

## **Evaluation of Ankole pastoral production systems in Uganda: Systems analysis approach**

Henry Mulindwa<sup>1, 3, 4</sup>, Esau Galukande<sup>2, 3, 4</sup>, Maria Wurzinger<sup>3, 4</sup>, Ally Okeyo Mwai<sup>4</sup>, Johnan Sölkner<sup>3</sup>

<sup>1</sup>National Livestock Resources Research Institute, Tororo, Uganda

<sup>2</sup>National Animal Genetic Resources Center and Data Bank, Entebbe, Uganda

<sup>3</sup>BOKU - University of Natural Resources and Applied Life Sciences, Vienna

<sup>4</sup>International Livestock Research Institute, Nairobi, Kenya

Corresponding author: [mulindwaha@yahoo.com](mailto:mulindwaha@yahoo.com)

### **Abstract**

The production objectives of Ankole cattle pastoral production system are shifting from traditional subsistence to commercial enterprises involving adoption of a new production system where farmers keep separate herds of Ankole and Friesians x Ankole crosses on the same farm. The ecological and economic sustainability of the emerging Ankole production system is currently being assessed through system analysis approach using a dynamic model to identify conditions under which either one or both genotypes can be kept on a sustainable basis. The dynamic herd-based model is used to simulate pasture growth, reproduction and production of the two cattle genotypes. The developed model was evaluated using post weaning growth. The calculated average RPE value of 0.075% for growth (body weight) after weaning across both breeds is below the acceptable 20% and means that the model predicts post weaning growth with an error of 7.5%. The model also predicted changes in herd milk production throughout the simulation for a herd that was managed by the same rules but grazed at dynamic stocking rates over the simulation period. Herd milk production increased with increasing stocking density. However, the increase in herd yield had a negative effect on milk production per individual animal. There is need to evaluate the system using controlled stocking rates (ecological carrying capacity values) and assess their economic viability as well as determining appropriate cattle off-takes.

**Key words:** Ankole cattle, model evaluation, modeling,

### **Introduction**

Ankole cattle pastoral production system in Uganda is characterized by extensive grazing but differs from other pastoral systems elsewhere in that there is no communal grazing (Byenkya, 2005). Milk and meat production are the main products of the pastoral households (Mugerwa 1992) but cattle are also kept for prestige, social and other cultural functions. In terms of production objectives, there is an on-going shift from traditional subsistence to commercial enterprises which has led to adoption of a new production system where farmers keep separate herds of Ankole and Friesians x Ankole crosses on the same farm as reported in (Serunkuuma, 1998 and Wurzinger et al 2008). The area is characterised by severe dry seasons and rains tend to be unreliable (Ocaido et al 2009) and the effects are becoming more severe as human population increases, livestock and crop enterprises expand, restricting a range of herd movements. The new system is bound to face a number of challenges and its success will depend on striking the right balance of all the variables involved which include; environmental conditions, health and productivity of animals of different genotype, management decisions and socio-economic

issues. Understanding the internal mechanisms for the interactions between major system components is essential to the development of good management practices that ensure maximum productivity and environmental sustainability (Mohtar et al 2000). In order to support farmers' decision-making, modelling was adopted as one of the useful techniques used to evaluate interactions among the major system components. The ecological and economic sustainability of the emerging Ankole production system is currently being assessed through system analysis approach using a dynamic model to identify conditions under which either one or both genotypes can be kept on a sustainable basis. The model was aimed at producing long-term simulations of the dynamic interaction between economic and climatic variations, and farm management at monthly and annual scales in order to evaluate the performance of the emerging production system. The dynamic herd-based model is used to simulate pasture growth, reproduction and production of the two cattle genotypes. In this paper, we present the structure and evaluation of the model.

## **2.0 Materials and methods**

### **Study area and data collection.**

The study was carried out in Kiruhura district, south-western Uganda where the landscape is with undulating plains in some and sloping to moderate steep topography in other areas. Mulindwa et al (2009) computed the mean annual rainfall for the Mbarara Meteorological site at Kakoba for the period 1963 -2008 and obtained a figure of 931 mm with a coefficient of variation of 16%. The rainfall is bimodal peaking in April-May and September to November, with two prolonged dry seasons in June to August and December to February. Temperatures can rise to 29°C with a variation of 2 to 7°C.

Eighteen farms were selected and on-farm production records, management and feeding strategies were obtained from these farms on a monthly basis. Some of the collected data, in addition to the existing literature and historical meteorological data were used to parameterise the model.

### **Model development**

The simulation was done using the graphical simulation environment of STELLA (2007) version 9.02 (High Performance Systems, Inc., Hanover, New Hampshire). The simulation time unit was “month” and a long-term time horizon of 120 months (10 years) was considered. The scenarios tested in this simulation was growing herds situation in which animals were raised without any major interference in the system except those practices done by the farmers. The model is composed of four sub models namely the forage production, animal inventory (production), nutrient requirement and the economic sub-model. It contains both deterministic and stochastic elements, and processes are simulated in separate sub-models, which combine to make the overall model. The study area is found in a semi arid region characterized by unreliable and high variability of rainfall. This variability, besides market availability, influences the dynamics and livestock feeding on vegetation. In the model rainfall is the main driving variable and its random variation is taken into account using cumulative frequency distribution developed

according to Grant et al (1997) and was constructed from historical (1963 -2008) rainfall data.

### **Forage dynamics model**

The pasture sub- model was a modified version of that used in the MALM model developed by Sikhalazo (2005) which he adopted from the SESS (Diaz- Solis et al 2003). It was modified to accomplish the simulation of pasture growth and utilisation under Ankole management and environmental conditions. The sub-model is based on a simple approach of estimating potential pasture productivity for a particular area by assuming a linear relationship between potential production and rainfall (Scanlan et al 1994). The model uses a concept of rain use efficiency proposed by Le Houreou, (1984) to estimate pasture growth, and pasture dynamics is represented by green and dry forage stocks. ANPP is distributed across the months depending on the seasonal distribution of rainfall where green forage is converted into dry forage via senescence. Movement of material from the green to dry stock is through senescence but a fraction of senescent forage is lost, which represents respiration and translocation (Diaz-Solis et al 2003). Dry standing crop is lost due to consumption by cows and via decomposition.

### **Nutrient requirement and DMI sub-model**

The requirements for the net energy were based on the factorial method in which the NE consumed is portioned into the amount of energy required for the maintenance, gestation, lactation, weight change and grazing activity. All these requirements were determined according to NRC (2001) and CSIRO (1990). Days in milk, milk fat, milk production, body weight, mature weight and day of gestation are inputs from the herd component to determine the nutrient requirements. Potential voluntary intake (PVI) was calculated according to NRC (2001) and MAFF (1975) in which intake is driven by forage quality and body weight. However, as forage availability declines, so too does the ability of the animal to reach its potential DMI based solely on forage quality (Charmley et al 2008). Therefore, actual DMI was calculated as a function of potential DMI and dry matter availability and a relationship developed by Coleman (2005) was adopted for this study. The diet selection portion of this sub-model is based on a model developed by Blackburn and Kothmann (1991) in which the proportion of green forage in the diet is obtained as a product of cattle preference for green forage (PGF) and its harvestability.

### **Herd structure sub-model**

The herd inventory sub-model is used to simulate dynamics of age groups in a cow herd (from birth to 9 years old); predict the number of replacements heifers, cows and culled cows and also mortality rate for the various cohorts. The sub-model determines the changes taking place in each animal's status during the month of simulation, using endogenous biological processes regulated by exogenous management policies. Considered as biological production parameters were the length of gestation, conception rate, calf mortality rate, number of growing calves, average production by categories,

nursing time, and time to achieve the adult phase and their initial values are listed in Table 1. Animal categories used in this model were: Cows, female and male calves; steers and heifers. The cows were grouped into parities under which were further categorized into lactating and non-lactating cows, pregnant and non-pregnant cows. Each category was considered a stock of animals (i.e. state variables) that can increase or decrease depending on the inflow and outflow rates. After each calving, animals changed categories to first parturition, second parturition, third parturition, fourth parturition, fifth parturition, and sixth parturition following the physiological conditions: pregnant or non-pregnant and lactating or non-lactating. The pure Ankole were modeled up to the eighth parturition because they are kept longer than the crossbreed animals. After the sixth and eighth pregnancy, cows stayed in the herd until the end of lactation period and then were culled. The sex ratio was considered 1:1 (male: female). Calves were nursed and weaned at 7 months old. After this age, all female calves grazed until they would reach the reproductive age of 24 month old for crossbred and 27 months for pure Ankole. At this age, a percentage of female kids entered in the breeding cycle and were able to breed in the subsequent breeding month. Males were sold of when they reached 1 year of age.

**Table 1: Model inputs and parameters**

Parameter	Parameter value	
	Ankole cattle	Ankole-Friesian
Potential milk yield (kg)	6	18
Weaning age (months)	7	7
Milk fact content (%)	5.25	3.5
Milk solids (%)	8.3	8.3
Lactation length (months)	211	270
Mature weight (kg)	360	460
Open period (months)	2-5	2-4
Gestation length (days)	280	280
Dry period (months)	2	2
Mortality rate pre-weaning (%)	5	7.1
Mortality rate for heifers (%)	5.3	7.3
Mortality rate (2- 9 years) (%)	4.2	6.5
Grazing area (ha)	150	150
Serving bulls	2	2
Cows	61	76
Heifers	35	36
steers	12	10
Weaner bulls	14	10

## **Economic sub-model**

The Economic sub-model measures bio-economic efficiency, as net return per cow, by subtracting total cost from total return. Total return is estimated from the sale of weaned calves, heifers and culled cows as well as milk sales. Total cost is the sum of variable costs. Variable costs included feed and non feed expenses such as labour, pasture improvements costs, veterinary service. However, gross margins per se may not reflect the real economic performance of the farms under the two production systems. It is important to consider Total Revenue (TR) in relation to Total Variable Cost (TVC) in order to establish financial efficiency of the farms under the two types of range condition. Financial efficiency was estimated using the TR/TVC ratio. The ratio shows the returns (revenue) per unit variable cost of production.

## **Milk production and animal growth determined by energy intake**

Milk yields are simulated deterministically by using a breed-dependent potential milk yield curve according to Fox et al (2004) equation in which milk production for cows was determined as a function of the time in lactation and the peak milk yield given by:  $PMY = n/(a e^{kn})$ , where  $PMY$  = milk yield during month  $n$  of the lactation cycle, kg/d;  $a = 1/(PKYD \times (1/T) \times \exp(1))$ ;  $PKYD$  = peak milk yield during the lactation, kg/d;  $k$  = shape parameter,  $1/T$ ; and  $n$  = time since calving (months) and  $T$  = month of peak lactation. The actual milk production was then determined by adjusting potential milk yield according to Tess and Kolstad (2000) which is based on the amount of energy available for lactation. The study adopted Ankole cattle lactation and milk characteristics reported by Petersen et al 2003 and Ndumu (2000) where peak milk day (45), potential peak milk yield (6 kg), mature weight (317 kg), milk solids (8.3%), milk fat (5.45%), lactation duration (212 days) were used. In the event that milk production is greater than the corresponding potential on a given day, the milk production would be equal to the potential. Growth of steers is determined based on the energy available for growth and an equation developed by Smallegange and Brunsting, (2002) was adopted.  $Growth\ rate = Growth\ Energy / (20.06 \times 0.2788 / Weight_{ebw}^{0.1107} + 33.41 \times 0.0039388 \times Weight_{ebw}^{0.788})$ , Where the time step is one month and the empty body weight:  $Weight_{ebw} = 0.91 \times Weight \times 550 / Weight\ adult$ . The weight of the animal is calculated each month by:  $Weight(t+1) = Weight(t) + Growth\ rate$

## **Statistical criteria for model evaluation and comparison**

The model simulated results were compared with the observed values of animal body weight from weaning to 18 months of age. The comparison was done using statistical approaches as summarized by Shah and Murphy (2006) and adopted by Beukes et al (2008) and McEvoy et al (2009). Schaeffer (1980) defined mean absolute error (MAE) as  $(\sum |O_i - P_i|)/n$ . Relative prediction error (RPE), which is MAE as a proportion of observed mean values,  $RPE = MAE / [\sum (O)/n]$ , was used to determine precision and reproducibility of prediction. For the whole farm model by Beukes et al (2008), RPE values of <20% are considered accurate and this criterion has been applied to evaluate the model predictions compared with observed data. Additionally, graphs comparing both the observed and

simulated data are presented for easy understanding. Technical evaluation was also made to find out whether the model components were behaving in a manner that is expected in real system based on published information rather than simply the extent to which they track the data accurately.

## Results and Discussion

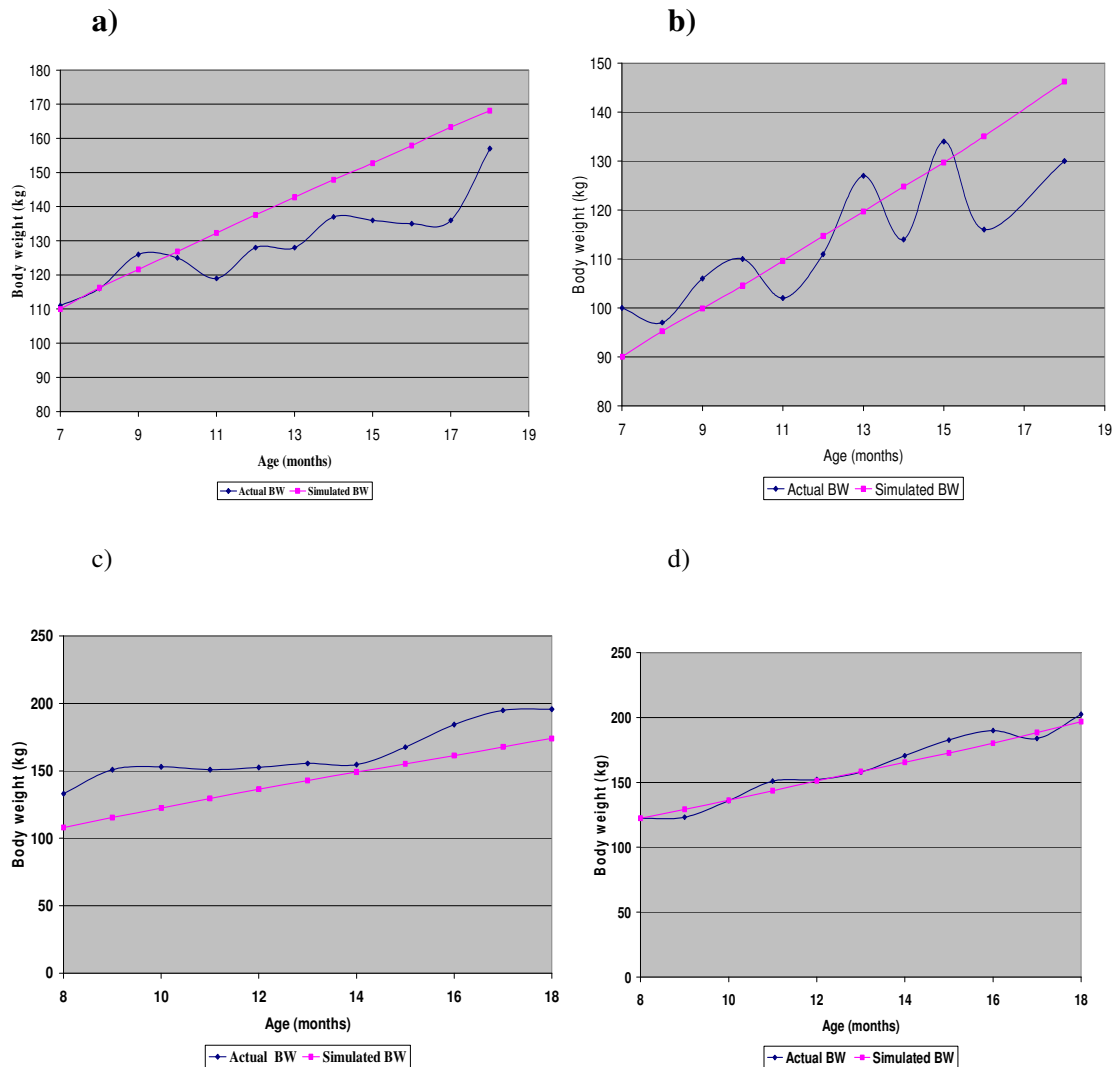
The observed and simulated average body weights are presented in Table 1. The evaluation of the model against data obtained over a 2 year longitudinal study showed that it can be used in evaluating some strategic and tactical management options of the grazing based dairy/beef system in south western Uganda. The calculated average RPE value of 0.075% for growth (body weight) after weaning across both breeds is below the acceptable 20% (Schaeffer, 1980; Shah and Murphy, 2006; Beukes et al 2008; McEvoy et al 2009) and means that the model predicts post weaning growth with an error of 7.5%. This exercise showed that the model has the potential to give acceptable predictions of animal growth. However, the model needs to be validated against other model parameters and observed data from other climatic regions and farm systems that include different levels of supplementation and cattle breeds before it can be used to explore management options on a wider scale. Further evaluation of the model based on annual pasture production and DMI is intended as soon as more pasture is obtained. The model also predicted changes in herd milk production throughout the simulation for a herd that was managed by the same rules but grazed at dynamic stocking rates over the simulation period Figure 5. Herd milk production increased with increasing stocking density. However, the increase in herd yield had a negative effect on milk production per individual animal which could be attributed to reduced energy available for production as a result of increased competition for available pasture. There is need to evaluate the system using controlled stocking rates (ecological carrying capacity) based on values reported in Mulindwa et al (2009) and assess their economic viability as well as determining appropriate cattle off-takes.

**Table 2:** Statistical parameters and observed and simulated values by the model

Item	Body weight (kg)			
	Ankole		Ankole- Frisian crossbred	
	Female	Male	Female	Male
Observed	129.50	113.36	163.69	161.06
SD observed	12.05	12.42	20.18	27.06
Simulated	139.77	115.40	142.01	158.57
SD simulated	18.89	17.58	21.74	24.55
MAE	11.17	8.39	21.00	4.57
RPE	0.08	0.07	0.12	0.03

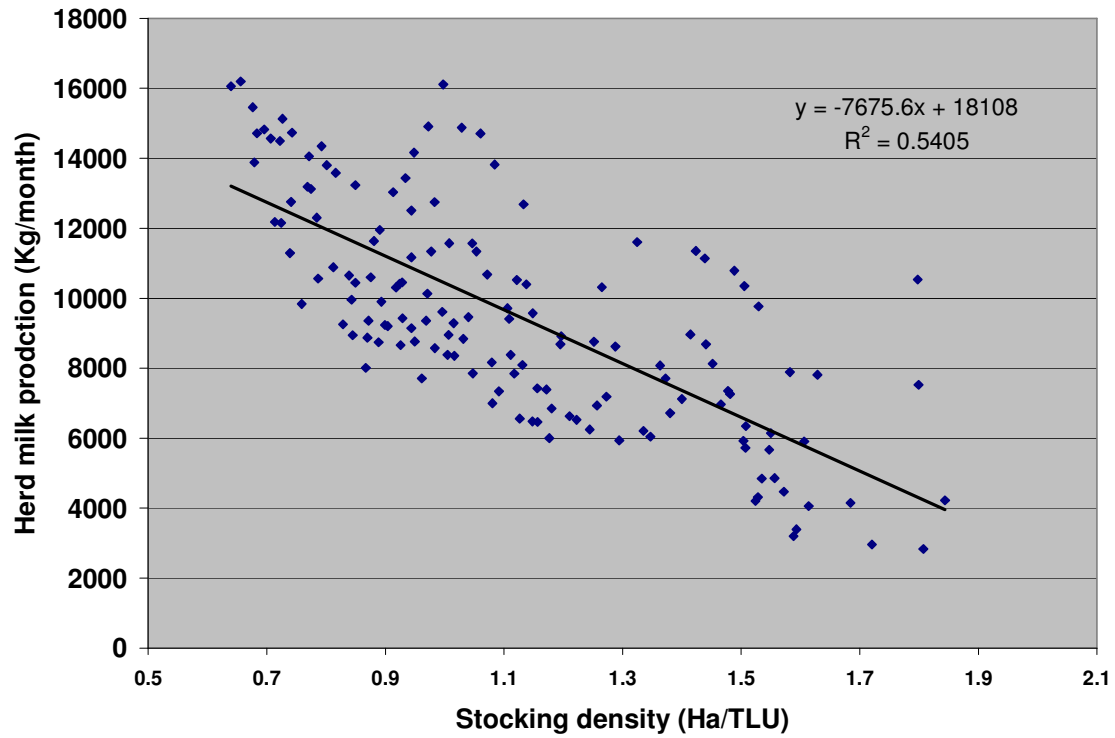
MAE = mean absolute error, RPE = relative prediction error, and SD = standard deviation

# **Observed and simulated post weaning body weight of pure Ankole and Ankole-Friesian crossbreds.**



a) Pure female Ankole, b) Pure male Ankole, c) Female Ankole- Friesian crossbreed , d) Male Ankole-Friesian crossbreed

**Figure 5: Stocking density effect on herd milk production**





## References

- Beukes, P.C., Palliser, C.C., Macdonald, K.A., Lancaster, J.A.S., Levy, G., Thorrold, B. S. and Wastney, M.E. 2008.** Evaluation of a Whole-Farm Model for Pasture-Based Dairy Systems. *Journal Dairy Science* 91:2353 – 2360
- Blackburn, H.D and Kothmann, M.M., 1991.** Modelling diet selection and intake for grazing herbivores. *Ecological Modeling* 57:145 –163
- Byenkya, G.S. 2004.** Impact of undesirable plant communities on the carrying capacity and livestock performance in pastoral systems of south-western Uganda. PhD Thesis, Texas A&M University.pp.192.
- Charmley, E., Stephens, M.L and Kennedy, P.M. 2008.** Predicting livestock productivity and methane emissions in northern Australia: Development of a bio-economic modelling approach. *Australian Journal of Experimental Agriculture* 48:109 -113
- Coleman, S.W. 2005.** Predicting forage intake by grazing ruminants, *In* Proceedings of 2005 Florida Ruminant Nutrition Symposium, United States Department of Agriculture, pp. 72 - 90.
- CSIRO, 1990.** Feeding standards for Australian Livestock. Ruminants. Commonwealth scientific and industrial research organization, Melbourne, Australia.
- Diaz-Solis, H., Kothmann, M.M. Hamilton., W.T., Grant, W.E. 2003.** A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazing lands. *Agricultural Systems*. 76: 655 – 680
- Fox, D. G., Tedeschi L. O., Tylutki, T. P., Russell, J. B., Van Amburgh, M. E., Chase, L. E., Pell, A. N. and Overton, T. R. 2004.** The Cornell net carbohydrate and protein system model for evaluating herd nutrition and nutrient excretion. *Animal Feed Science and Technology*.112:29 –78
- Grant, W.E., Pedersen E.L. and Marín, S.L. 1997.** Ecological and natural resources management: systems analysis and simulation. John Wiley & Sons, New York. pp. 373
- Le Houereou, H. N. 1984.** Rain use efficiency: a unifying concept in arid-land ecology. *Journal of Arid Environments* 7: 213 - 247
- MAFF, 1984.** Energy allowance and feeding systems
- McEvoy, M., Delaby, L., Kennedy E., Boland T.M., O'Donovan, M. 2009.** Early lactation dairy cows: Development of equations to predict intake and milk performance at grazing. *Livestock Science* 122:214 –221
- Mohtar, R.H., Zhai, T. and Chen, X. 2000.** A world wide web-based grazing simulation model (GRASIM). *Computers and Electronics in Agriculture* 29:243 – 250
- Mugerwa, J.S. 1992.** Management and utilization of rangeland: The case of Uganda. Paper presented at 2<sup>nd</sup> FAO regional workshop on grazing resources for East Africa, Kampala Uganda, 30<sup>th</sup> March - 3<sup>rd</sup> April, 1992.
- Mulindwa H, Galukande E, Wurzinger M, Okeyo Mwai A and Sölkner J 2009:** Modelling of long term pasture production and estimation of carrying capacity of Ankole pastoral production system in South Western Uganda. *Livestock Research*

- for Rural Development. Volume 21, Article #151. Retrieved September 10, 2009, from <http://www.lrrd.org/lrrd21/9/muli21151.htm>*
- National Research Council. 2001.** Nutrient Requirements of Dairy Cattle. 7<sup>th</sup> revision. edition. National. Academic. Science, Washington, DC
- Ndumu, D.B. 2000.** Identification and characterization of elite performing Ankole Longhorn cattle for milk production. M.Sc. Thesis, Makerere University, Kampala, Uganda.
- Ocaido, M., Muwazi, R.T and Opuda-Asibo, J. 2009:** Financial analysis of livestock production systems around Lake Mburo National Park, in South Western Uganda. *Livestock Research for Rural Development. Volume 21, Article #70.* Retrieved September 3, 2009, from <http://www.lrrd.org/lrrd21/5/ocai21070.htm>
- Petersen, P.H., Ndumu D.B., Kiwuwa G.H., Kyomo M.L., Semambo, D.K.N., Rowlands, G.J., Nagda, S.N. and Nakimbugwe, H. 2003.** Characteristics of Ankole Longhorn cattle and their production environments in South Western Uganda: milk offtake and body measurements. Animal genetic resources information, FAO. 34:1- 9
- Scanlan, J.C., McKeon G.M., Day, K.A., Mott, J.J. and Hinton, A.W. 1994.** Estimating safe carrying capacities of extensive cattle grazing properties within tropical, semi-arid woodlands of north-eastern Australia. Rangeland Journal. 16(1): 64 -76
- Scarnecchia, D.L. 1988.** Grazing, stocking, and production efficiencies in grazing research. Journal of Range Management 41:279 – 281
- Shah, M. A. and Murphy, M. R. 2006.** Development and evaluation of models to predict the feed intake of dairy cows in early lactation. Journal Dairy Science. 89:294 –306
- Shi,T. and Gill, R. 2005.** Developing effective policies for the sustainable development of ecological agriculture in China: the case study of Jinsham County with a systems dynamics model, Ecological Modelling. 53:223 – 246
- Sikhalazo, D. 2005.** A model for adaptive livestock management on semi-arid rangelands in Texas. PhD Thesis. Texas A&M University. PP. 125
- Smallegange, I.M. and Brunsting, A.M.H. 2002.** Food supply and demand, a simulation model of the functional response of grazing ruminants. Ecological Modelling 149:179 –192
- Sserunkuuma, D. and Olso, K., 1998** Externalities, risk and the private property-overgrazing paradox: The case of private property farm sin Nyabushozi county, western Uganda. Center for international food and agricultural policy. <http://ageconsearch.umn.edu/bitstream/14372/1/wp98-01.pdf>
- Stella 9.0.2 2007.** Technical documentation for Ithink & Stella software. HPS Inc., Hannover, New Hampshire
- Tess M.W. and Kolstad B.W. 2000.** Simulation of cow-calf production system in a range environment. I. Model development. Journal of Animal Science. 78: 1159 – 1169
- Wurzinger, M., Ndumu, D., Okeyo, A. M and Sölkner, J. 2008.** Lifestyle and herding practices of Bahima pastoralists in Uganda. African Journal of Agricultural Research. 3 (8):542 - 548

