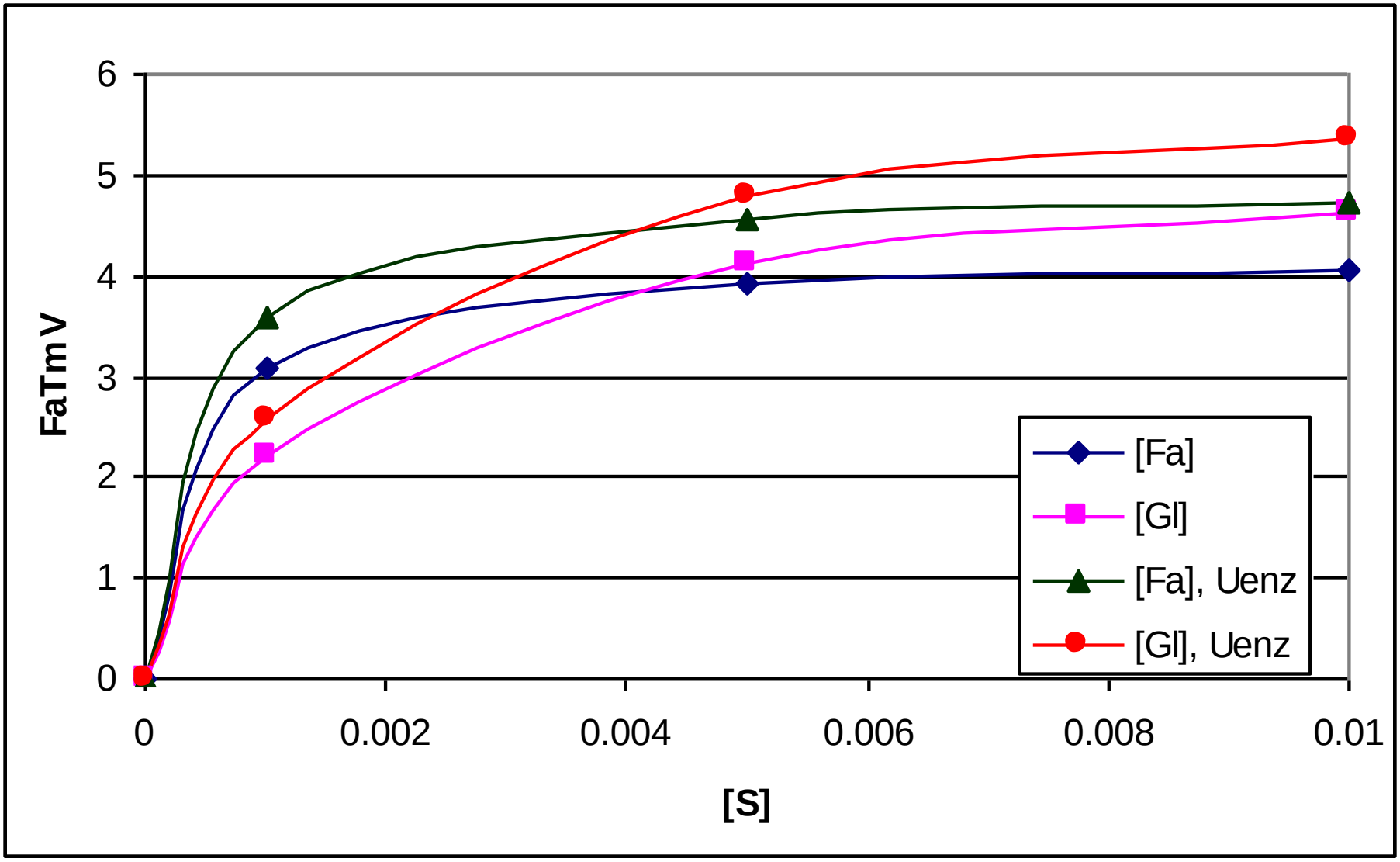
3. $AcTmV = V_{AcTmV} * uenz * INS * kminh / (1 + k_{AcTmV}/[Ac] + k1_{AcTm}/[GI])$

4. $AaPmV1 = V_{AaPm} * uenz * kminh / (1 + (k_{AaPm}/[Aa])^{EXP})/fPmAa$

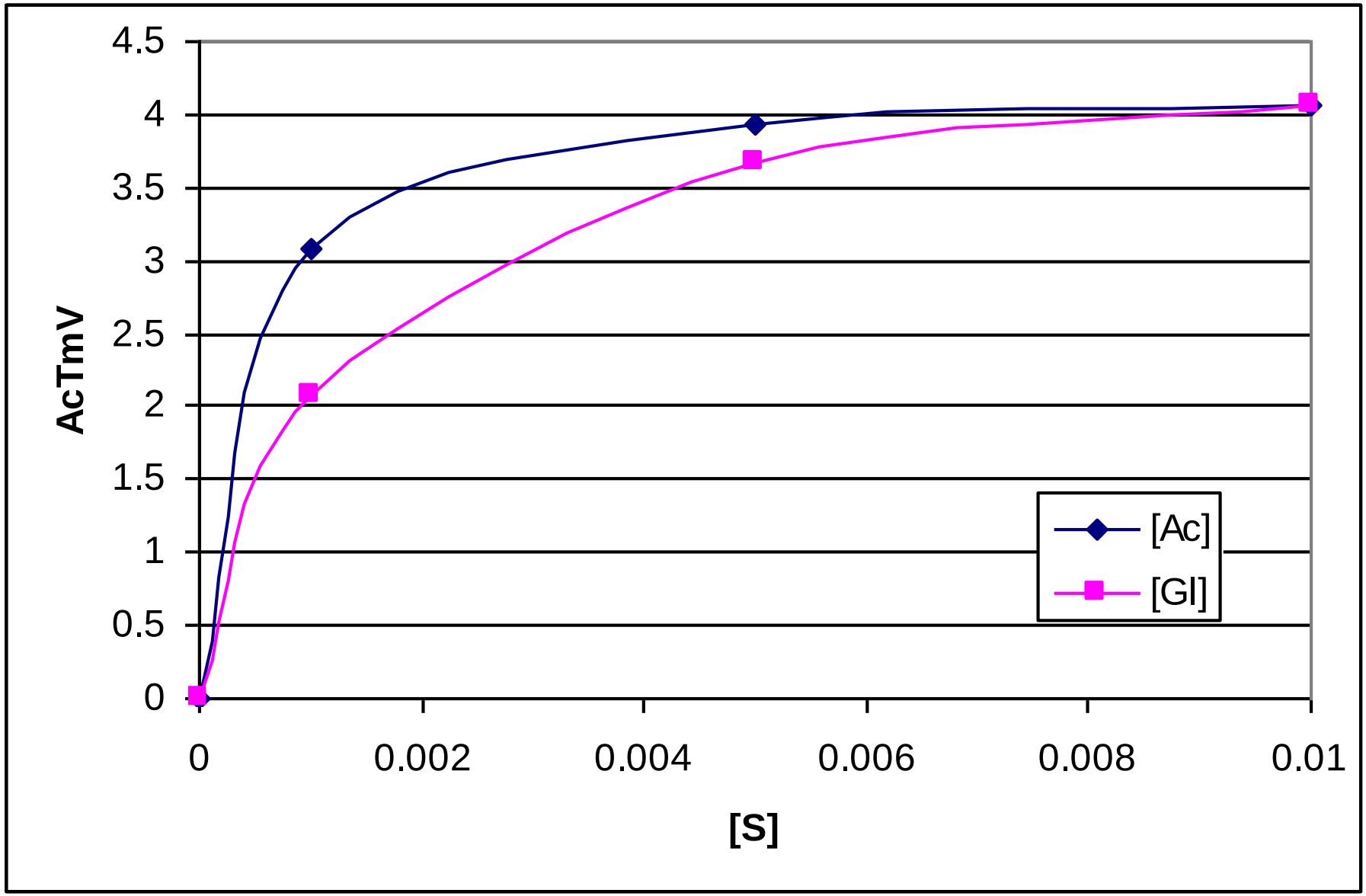
$$GILmV = V_{GILmf} * (V_{AaLA} * uenz * kminh / (1 + ((k_{AaLA}/[Aa])^{EXP})) / fLAAa$$



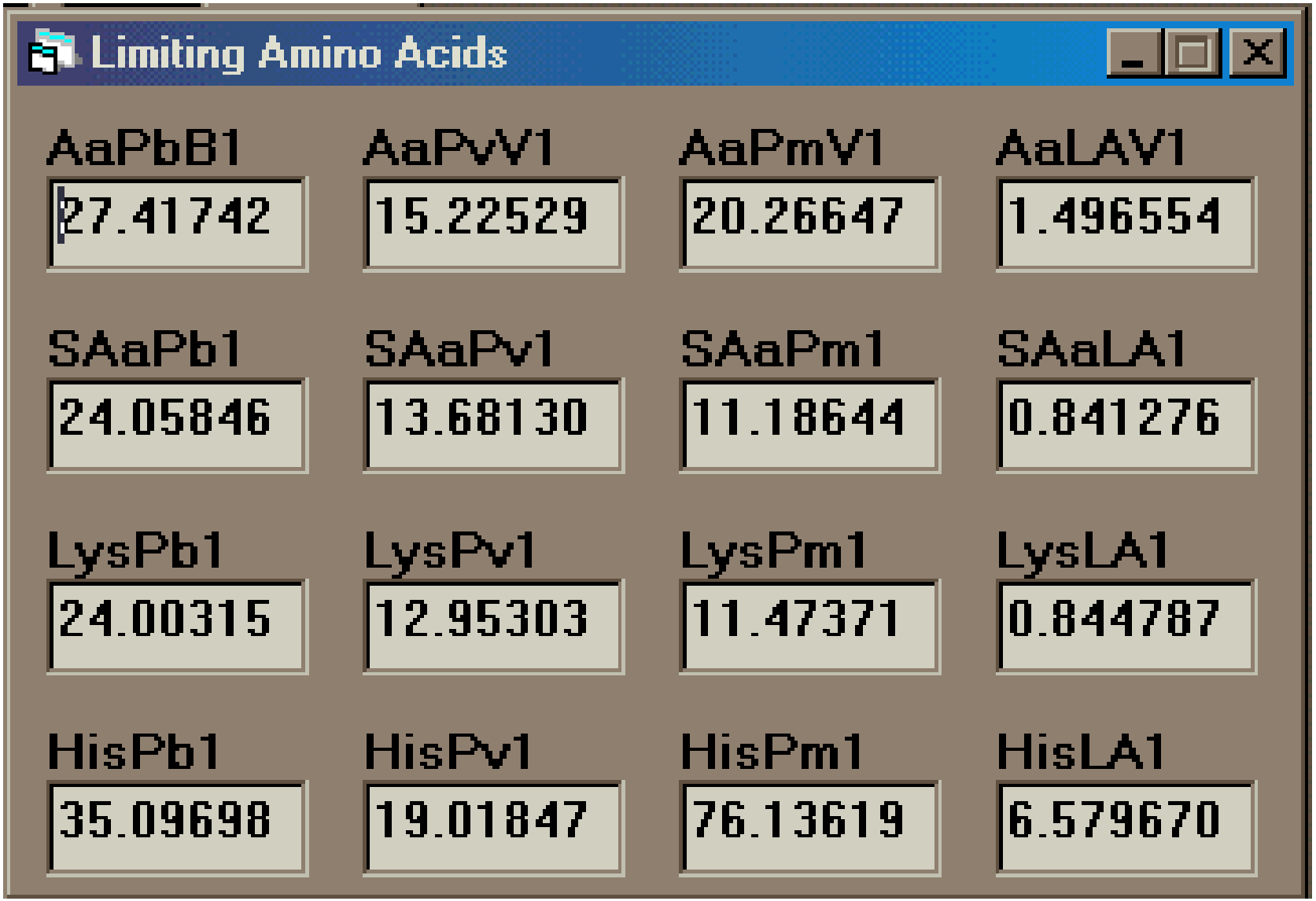
$$FaTmV = V_{FaTmV} * uenz * INS * kminh / (1 + k_{FaTmV}/[Fa] + k1_{FaTm}/[Gl])$$



$$AcTmV = V_{AcTmV} * uenz * INS * kminh / (1 + k_{AcTmV}/[Ac] + k_{AcTm}/[Gl])$$



$$AaPmV1 = V_{AaPm} * uenz * kminh / (1+(k_{AaPm}/[Aa])^{EXP})/fPmAa$$



Molly v3

File Diet Model View Window Help

Input Simulation Data

Initial Simulation Settings

Initial Bodyweight 700
Udder Cells 1000
Body Fat % 0.207
BCS (1-5) 3.2
Length of Simulation: Long
Milk Price $/kg

Time (d) 70

Go Until day 70 | Milking: Continuous | Conception at Day 90

Select a Diet List: Standard Diet List

Select Diet: diet1

Intake 1: Fixed Intake (kg/d) — Fixed Intake 11
Intake 2: Intake based on Milk — Intake (kg) / kg milk 0.33

BST at 1.0 times basal | Ionophore | Diet Price $/kg

Abomasum Infusions (moles AA/d or kg Protein/d)
Sulfur AA 0 | Lysine 0 | Histidine 0 | Casein 0

Enter ACSL CMD

Log variables over time | Save data for multiple lactation plots

Acetate

Time (d) 70

absAc 69.08464 → Ac 78.0172424316406 → AcCd 33.59507
cAc 1.98942609131336E-03 → AcTsF 10.67335
TAaAc 3.593405 → AcTmV 28.18128

Fatty Acids

Time (d) 70

absFa 2.636204 → Fa 3.54315304756165 → FaCd 1.655520
cFa 5.90887619182467E-04 → FaTsF 6.354977
TsFaF1 8.753406 → FaTmV 3.380170

General Production

KG LB | Time (d) 70

kg BW	kg EBW	BCS
728.9989	599.6323	2.0423316

DMI kg/d 24.31850 | Tot DMI kg 1535.231 | Profit /d 6.4283118

kg Lean Body 417.5971 | Feed Cost /
kg viscera 90.78244 | 4.4536280
kg adipose 91.25265 | Profit /Sim 390.40472

Glucose

Time (d) 70 | PrCdV 10.34290

absPr 34.47634 → PrGlV1 12.06672
TAaGl 3.130599
LaGlV1 15.04781
GyGlV1 2.021699
absGl 11.42089 ← UpGl 1.142089
GGlLa 20.55761

Gl 13.9547338485718
cGl 3.87869169935584E-03

GlLmV 11.46350
GlHyF 1.869971
GlTpF 2.582765
GlLaB 4.028314
GlHyV 4.937362
GlTpV 0.646374
GlCd 7.877070

Milk Production

KG LB | Time (d) 70

Daily milk yield kg	Milk Protein %
40.81751	3.090930
Total milk kg	Milk Lactose %
2446.653	4.800000
Total milk lactose kg	Milk Fat %
117.4393	4.544253
Total milk protein kg	
75.38944	
Total milk fat kg	
112.8343	

Limiting Amino Acids

AaPbB1	AaPvV1	AaPmV1	AaLAV1
27.545820	15.153165	20.233058	1.4940869
SAaPb1	SAaPv1	SAaPm1	SAaLA1
24.163116	13.626000	11.166792	0.8397984
LysPb1	LysPv1	LysPm1	LysLA1
24.008815	12.847830	11.257755	0.8288865
HisPb1	HisPv1	HisPm1	HisLA1
35.105587	18.864179	71.202682	6.1533174

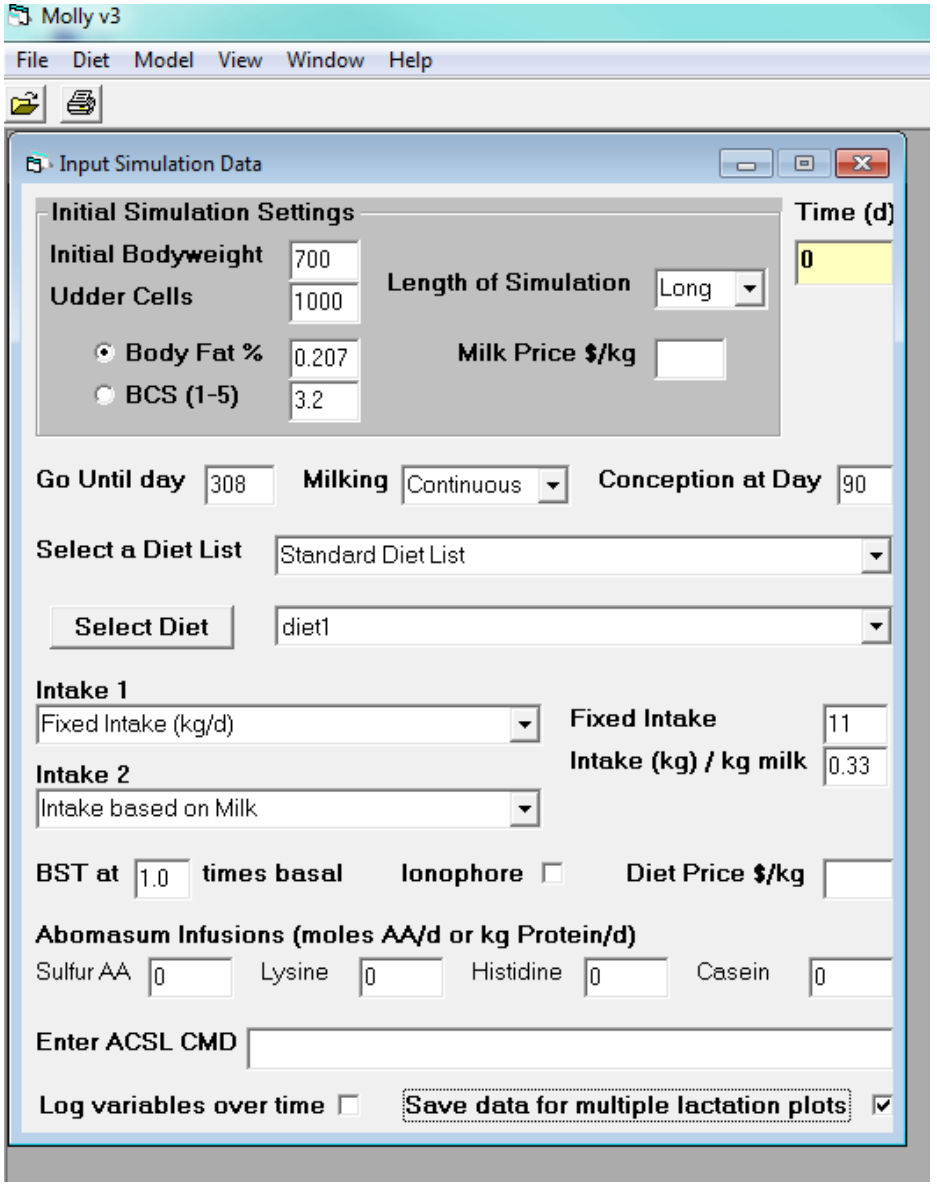
Ready | Simulation number 1

Demo using BST

1. Control

Go until day 308
Diet1
BST 1.0
Save data….

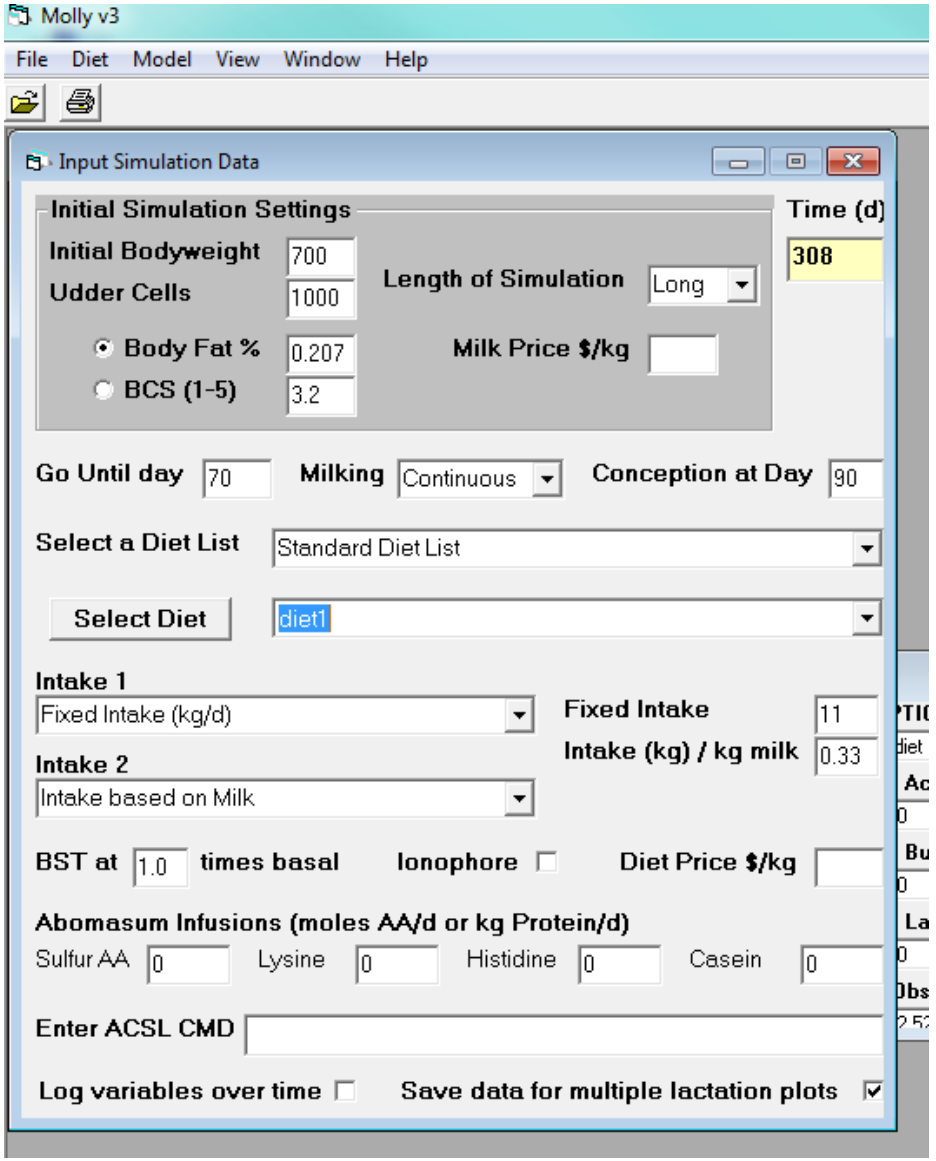
Model load
Model reset to T=0
Model run



Demo using BST

2. BST lactation
Go until day 70
Diet1
BST 1.0
Save data….

Model reset to T=0
Model run

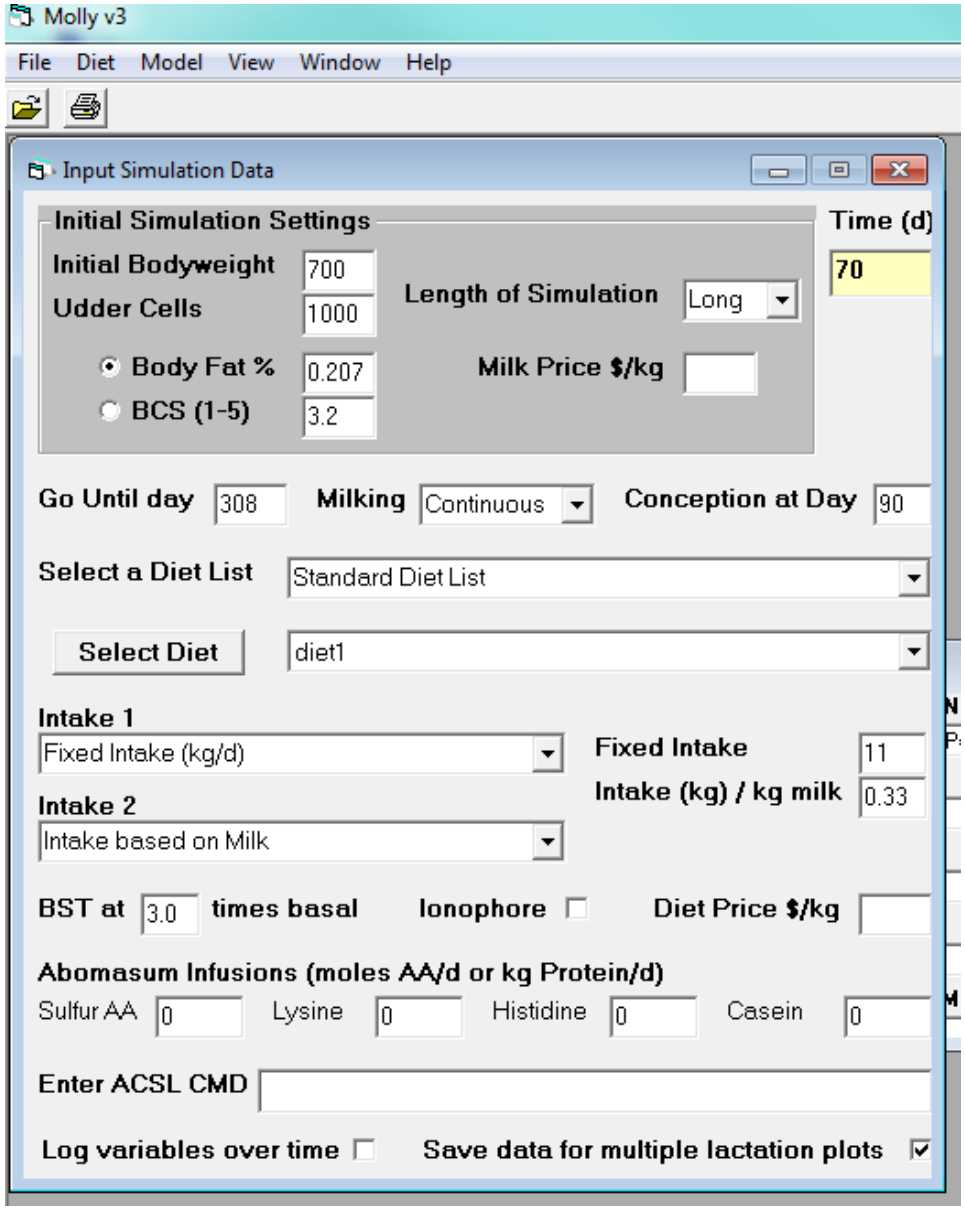


Demo using BST

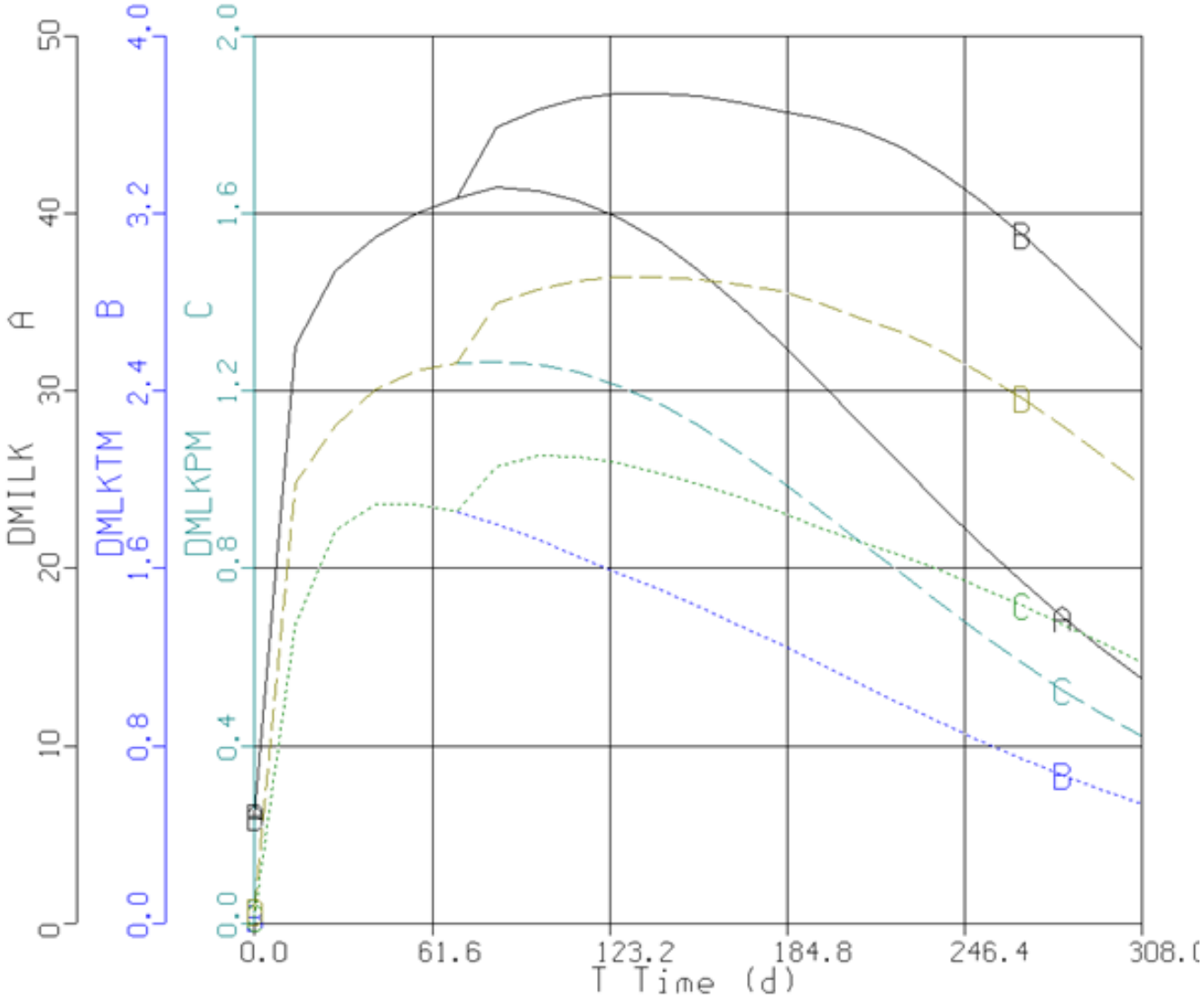
3. Give BST
Go until day 308
Diet1
BST 3.0
Save data….

Model Continue

View Plot
Dmilk
Dmlktm
dmlkpm



Results

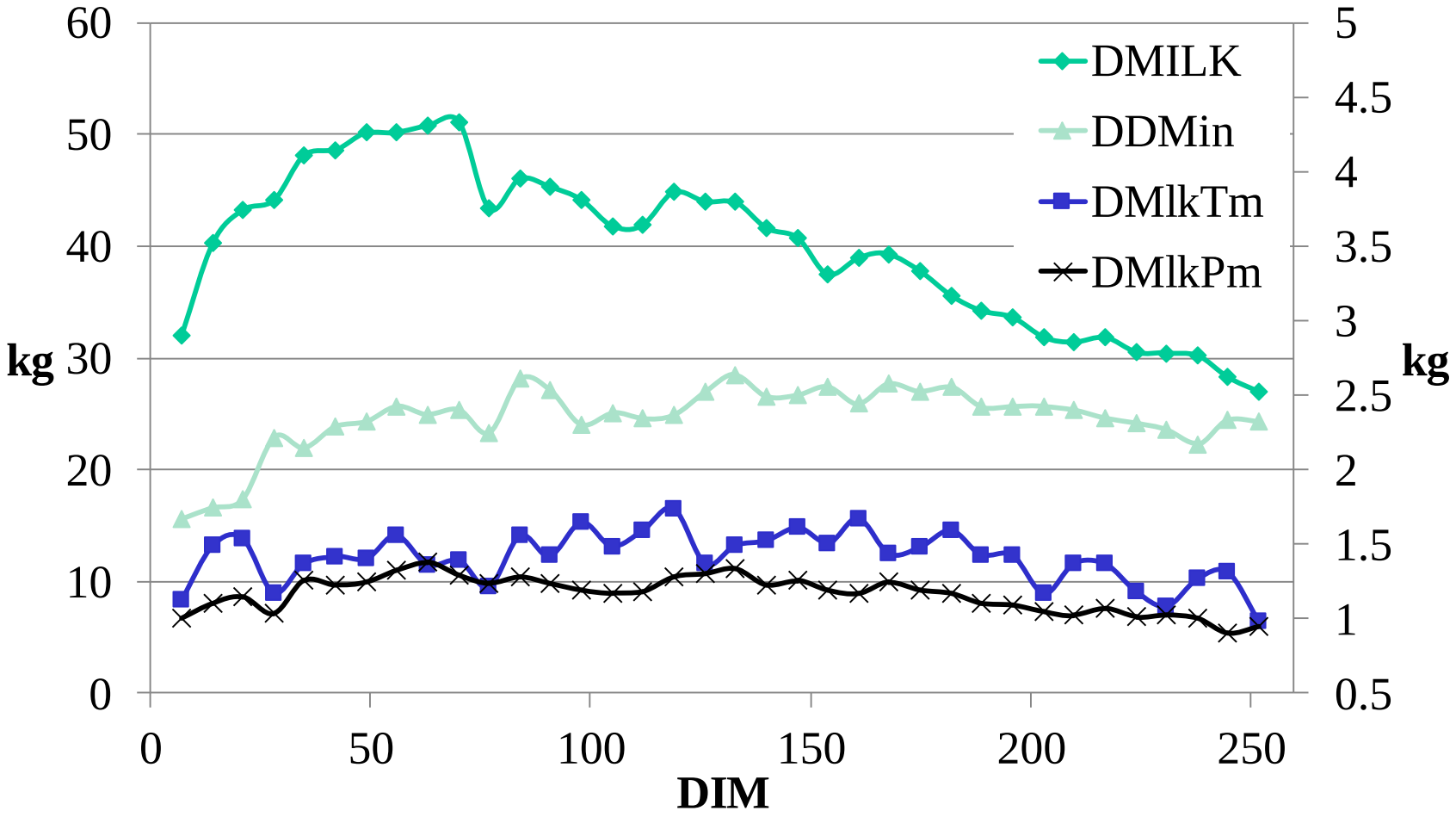

DMILK A
DMLKTM B
DMLKPM C
0
10
20
30
40
50
0.0
0.8
1.6
2.4
3.2
4.0
0.0
0.4
0.8
1.2
1.6
2.0
0.0
61.6
123.2
184.8
246.4
308.0
T Time (d)
A
B
C
D

Modeling Exercise

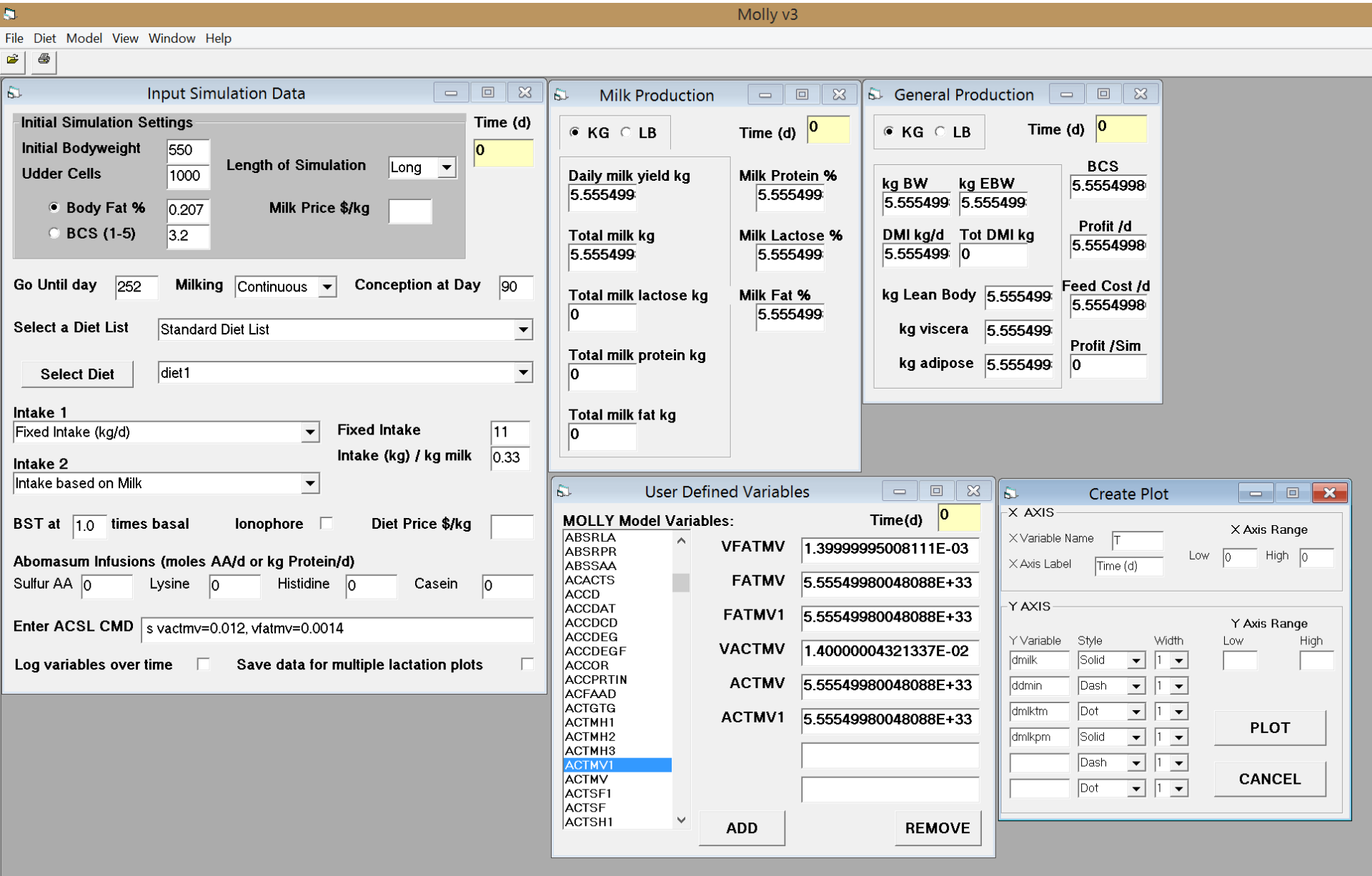
Adjust ucells to match the cow's milk production

Total milk = 10042, total fat=355, total protein=293

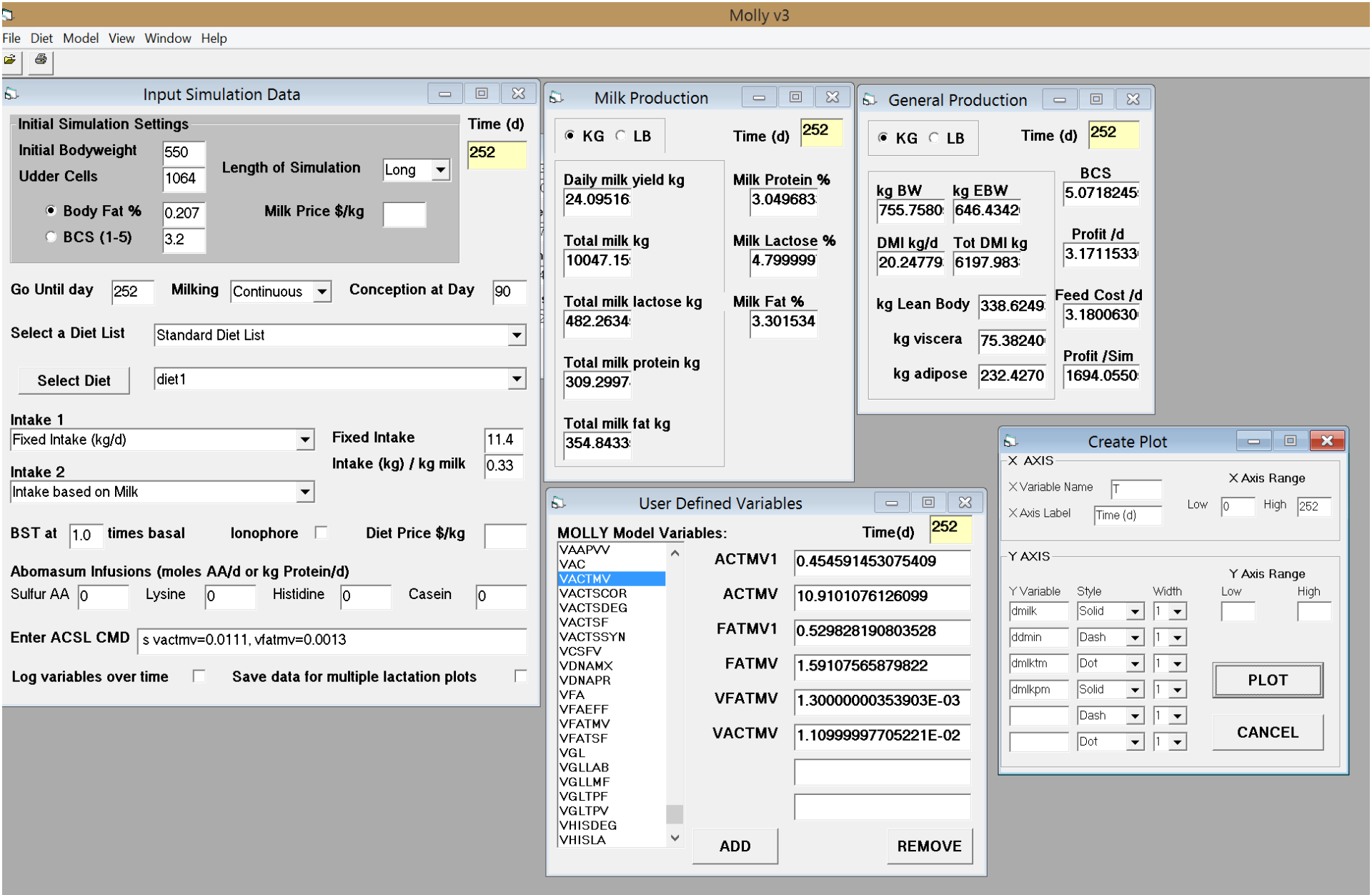
iBW = 550, fBW=612, tot DMI=6197



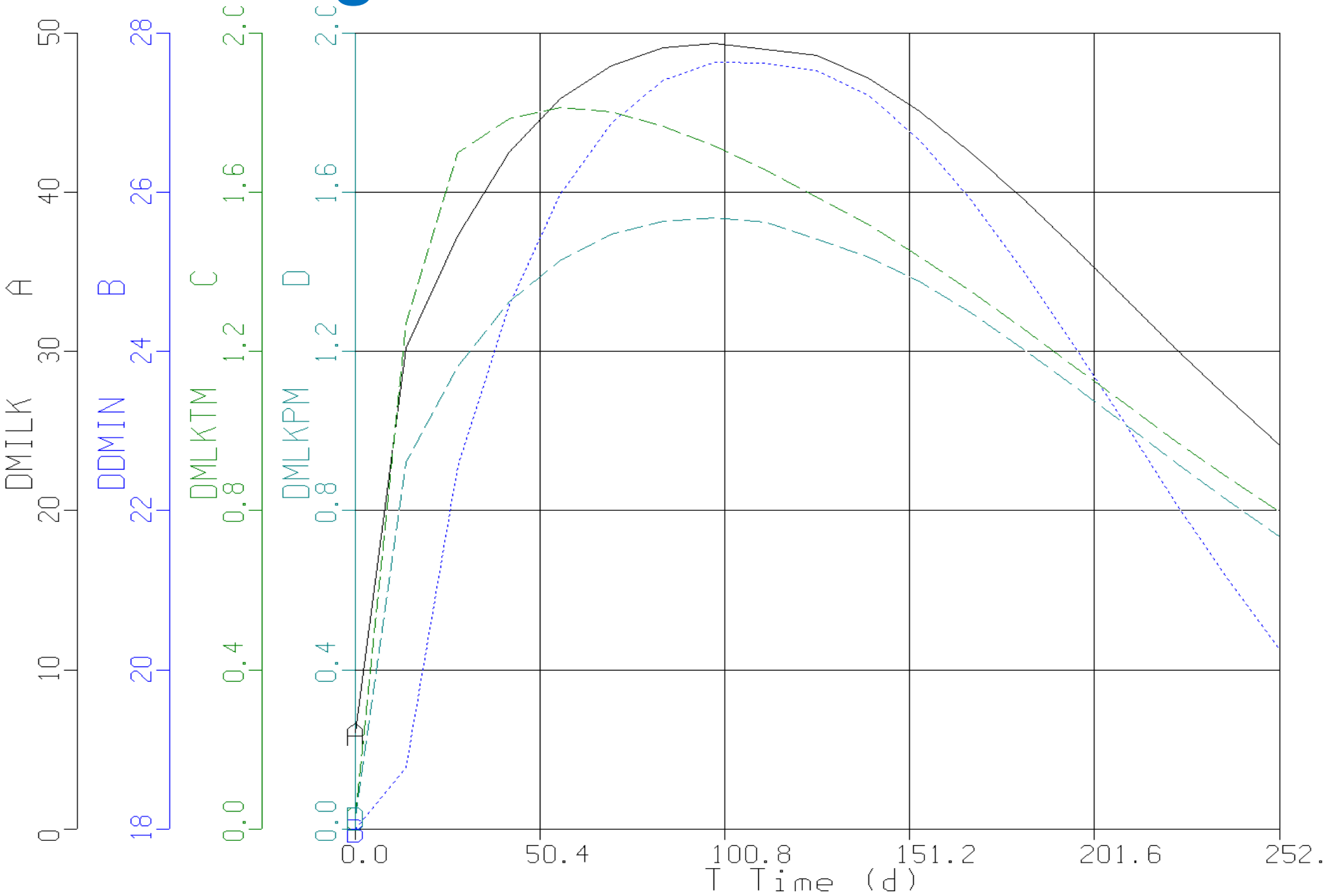
Modeling Exercise



Modeling Exercise - Solution



Modeling Exercise - Solution



Thanks…

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Leveraging Resources, Linking Researchers

http://www.vmtrc.ucdavis.edu/laboratories/metabolic/molly.cfm