Biotechnology in Animal Husbandry, 21 (5-6), p 61 - 67, 2005 ISSN 1450-9156
Publisher: Institute for Animal Husbandry Belgrade – Zemun UDC 636.082

BIOMETRICS AND BIOMATHEMATICS IN SUSTAINABLE LIVESTOCK PRODUCTION[1]

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Abstract: The future progress of animal production in the conditions of sustainable agriculture cannot be realized without use of modern advanced biometrical or biomathematical methods in animal breeding. The short enumerations of these methods referring to their application in the various regions of animal breeding sciences are subject of our paper.

Key words: biology, genetics, biotechnology, sustainable agriculture, livestock production, biometrics, biomathematics, econometrics, biosystems, modelling and simulation, system analysis.

Introduction

Present state of animal experimentation is very wide, practically is spanned from the problems of theoretical biology on the cell basis, over the growth and development of living substances and higher organisms, biochemistry and metabolism of open systems (*Bertalanffy, Von,* 1968), molecular genetics and genetics of population and biotechnology methods, realized in sustainable agriculture with the aim of production of qualitative animal products. The new techniques of molecular genetics (*Bulla et. al;* 1997) enable further development in genetics of populations which can be studied (*Fľak,* 2000) in the chain: *DNA* (biochemistry) → *gene* (molecular genetics) → *chromosome* (cytogenetics) → *organism* (immunogenetics) → *population* (genetics of populations). Intensively are used new procedures such as DNA fingerprinting, RFLP and marker assisted selection (MAS).

Complexity of agricultural problems show, that the complex solution of any animal-genetics tasks by optimal animal experimentation cannot be realized without usage of modern biometrical or biomathematical methods. Therefore in the paper we will introduce very briefly the main methods of analysis of biological or genetical variability or other modern methods of analysis of biological events and processes.

Biological and genetical diversity

Modern biotechnological methods are used, which caused narrowing the genetic pool and probably the reduction of DNA polymorphism takes place. Decreasing of genetic variation can be caused also by sampling or genetic drift, due to finite population size, and as a result of selection (*Hill,* 1998). Genetic variation is produced by spontaneous mutation, and can be introduced into population by immigration, by induced mutation, or by direct genetic manipulation. *Hill* (1998) discussed these problems on the basis of analysis of genetic variation of closed populations, selection experiments, correlated traits, by utilization of different populations and also by other sources of variation as are marker assisted introgression, induced mutagenesis of unspecified quantitative variation, site directed mutagenesis and as by gene transfer. By author opinion there are two quite different issues that have been addressed:

1. what factors determine the availability of genetic variation which can be utilized in improvement programmes, which is essentially a genetic issue, and
2. what is the importance of such long term response or opportunity, which is essentially an economic, political or cultural question.

By definition, a population which has undergone genetic improvement *has* changed; economic and technical circumstances *will* change. From these aspects the author is not clear whether sustainability of a programme is a meaningful concept. We see, that problems are not simple, when we will consider animal breeding goals for sustainable genetic improvement (*Gibson* and *Wilton,* 1998) or for sustainable production systems (*Olesen et al;* 2000).

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1 Original scientific paper – Originalni naučni rad
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Sustainable livestock production

The currently popular term "sustainable agriculture" is used nowadays to represent everything from organic agriculture to agriculture that maximizes economic yields. *Thompson* and *Nardone* (1999) discussed two methodological approaches to sustainable livestock production: *resource sufficiency* which presumes that a production practice is sustainable if the resources needed to carry on the practice are available or foreseen to be available in the future and *functional integrity*, which presupposes that the crucial elements of the system are reproduced over time in a manner or at a rate that depends on previous system states. *Vavra* (1996) explored and suggested that sustainable animal production systems exist in the overlap of what the current generation wants for itself and future generations and what is biologically and physically possible in the long run. Environmental and economical aspects were also considered here in addition to biodiversity and ethical aspects. The new idea in the term "sustainability" is that environmental, genetic diversity, ethical, and social aspects should be accounted for in addition to short- and log- term economic value. *Francis* and *Callaway* (1993) summarized elements of sustainability as follows:

1. resource efficiency,
2. profitability,
3. productivity,
4. environmental soundness (negative impact both on the farm and their area), and
5. social viability.

To the more important characteristics of future agricultural systems belong mainly *genetics* and *biotechnology* methods and very good *animal welfare*. *Genetic improvement* is a biological and technological development. The essence of these developments is to improve the efficiency of a production system: saving inputs of production factors per unit product and change toward the use of cheaper production factors. There are different constraints of production system: constrained feed resources (adaptability and feed efficiency) and unconstrained feed resources (adaptability, productivity or product quality), and an additional reason which influenced animal production and differentiate between breeding goals and to perform testing programs in specific environments is the *genotype x environmental interaction*. Sustainability of animal breeding goals is dependent on deriving economic values, choice of it (*Groen et al;* 1997) are dependent on:

1. modelling approach (objective data simulation or data analysis, or a subjective method),
2. definition of efficiency (economic or biological in terms of energy, protein, or mineral/element),
3. planning term (short-term, or long-term, strategic planning horizon),
4. system level (animal, farm, sector, national, or international level),
5. size of the system (fixed number of animals, fixed input of a production factor, or fixed output of a product), and
6. interest of selection (profit maximization, price minimization, or maximization of return on investment).

Olesen et al. (2000) by discussion about sustainable animal breeding as a long term and complex process, by which we must consider need for more focus on long term biological, ecological and sociological solutions, for functional integrity of animal breeding stressed that in future must be answered on the problems:

1. the ethical aspect and priorities of top management need to be clear,
2. define the system with respect to limits and structure,
3. define criteria required for or indicators that measure or characterize the above ethical priorities and critical effects of the production systems, and finally
4. identify animal traits and characters that are important or critical to meet these criteria or objectives.

Balance or weigh these traits (*aggregate genotype* consists not only of traits of economic or market weight/values but also of traits of the nonmarket values) such that the animals contribute to optimize the whole system constrained on the ethical limits and priorities. The resulting nonmarket and market genetic gains give us an opportunity to evaluate the breeding programs in a more holistic perspective, in which social, cultural (including subjective values), ecological, and economic objectives and effects can be taken into account. *Thompson* and *Nardone* (1999) concluded that animal sciences have a significance capacity to address sustainable livestock production as a problem of resource capacity. By defining multiple trait objectives for sustainable genetic improvement *Gibson* and *Wilton* (1998), recommended that the nonlinear optimization techniques can be used to find optimum economic weights of traits, but uncertainty of future production and marketing environments creates risk that might be lessened by maintaining or selecting for diverse genetic stocks that could be used in the future. Such programs may need to be coordinated internationally because they may be too expensive for individual companies to undertake. Consideration of risk and careful analyses of future technical and environmental conditions are needed to define multiple trait objectives for long-term genetic change. The future progress in animal production is completely depended on the government, academic, and breed association which must provide additional technical guidance and leadership so that all livestock improvement industries will mature to be science-based, profit-oriented, and customer-driven and will intelligently use selection and crossbreeding technologies based on sound biology, sound statistics, and sound economics, with these all systematically combined, (*Harris,* 1998). In the process, the lingering residue of the art of breeding should diminish and be fully replaced by scientific methodology.

Complexity of outlined problems showed, that the complex solution of any animal-genetics tasks by optimal animal experimentation cannot be realized without usage of modern biometrical or biomathematical methods.

Biometrical methods

For animal experiments is characteristic the use of *biometrical methods.* Their applications can be divided practically in ten parts (*Fľak,* 1998 a), as follows:

1. models and methods for analyses of animal growth and development,
2. planning and evaluation of rearing of animals and designs for comparative feeding trials of animals,
3. experiments for feed description and methods for reporting nutritive values and efficiency of feed utilization,
4. methods for evaluation of physiological processes of reproduction and animal health,
5. methods for evaluation of production traits and quality of animal products,
6. methods of ethological and ecological trials,
7. biometrical methods in genetic of population and quantitative genetic methods,
8. biometrical methods for evaluation of experiments in biotechnology and trials in genetic engineering,
9. econometrics methods in biometrical genetics methods, and
10. applied biometrical methods for modelling and evaluation of biological (biosystems) and agricultural systems.

Short review of each of cited parts, with the simple enumerating biometrical methods for its solution was given in the paper. The significance of biometrical methods in *genetics of populations* which concern both methods we reviewed in several papers (*Fľak,* 1989, 1998 b, 2001, 2002, 2003).

Population genetics and quantitative genetics

Methods of *population genetics* are concentrated on the analysis of frequency/probability of various genetic events, genes, loci, genotypes on the theoretical basis by use of simple Mendel model, one, two or multiple- locus models, by the definition of means/expected values and variances or co/variances of various genetic entities (parents, progenies, etc.), for the study frequency changes of genes or loci by help of analysis of variability, inbreeding or effective size of population, mainly caused by migration, mutation and selection processes. Definitions of genetic and breeding values on the basis of simple genetic models, phenotypic and genetic variance and their components, genetic similarity or resemblance between relative individuals, genetic parameters (e.g. heritability, and genetic correlations) and theoretical genetic evaluations, are very important notions for practical consideration and construction of selection criteria not only in genetics of populations or quantitative genetics methods but also in *biotechnology* and *genetic engineering.*

Methods of *genetics of populations* are mainly concentrated on the estimation of *genetic values*, i.e. on estimation of *breeding value* in pure-breeding and *crossing effects* in crossbreeding, by using corresponding *linear model* (*Fľak,* 2001), which basis creates the so called *infinitesimal model*.

Breeding value in pure-breeding can be estimated by simple regression models, methods of analyses of co/variance components and multiple regression models, and nowadays by solution of *mixed linear models* by *Best Linear Unbiased Prediction (BLUP)* method or by *BLUP-Animal* model. There are univariate and multivariate methods estimation of breeding values, which serve for selection purposes in animal breeding. Genetic evaluation of *hybrid populations* is based on using non-additive genetic effects, mainly dominance and epistasis, for estimation of *crossing effects*, mainly *heterosis*. For the description and estimation of crossing effects are used various genetic models, from which the most important are *additive-dominance* model, *Cockerham`s general linear* model and *Dickerson* model. Generally, the unknown parameters of linear models used in genetics of populations can be estimated using the *Least Squares method, LS, Weighted Least Squares method, WLS,* and *Generalized Least Squares method, GLS,* or *Maximum Likelihood method, ML* or its varieties. Specific biometrical methods are used for estimation of crossing effects in planed/designed experiments. There are methods for simultaneous estimation of breeding value from evaluation of mixed populations on the basis of simultaneous evaluation of intra- and inter- population variability.

Nowadays are used also modern methods of modelling, simulation and optimalization of estimated unknown genetic parameters (Monte Carlo methods, Gibbs sampling, etc.).

Modern genetic analyses

The future progress in animal production depends on using the methods of *genome analysis* in farm animals (*Schwerin,* 2001) by using advances technologies as primary marker and comparative maps, large insert libraries, chromosome microdissection and radiation hybrid mapping. At present are known various genetic variants directly affecting the phenotype in cattle (e.g. various diseases, muscle hypertrophy, cheese properties), genes affecting significantly phenotype in cattle indirect genetic assays (e.g. loci for milk yield, coat color) or bovine chromosomes on which QTL regions underlying milk performances, growth, exterior and functional traits have been mapped. The advanced biometrico-genetical methods of maker assisted selection (MAS, *Fľak,* 1991*,* 2000) and integration of quantitative trait loci (QTL) or (economic) ETL mapping (e.g. by ANOVA, mixture models, regression, BLUP based methods, mixed inheritance model with adequate hypothesis testing in outcross population, with detection of linkage disequilibrium between marker and QTL, if marker and the QTL are closely linked and by adequate effective population size of population, *Bovenhuis et. al.,* 1996) and developing technologies (such as high-throughput gene expression analysis, novel molecular genetic tools for genome manipulation, comparative mapping and sophisticated bioinformatics applications) will facilitate efficient large-scale functional mapping of genes to complex traits, and to estimate the effects of environmental factors, can be high significance for the optimal animal production.

Biotechnological methods

Modern *biotechnological methods* are used in animal production (*Fľak,* 1988), mainly in technology of reproduction processes (insemination, estrus synchronization, superovulation, embryo-transfer, embryo-manipulation, nucleo-transplantation, gene transfer, MOET, semen selection, gameto- and embryo conservation, selffertilization, animal cloning, recombinant DNA technologies in conjunction with animal cloning, etc.), biotechnology for control of growth and product quality in meat production with the aim to create target health animal produced in optimal welfare with optimal energy and protein requirements. Very important are methods of conservation of farm *animal genetic resources* (*Hansen,* 1992) by conservation of living ova, embryo, semen and somatic cells stored cryogenically in liquid nitrogen, preservation of genetic information in form of DNA, stored in frozen samples of blood or other animal tissues or as DNA segments or conservation of living populations, i.e. *in situ* conservation. These forms of technology provide animal breeders usage of *genetic diversity* in a form of *biodiversity*, which have an important role for maintaining the genetic variability usable for selection processes.

From the complexity of described regions can be concluded, that its biologic or genetic evaluation can be not done without corresponding analytical and synthetical analyses by *biomathematical methods* or without use of *numerical description* of analyzed biological events and processes by their *modelling* and *simulation* or without of use *of system analysis.*

Modelling and simulation

Basic principles of *modelling* and *simulation* with examples of its applications in animal research were reviewed by *Fľak* (1992). Principles of modeling and simulation in research and teaching were presented by *Mertens* (1977). A well defined mathematical model allows manipulation, condensation, interpretation, and utilization of quantitative information about complex problems. Modelling aids the researcher or teacher by:

1. organizing information and crystalization his thinking,
2. identifying new research and teaching areas and techniques and
3. testing research and hypotheses.

In addition to the attributes of modelling, simulation can aid the researcher and teacher by

1. quantifying experimental benefits and
2. predicting outcomes under new conditions and assisting in deriving important experimental estimates of parameters.

Although modelling and simulation are combination of art of science, there are guidelines which can be used by the teacher and reseacher to develop and utilize models:

1. define the problem and modelling goals,
2. observe and analyze the real system,
3. block diagram and synthesize the model,
4. mathematically formulate and implement the model,
5. process relevant data for variable and parameter estimates,
6. verify and validate the model,
7. improve the model,
8. accept it,
9. simulate results using the model, and
10. evaluate the simulation results.

Modelling and simulation require extensive communication between modeler and his audience. Both the model and the data for is implementation must be reproduced in such way that other researchers and teachers can duplicate the results and build upon its base. Finally, modelers should retain a healthy scepticism of models, especially their own, to ensure that they are evaluated adequately and used correctly.

Young (1983) stressed from the panel discussion about problems of *modelling* and *data analysis in biotechnology* and *medical egineering* the main lines of model building in biotechnology under the following major headings:

1. model building and the scientific method,
2. the objectives and purposes of model building in biotechnology and medical engineering,
3. model formulation,
4. structure identification,
5. model parameter estimation,
6. model validation, and
7. model use: analytical and simulation requirements.

In particular problem, the study objectives will usually define the model requirements. *State -of - the art - understanding* of the system should then suggest a dynamic „physical“ model, the nature of which will be dependent upon many factors such as whether the problem has received attention previously, the availabilty of data and the ability of reasearch workers to conduct planned experiments. Even when experimental planning is feasible, the *state - of - the - art model* may be so complex that the analyst will be unable, with practical limitations, to plan experiments that are sufficiently rich to allow for complete identification of all the model parameters and he must simplify the model. These kinds of problem do not currently receive sufficient attention and the question of experimental design in biotechnology and medical engineering is a suitable topic for more research effort.

System analysis

System analysis (*Cartwright,* 1979) provides a method of more systematically organizing knowledge, including ad hoc research results, in animal science with empasis on animal breeding. It is also a method of more effectively utilizing research information for current application to increase production efficieny for specific sets of condition. Since the mathematical model is constructed so as to desribe animal functions and responses, there is a feedback stimulus to the more basic subdisciplines; this process encourages an integration of the subdisciplines in animal science.

More specifically in animal breeding, system analysis provides a method for overcoming some long recognized major weaknesses. One of these is related to definig merit objectively and realistically especially in terms of production and mating sysems; i.e. in terms of production populations rather than in terms of individuals whose effects may not be additive. A second is that of designing selection and breeding systems to cope with nonlinearity of economic values of characters and to cope with genetic-environmental interaction where the genetic component includes mating systems and environmental component includes time and space variables, some of which might be volatile measured in terms of livestock generation intervals. Specific selection and mating plans or strategies can be designed for given objectives and environments.

The greatest value of system analysis in animal science may be to encourage a manner of thinking, an ecology philosophy, in teaching, research and extension. Perhaps this in turn will inspire a new wave of originality and development in applied and theoretical animal breeding as well as composite or production animal sciences.

Conclusion

Present state of animal breeding experiments desire applications and usage of modern biometrical or biomathematical methods in the fields of theoretical biology, growth and development of living substances and higher organisms, biochemistry and metabolisms, molecular genetics and genetics of populations, biotechnology, econometrics and other allied disciplines for sustainable livestock production. In paper were briefly enumerated the various advanced statistical and mathematical methods by which we can solve various outlined problems in animal breeding for sustainable agriculture.

BIOMETRIKA I BIOMATEMATIKA U ODRŽIVOJ STOČARSKOJ PROIZVODNJI

Pavel Fľak

Rezime

Budući progres stočarstva u uislovima održive poljoprivrede ne može biti realizovan bez upotrebe modernih naprednih biometrijskih i biomatematičkih metoda u stočarstvu. Predmet ovog rada je kratko navođenej ovih metoda kao i njihove oblasti primene u različitim oblastima nauke u stočarstvu.

Ključne reči: biologija, genetika, biotehnologija, održiva poljoprivreda, stočarstvo, biometrika, biomatematika, ekonometrika, biosistemi, modeliranje i simulacija, analiza sistema

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