**Deutscher Tropentag 1999 in Berlin**
**Session: Research Organization and Cooperation**

# Performance Evaluation in Agricultural Research: Lessons from low input – low output research systems in Sub-Saharan Africa

Frank Hartwich and Matthias von Oppen

Institute of Agricultural Economics and Social Sciences in the Tropics (I490b),
University of Hohenheim, D-70593 Stuttgart, Germany
Telephone: (+49) 711 4593392, Fax: (+49) 711 4593762,
E-mail: hartwich@uni-hohenheim.de, m-voppen@uni-hohenheim.de

## Abstract

The paper analyzes technical efficiency of research operations at universities in sub-Saharan Africa in relation to other national research organizations. Research outputs in agroforestry, beef-cattle and cassava research in Cameroon and Tanzania are evaluated and then and merged into an output indicator by using weights derived from the Analytical Hierarchy Process (AHP) method. The indicator is then used to calculate technical efficiency of input output relations applying a Data Envelopment Analysis (DEA) model. Through this procedure efficiency scores are derived which enable a comparison of different research units, among those the university departments.

Results show that in particular research fields universities are near the technical production frontier. At an average universities account for higher technical efficiency in their research operations than national agricultural research organizations (NAROs) and international agricultural research centers operating under the umbrella of NAROs (IARC/NAROs). However, testing reveals that technical efficiency of universities is not significantly different from those of NAROs and IARC/NARO arrangements. As universities provide at least not lower degrees of efficiency a further integration of universities in national agricultural research may be appropriate. IARC/NARO provide important research outputs but do this on the account of high costs in human resources when compared to national research units.

**Keywords:** Agricultural Research, Evaluation, Analytic Hierarchy Process, Data Envelopment Analysis, Cameroon, Tanzania

## Introduction

Governments and various bilateral and multilateral donors have since long been promoting agricultural research in sub-Saharan Africa by supporting national agricultural research organizations and universities as well as international research centers. However, agricultural research organizations have been criticized for not being efficient and effective enough in addressing the needs of potential users of research results. Consequently, national agricultural research systems are not adequately funded. In this situation the evaluation of agricultural research operations provides useful information for improvements. Research evaluation could particularly contribute to knowledge on the “who should do what” question and guide future allocation of funds.

Evaluation of research performance is a difficult and costly exercise. Results of the research process are particularly diffuse, unpredictable and their importance is difficult to judge. Currently, performance in research is mainly judged through scientific peers and not by potential users and beneficiaries of research. However, peer review systems have become under pressure as criteria of austerity, good governance and efficiency are introduced into research management and funding decisions. In addition to peer review systems there are other approaches which use economic data to determine the importance and social benefits of research. Those economic approaches, involve in extensive data collection and risky assumptions on the functional forms. There application in research evaluation, apart from general justification of research, is limited: (1) Economic approaches are focused on specific research topics, e.g. the development of a new crop variety. They are insufficiently capable to deal with a wide range of research activities which simultaneously produce a multiple set of research outputs. (2) They are not capable of comparing different research units. (3) They only focus on the outputs of the “technology factory” and not on the results of the knowledge generation process taking taking place in complex knowledge systems involving multiple actors.

Currently evaluation approaches are tested which try to integrate diverse performance indicators in order to improve the analytic capability of the evaluation. For example, in Brazil 37 national agricultural research institutes of the Brazil NARO are evaluated with the use of Data Envelopment Analysis (DEA) (da Silva e Souza et al, 1997). At the International Service for National Agricultural Research (ISNAR) in the Hague, Peterson (1998) developed a framework of output/outcome evaluation and periodic organizational assessment. Also at ISNAR an ex-ante evaluation method for priority setting in biotechnology research has been developed by Braunschweig and Janssen (1998) using the use of the Analytic Hierarchy Process (AHP). Recently a methodology combining AHP and DEA in ex-post evaluation was developed by a joint project between the University of Hohenheim, Germany, and ISNAR: Within categories AHP is used to weigh different outputs according to their relevance and effectiveness. Then, to avoid further agglomeration of outputs of very different nature DEA is applied calculating Pareto efficiencies. This procedure leads to relative performance indicators which enable comparison of research units. This paper presents results from a study in Cameroon and Tanzania in which the AHP/DEA research evaluation methodology was applied. In the first section of the paper we introduce conceptual issues of agricultural research evaluation. In the second section we set forth the Analytic Hierarchy Process (AHP) used in research performance evaluation as a tool for addressing relevance of research outputs. In the third section inputs and outputs are merged in a linear programming model (DEA) to generate scores of technical efficiency which then will be interpreted. In the conclusions we summarize the results and draw conclusions on the strength and limitations of using the methodology in ex-post evaluation of agricultural research.

## 2. Evaluating Research Performance - the Concept

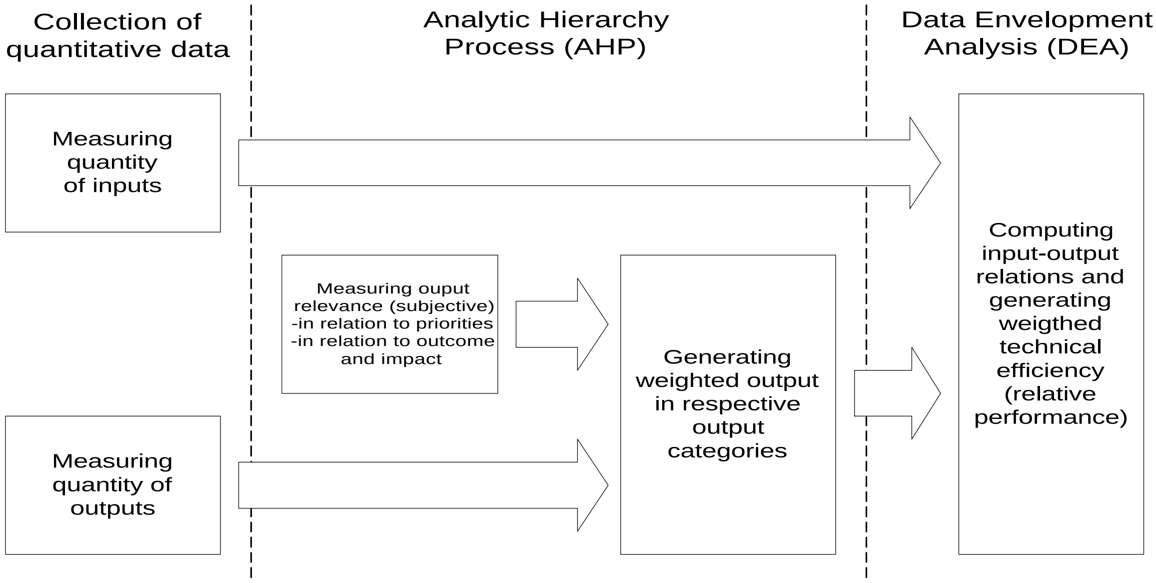
The approach to research evaluation in the study is based on the research production model (for example Brown and Svenson, 1988; Andrews 1997) was used as. In short, the research production model enables a combination of the dimensions of efficiency and productivity with measures of effectiveness and relevance. The core of the model is the research operation. Inputs in research as human and financial resources as well as physical infrastructure are used to produce outputs, which is new knowledge and technology. The relation of inputs to outputs is dependent on attributes to the process, i.e. institutionalization, management, structure, and administration. Outputs are measurable products of the research process, such as procedures developed, technologies improved, and papers written. They indicate that new and/or advanced knowledge has been acquired. By applying knowledge, users transform these outputs into positive outcome such as improved production, cost reduction, and profits. Outcome is usually measured in an assessment of long-term impact at the user end of research and depends on a wide range of factors in the research environment.

In the current study overall impact (outcome) is incorporated in the evaluation indirectly through the opinion of experts. Figure 1 shows how the evaluation of multiple research outputs is operationalized using both the output (direct quantitative measurement) and outcome levels (indirect qualitative measurement). The procedure involves:

- Measuring the quantity of inputs and outputs,
- Qualifying relative importance of research outputs against priorities, objectives and the overall outcome using the AHP methodology, and
- Modeling the relation of weighted outputs in categories to inputs using DEA.

At the end research units can be compared with one single overall relative performance indicator which is the weighted technical efficiency in generating research results.

Figure 1: Operationalization of Performance Evaluation




## 3. Measuring Quantity of Inputs and Outputs

Agricultural research in Cameroon and Tanzania is conducted by various public and private research organizations. Traditionally, national agricultural research is nested in government research stations. However, increasingly other research organizations contribute to national agricultural research, particularly the universities as they are endowed with qualified human resources. Not all agricultural research in the two countries was evaluated but a sample of three important research fields (cassava, beef-cattle and agroforestry research) which represent national agricultural research in the domain of crop research, livestock research and natural resource management research. Altogether, in the two countries, 119 researcher were identified to be involved in those research fields. 87% of them were interviewed. In the interviews information on inputs and outputs of the agricultural research operation was collected. The 119 researchers were involved in a total of 299 research operations.

In the identification of input and output measures emphasis was put on applicability of the indicators to the evaluation problem and their meaningfulness to the research operation. Inputs in research were defined as all resources which are put at the disposition of the research operation. It was assumed that knowledge as an input to research is embodied in the human resources involved in research. Outputs of research were defined as measurable products of the research process as for example technologies developed and reports and papers written. According to information available in project documentation and due to discussions with research staff from the countries the following inputs (X) and outputs Y were identified: (X1) human resources, (X2) Financial resources, (X3) Physical resources, (Y1) Master thesis conducted, (Y2) PhD thesis conducted, (Y3) Publications in international journals and presentations on international conferences, (Y4) Publications in regional journals and presentations on regional conferences, (Y5) Publications in national journals and presentations on national conferences, (Y6) Internal reports submitted, (Y7) New technologies generated, and (Y8) Technologies adapted. Information on the quantities of the above outputs were collected from individual researchers in a 9month field trip to Cameroon and Tanzania.

## 4. Weighting Agricultural Research Outputs

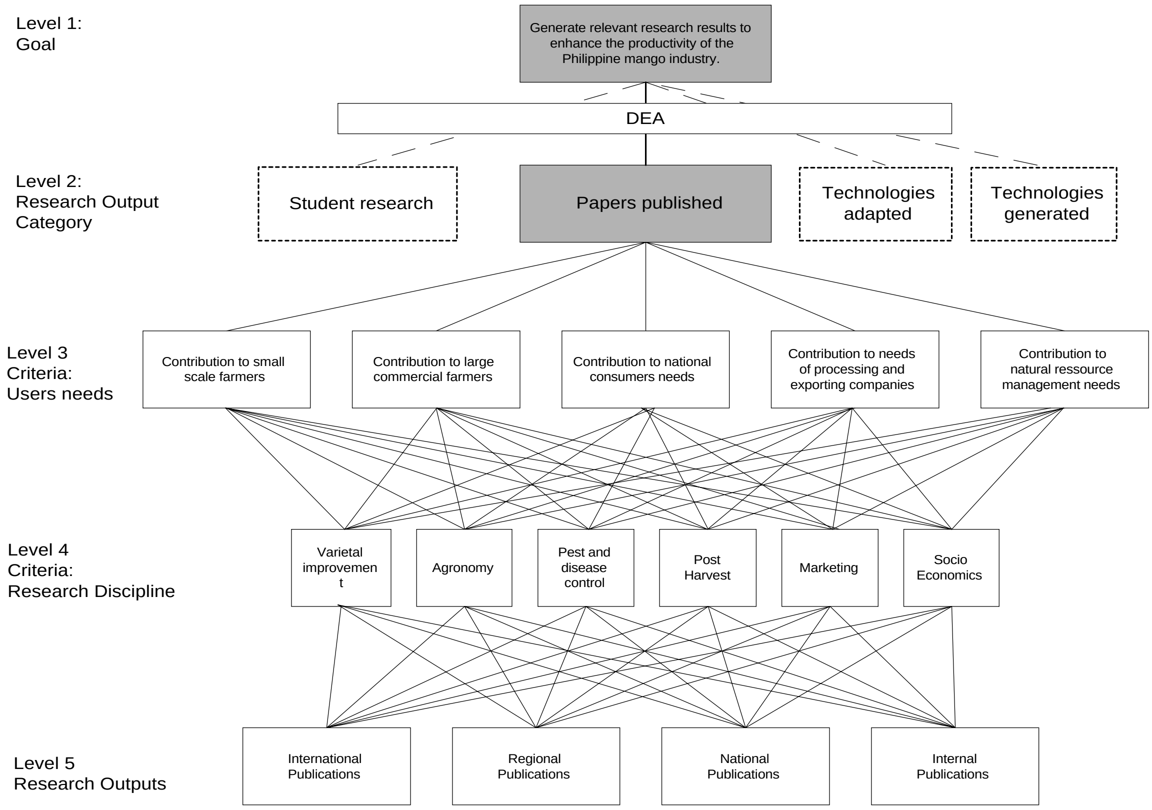
When involving in an aggregation of outputs to come to an overall performance indicator the need for a weighting system arises. To derive weights for comparing research ouptus the Analytic Hierarchy Process (AHP) was applied. With AHP the analyst structures a problem hierarchically and then, through an associated measurement-and-decomposition process, determines the relative priorities consistent with overall objectives. The method involves a pairwise comparison procedure. Each pair of alternatives is compared with regard to the respective next level criteria. Those comparisons are verbalized according to a scale from 1 to 9 which follows psychological insights indicating that the human mind uses multiplicative dimensions when comparing two alternatives.

The AHP is of process character meaning that it is not a one-occasion evaluation exposed on a unit to be evaluated from the outside but a continuos process of defining priorities with the participation of all stakeholders. For our purpose the process was divided into 7 steps (compare Saaty 1990, Huizingh 1993): (1) Defining the evaluation problem, (2) Defining and selecting the units of evaluation, (3) Identifying a set of alternative research outputs, (4) Identifying a set of relevant criteria, (5) Developing the hierarchical structure, (6) Collecting information and eliciting local and global priorities, (7) Preparing recommendations for action.

In the study the working definition was adopted that the overall goal of agricultural research in the two countries is to generate results which contribute to national welfare, availability and quality of agricultural products, agricultural production, and natural resource management; in other words, to generate results that serve the country’s needs. To achieve weighting of different research outputs within the categories criteria are needed against which those outputs are judged. The study applied a “user” perspective to the definition of criteria, in other words, the beneficiaries of research output were identified. They include the following five main groups: (a) Farmers, (b) Consumers, (c) Society as a whole, (d) Environment, (e) Other components of the research system.

With regard to c it hat to be noted, that not only farmers and consumers benefit from agricultural production, but also society as a whole. The state, through taxes and levies, generates income from agricultural production and exports and redistributes this income to the society in the social infrastructure (transport systems, education, health). Some research particularly focuses on technologies related to agricultural products from which the state can generate income.

Figure 4: Hierarchical structure of the research output weighting problem in cassava research for the category of "Papers published"




The hierarchical structure reveals the logical connection of the elements of the evaluation process. Four levels are defined in this evaluation study: Level 1 determines the overall goal of the research to be evaluated, level 2 determines the output category (judgments between categories are not made as DEA is applied in section 5), level 3 determines the criteria against which the research outputs (level 4) are weighed. Figure 4 describes, as an example, the logical hierarchy for cassava research in the category of papers publishe. Equivalent figures can be constructed for other categories (student research, technologies adapted and technologies generated) and other research fields (agroforestry research and beef cattle research). The categories technologies generated and technologies adapted only have three level hierarchies as level 4 (distinction of alternative outputs) does not exist. The lines in figure 3 indicate the logical links between the different elements. For example, within the category of technology generated in cassava research the output results in "plant breeding" have to be weighted against other research outputs e.g. in agronomy with regard to the criteria "contribution to national farmers' needs." Then, the criteria "contribution to national farmers' needs" has to be weighted within the frame of possible research output categories.

According to the analytic hierarchies above information has been gathered from interviews with Cameroonian and Tanzanian key actors in national agricultural research, such as institute and program directors and heads of university departments (level 3), and from researchers in the research field of concern (level 4). A total of 74 keyactors and researchers were involved in this judgement process. The composition of those peer groups can be subject of concern. In the study no representatives from farmers groups and NGOs and few representatives of the policy environment and donor were included. The results of the judgments process are shown in Table 2. Weights within the categories do not necessarily add up to 1,00. The AHP method is based on multiplicative judgements (how much more important is a over b), and thus in the cumulation of judgements, geometric means have to be built over the range of researchers judgements which not necessarily add to 1,00. For further explanation see Forman and Peniwati (1996).

Results from the AHP weighting have shown that some of the classical research areas are judged to be rather unimportant in their contribution to the countries' needs. This is true to breeding in both cassava and beef-cattle research. Other classical research areas as animal nutrition and agronomy remain important. Some new research areas, as for example post harvest research become important. In agroforestry, which is a new research field, the different research areas are equivalently important. AHP weights are shown in Table 2 for the example of "Agroforestry Research. Aquivalent weights have been derived for Cassava Research and Beef Cattle Research.

Table 2: Weights of agricultural research output categories derived from the AHP

| | | *Cameroon* | *Tanzania* |
|---|---|---|---|
| Agroforestry Research | | | |
| Student research | MSc thesis | 0,400 | 0,400 |
| | PhD thesis | 0,600 | 0,600 |
| Publications | Internal publications | 0,098 | 0,217 |
| | National publications | 0,054 | 0,182 |
| | Regional publications | 0,246 | 0,245 |
| | International publications | 0,602 | 0,175 |
| Technology generated & Technology adapted | Fuelwood production & poles | 0,120 | 0,122 |
| | Soil fertility | 0,209 | 0,155 |
| | Soil conservation | 0,157 | 0,192 |
| | Fodder production | 0,082 | 0,095 |
| | Alternative Products | 0,122 | 0,047 |
| | Socio-Economics | 0,135 | 0,199 |

## 5. Measuring Technical Efficiency

Efficiency is defined by a relation of output to input. If, as in our case, total factor efficiency is of concern we need to relate all inputs to all outputs. This is usually done by relating the sum of all inputs to the sum of all outputs. For deriving the summation terms inputs and outputs have to be made comparable. This is usually done by multiplying them with their respective weights or prices. Merging Table 3 and Table 4 enables computation of sums of outputs in categories. Further aggregation is not possible because no weights have been derived for output categories as those categories are considered to be of very different nature. Alternatively, inputs and outputs can be related to each other simultaneously using a programming model. This approach was undertaken in the study when applying DEA. Within DEA, multiple inputs and multiple outputs are reduced to a single virtual input and virtual output and finally to a single summary relative efficiency score. It is a distinct characteristic of DEA to draw on the legitimacy, that units might value inputs and outputs (in our case output categories) differently and therefore adopt different weights. As Gillespie et al. (1997) state, DEA is useful in situations where (a) there are multiple outputs and multiple inputs and (b) there is not an objective way to determine the efficiency of a unit based upon one efficiency index formula.

Estimation of an average practice function, as usually applied in traditional economics, only reveals average technology under the inclusion of inefficient units. DEA enables the estimation of a frontier function which refers to the best performing units and hence reflects the existing best research generation practice. This is particularly useful as it is most unlikely in agricultural research that research units conduct research according to the same average research generation technology.

The DEA weights (multipliers) for both outputs and inputs are to be selected so as to calculate the Pareto-efficiency measure of each unit (Charnes et al. 1995). Pareto efficiency is attained when no input can be reduced without reducing the output or when no output can be increased without increasing the input. No unit can have a relative efficiency score greater than unity. The DEA calculations are designed to maximize the relative efficiency score of each unit, subject to the condition that the set of weights obtained in this manner for each unit must also be feasible for all the other units included in the calculation. DEA optimizes the performance measure of each unit. Non-performance is established when no outputs or irrelevant outputs are generated. Under the restriction, that research each unit's efficiency is judged against its individual criteria (individual weighting system), efficiency of a target unit $h_1$ can be obtained as a solution to the following problem: Maximize the efficiency of unit 1, under the restriction that the efficiency of all units is $\leq 0$. Following Charnes and Cooper (1962) the algebraic model of our linear programming problem in dual form is depicted in (1).

$$\min_{\Theta,\lambda} \quad \Theta_1$$

$$subject \cdot to: \quad \sum_{i=1}^{n} \lambda_{1i} y_{r1} \geq y_{ir}, \qquad (1)$$

$$\Theta_i x_{ij} - \sum_{i=1}^{n} \lambda_{1i} x_{j1} \geq 0,$$

$$\lambda_{1i} \geq 0$$

*where* $\theta_1$ *= the technical efficiency score for unit 1 to be estimated*
$\lambda_i$ *= a n-dimensional constant to be estimated*
$y_1$ *= student research output of the 1st unit*
$y_2$ *= publications output of the 1st unit*
$y_3$ *= new technologies developed of the 1st unit*
$y_4$ *= technologies adapted of the 1st unit*
$x_1$ *= human resource input of the 1st unit*
$x_2$ *= financial resource input of the 1st unit*
*i indicates the n different research units of the dataset to be analyzed*
*r indicates the 4 different outputs*
*j indicates the 2 different inputs*

The linear programming problem must be solved n times, once for each unit in the sample. After computation a value of h is then obtained for each unit. Equation (1) constitutes the DEA model under the constant return to scale (CRS) assumption. However, CRS assumption is only appropriate when all research units are operating at an optimal scale (Coelli et al, 1998). Imperfect competition, constraints on finance, etc., may cause a research unit to be not operating at optimal scale. A further development towards a variable returns to scale (VRS) DEA model includes the convexity constraint $\Sigma\lambda_{i1} = 1$, meaning that under variable returns to scale the $\lambda$ add to one (Banker et al. 1984). This approach forms a convex hull of intersecting planes which envelope the data points more tightly than the CRS conical hull and thus provides technical efficiency scores which are greater than or equal to those obtained from the CRS model. Thus, inefficiency under VRS is a stronger argument than inefficiency under CRS. Differing CRS and VRS technical efficiency estimates indicate that the firm has scale inefficiency. The equation of the VRS model is depicted in the linear program (2).

$$\min_{\Theta,\lambda} \quad \Theta_1$$

$$subject \cdot to: \quad \sum_{i=1}^{n} \lambda_{i1} y_{ir} = y_{r1}, \qquad (2)$$

$$\Theta_1 x_{j1} - \sum_{j=1}^{n} \lambda_{i1} y_{ji} = 0,$$

$$\sum_{i=1}^{n} \lambda_{i1} = 1$$

The study used the DEAP © software to compute technical efficiency scores (Coelli, 1996). The model was run on 6 different datasets each related to one of the three research topics in one of the two countries (see Table 3 to 5). Under the conditions of constant returns to scale

(CRS) 25 of the 52 research units investigated are technically inefficient, i.e. they are below the technical production frontier. Under VRS conditions there are 9 institutes which are inefficient, meaning that they could increase their technical efficiency simply through decreasing the inputs or increasing the outputs. Among those are 5 from the NARO, 1 from the NARO/IARC and 2 from the universities.

Results shows that from 29 NARO research units investigated 16 were inefficient under CRS conditions and 5 under VRS conditions. Meanwhile of the 18 university research units 8 were inefficient under CRS and 2 under VRS conditions. The IARCs, i.e. IITA and ICRAF, which cooperate with NARO on the national level, provide particularly high outputs as reported in section 3. However, of the 6 existing NARO/IARCs research units 3 are inefficient under CRS and two under VRS conditions. The DEA computations reveal that university research units, at an average, were efficient with a score of 81% at CRS conditions. At VRS conditions this efficiency was at 97%. NARO research units are efficient to a degree of 71% under CRS conditions and 94% under VRS. Arrangements of IARCs and NAROs were efficient at 60% under CRS and 92% under VRS conditions. Altogether NARO/IARCs arrangements have the lowest mean technical efficiency und CRS as well as under VRS conditions. This lower efficiency (relative to the other research organizations) may be due to the high costs of internationally recruited staff.

Figure 5: Box-Whisker-Plot on the distribution of VRS technical efficiency scores (derived from 6 DEAs models)

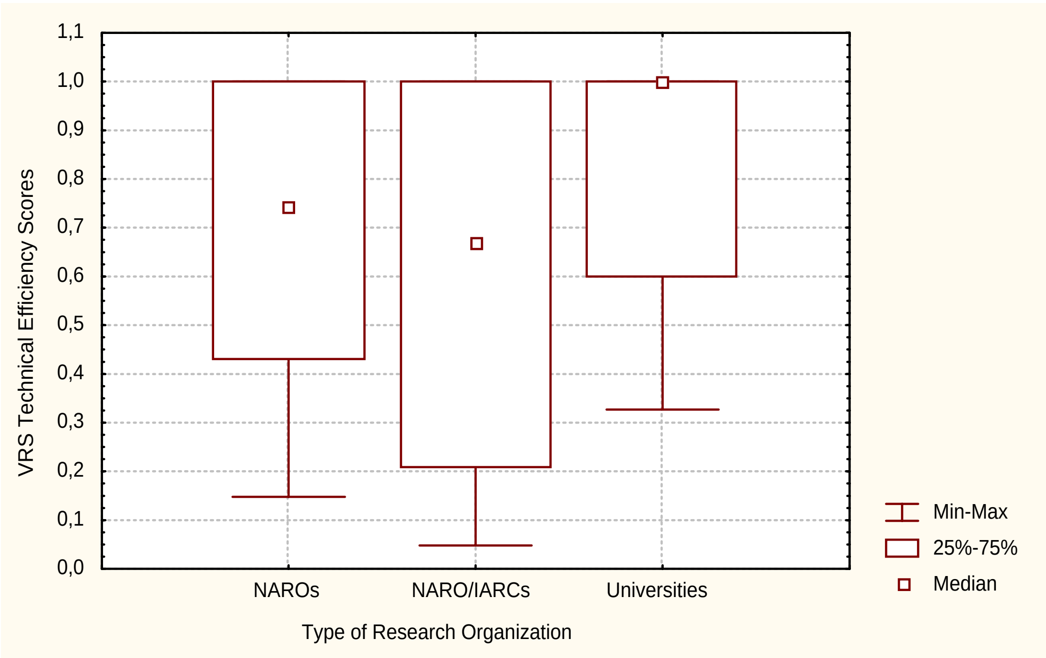
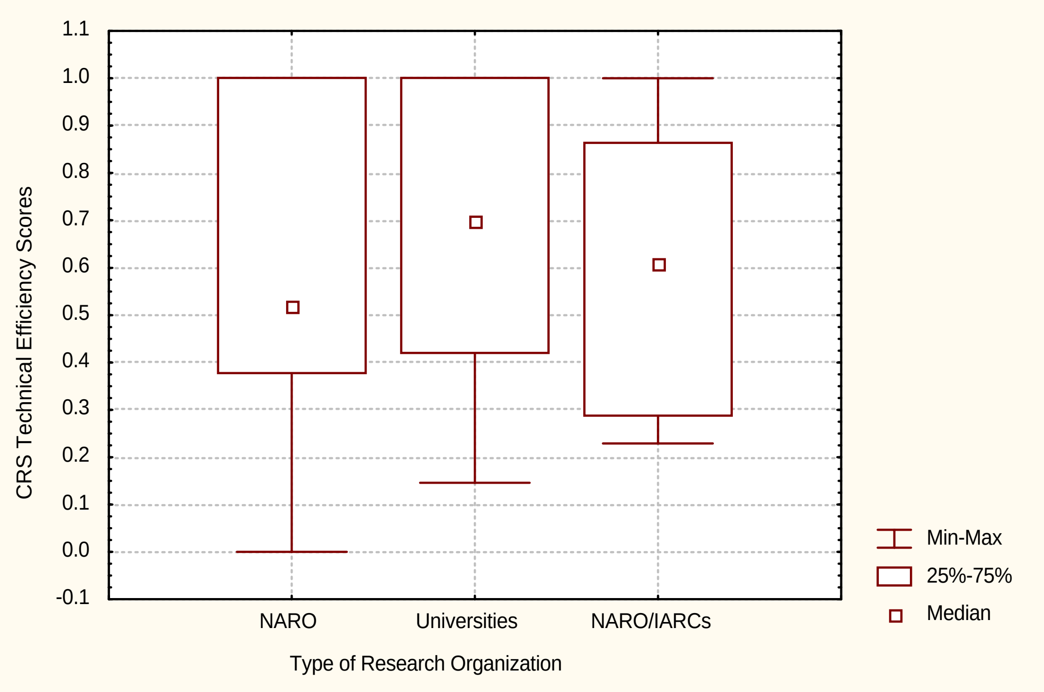



Figure 5 indicates that university research units tend to have a higher efficiency score than NAROs and NARO/IARCs. Drawing from those results, the argument, that universities in Cameroon and Tanzania are less efficient than NAROs has to be denied at least in the fields of cassava, beef cattle and agroforestry research.

Figure 5 presents the distribution of technical efficiency scores generated by six DEAs which were conducted separately in order to account for geographical effects (the countries Tanzania and Cameroon) and discipline effects (cassava research, beef cattle research, agroforestry research). Additionally the analysis was conducted for the entire dataset meaning that regional and disciplinary effects were disregarded. Results are shown in Figure 6.

Figure 6: Box-Whisker-Plot on the distribution of VRS technical efficiency scores (from one DEA model)




From Figure 6 we can see that excluding the side effect of region and discipline (compare Figure 5) NAROs get less efficient in relation to Universities. This may be due to the fact, that NAROs have particular comparative advantages when regionally relevant and disciplinary research is conducted. Universities, however, have the highest Median and the highest 25%-75% Quartiles indicating that they are the most efficient of all three research organizations. NARO/IARCs under the exclusion of regional and disciplinary effects tend to have a lover variance than including them. This may be an indication that some of their research is very region and discipline specific and some not.

## Conclusion

The study used a combination of two approaches to analyze performance in national agricultural research. In a first step data on inputs and outputs have been collected. Then, in a second step peers have weighted importance of research outputs in research output categories with regard to their impact (outcome) following the algorithm of the Analytic Hierarchy Process (AHP). In a third step multidimensional input output relations were modeled with the use of Data Envelopment Analysis (DEA) following the criteria of Pareto Efficiency.

The empirical results show, that Universities as well as NAROs in Cameroon and Tanzania are operating on very low levels of activities, their outputs are low, the inputs are low as well. The research systems in the two countries can thus be categorized as low-input / low-output NARS. However the efficiency in low-input low-output systems varies and not necessarily has to be low. It is among one of the discoveries of the study that, often without the knowledge of central research organization bodies, some researchers in remote stations produce research results with few inputs and simple tools available.

From the technical efficiency scores we can conclude that universities should be further integrated in national agricultural research. Universities produce less output than NAROs and institutional arrangements involving international agricultural research centers under the umbrella of NARO. But universities are not significantly less efficient in conducting relevant research. They actually account for the highest mean technical efficiency scores. The fact that universities hardly have the mandate to conduct research and the fact, that Universities are provided with only marginal research budgets do not constrain university research units to account for good research performance. Based on this results further research may be conducted on the issue of identifying the factors which determine the degree of technical efficiency.

With regard to methodology a combination of AHP and DEA accounts for the following advantages:

- It enables simultaneous analysis of multiple inputs and multiple outputs without applying weights to different research output categories which cannot be combined. The concept of Pareto efficiency used by DEA is an elegant solution to the weighting problem.
- It combines quantitative with qualitative data on the relevance of research outputs. Qualitative weights are derived only within categories in which outputs are comparable. The weights derived from AHP outperform the weights resulting from often subjectively biased scoring methods. AHP is adapted to structuring of complex weighting problems, particularly when a set of discrete alternatives is related to a multiple and complex set of objectives, as being the case in agricultural research.
- It avoids the assumption that all research units generate research under the same average conditions (the same average research generation technology). Instead, the assumption of a frontier of best practicing units is made which is much closer to reality in the research sector.
- It provides easy to interpret overall efficiency scores for the research units analyzed which can be used benchmark studies on best practicing units. It allows analysis of a whole set of different research units. The weights and efficiency scores can be used to make decisions on future funding decisions in agricultural research.

The study shows that the methodology used may be an interesting alternative to economic impact assessment and scoring and peer review methods in agricultural research evaluation. Further application and testing may proof this statement. Further research should be particularly guided in two directions. First there is the possibility of incorporating a cost measures of technical efficiency as described by Coelli et al. (1998). A weighting system for research categories derived from AHP may be appropriate for this. Further, data could also be used to apply the parametric Stochastic Frontier Approach. In this case variables describing inefficiency effects have to be included. Alternatively the inefficiency residual as derived above could be decomposed applying Tobit regression analysis.

## References

Brown, M.G.; Svenson, R.A. (1988). Measuring R&D Productivity. Research Technology Management, July August 1988.

Braunschweig, T.; Janssen, W. (1998); Establecimiento de Prioridades en la Investigacion Biotechnologica mediante el Proceso Jerarquico Analitico. ISNAR, Research Report 14. International Service for National Agricultural Research, The Haag, The Netherlands.

Charnes, A.; Cooper, W.W. (1962). Programming with Linear Fractional Functionals. In: Naval Research Logistics Quarterly, Vol. 9.

Charnes, A.; Cooper, W.W.; Lewin, A.Y.; Seiford, L.M. (1995). Data Envelopment Analysis: Theory, Methodology and Applications. Kluwer Academic Publishers, Boston/ Dordrecht/London.

Coelli, T.J. (1996). A Guide do DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program. CEPA Working Papers No 8/96, Department of Econometrics, University of New England, Armidale, Australia. Website: http://www.une.edu.au/econometrics/cepawp.htm.

Coelli, T.J.; Prasada Rao, D.S.; Battese, G.E. (1998). An Introduction to Efficiency and Productivity Analysis. Kluwer Academic Publishers, Boston/ Dordrecht/London.

Da Silva e Souza, G.; Alves, E.; Dias Avila, A.F.; da Cruz, E.R. (1997). Technical Efficiency of Production in Agricultural Research: A case study. EMBRAPA, Brazil.

Forman, E.; Peniwati, K. (1996); Aggregation Individual Judgments and Priorities with the Analytical Hierarchy Process. ISAHP, Vancouver, Canada, July 12-15.

Gillespie, J.; Schupp, A.; Taylor, G. (1997). Factors Affecting Production Efficiency in a New Alternative Enterprise: The Case of the Ratite Industry. In: Journal of Agricultural and Applied Economics. No 29, Vol 2, Southern Agricultural Economics Association.

Hartwich, F. (1998). A Cumulative Indicator for Measuring Agricultural Research Performance: Accumulating performance measures of agricultural R&D operations in a developing country. ISNAR Discussion Paper, No. 98-1, ISNAR, The Hague, The Netherlands.

Huizingh, K.R.E. (1993). Analytic Hierarchy Process: Een methode om appels met peren te vergelijken. Tijdschrift voor Marketing, maart 1993.

Peterson, W. (1996). Organizational Performance Assessment System Guidelines, Test Version, July 1996. ISNAR, not published.

Saaty, T.L. (1990). How to make a decision: The Analytic Hierarchy Process. In: European Journal of Operational Research, Vol. 48.