Expl Agric. (1997), volume 33, pp. 73–82
Printed in Great Britain

STATISTICAL LITERATURE FOR PARTICIPATORY ON-FARM RESEARCH

By J. RILEY *and* C. J. ALEXANDER

IACR-Rothamsted, Harpenden, AL5 2JQ, UK

(*Accepted 10 April 1996*)

SUMMARY

A review is presented of available documents containing statistical methodology for participatory on-farm research. Further needs in this area of work are commented upon.

INTRODUCTION

One of the current major themes of *Experimental Agriculture* is agricultural production systems, including social and economic aspects, particularly in the warmer regions of the world. A Farming Systems Series of papers has appeared in the journal since Simmonds (1986) presented a review of research in this area of work. The complexity of research into such systems leads to information and data that are both quantitative and qualitative. These data are dependent upon interrelationships between disciplines whose study demands an understanding of experimental design, statistical analysis and interpretation that reaches far beyond the standard statistical texts. Such complexity often leads to the omission from studies of any statistical input at all; this unfortunately can result in poorly designed studies, and ambiguous or biased interpretations of data. Criticism of statistical quality in a number of research areas has appeared in the international literature (Bryan-Jones and Finney, 1983; Lauckner, 1989; Riley and Darmi, 1995; Reid and Asiedu, 1995). As agricultural research becomes more multidisciplinary, deficiencies in the use of statistical methods are not likely to decrease but will increase with greater study complexity.

This problem was confirmed by a brief screening by the authors of 60 papers on participatory farming systems in a range of agricultural journals. The investigation demonstrated that statistical methodology was often poorly defined and inadequately used. Typically, the more farmer participation that was involved, the more complex the underlying design structure, although traditionally-taught block and plot designs were unlikely to be required. Confounding of effects and inadequate sampling were encountered frequently due to lack of clear design structure. Discussion of collected data was often the only method of data summary, particularly when data were qualitative. On-farm studies of livestock were frequently subject to these types of design and analysis problems. Economic analyses that were done were not always based upon robust formulae and were dependent much upon the quality of the experimental data that were used.

In order to determine the availability of documented statistical advice appropriate for participatory farming systems research, the authors established a short review project. The purpose of the project was not to say that statistical methodology *should* be used in such studies: that would be dependant upon the specific study objectives (Riley, 1994). Rather it was to identify available documentation to assist the researcher and to identify any areas where dissemination of methodology requires improvement. This publication contains a review of the most useful documents available; a lengthier list, containing documents with minor statistical recommendations and applications is available from the authors.

Statistical documentation was found through electronic database searches and through contact with scientific institutes involved in on-farm work. This second source identified university and institute publications not listed in international databases but classed as 'grey' literature. The publications fell naturally into six individual categories of work. These six categories are used here to assist the reader to identify relevant publications: genotype by environment interaction studies, livestock and aquaculture work, intercropping, agroforestry, multidisciplinary participatory studies together with a general category which may encompass any aspect. This breakdown may appear to be rather crude: for the *development* of statistical methodology for use in participatory farming systems research, this would certainly be true. However, as a device to determine the availability of *existing* material and as an indicator of the general perceptions of statistical need it proved to be a useful tool.

STATISTICAL DOCUMENTATION

When discussing the application of statistical methodology to participatory farming systems work, the degree of farmer participation is important as it will effect both increasing sources of variability and the likelihood of qualitative data. We ignored any publications having studies confined to research stations with input only from researchers and considered the following four types:

- On-station work, planned and activated by researchers but where the farmer influences its design or comments upon its outcome or relevance.
- On-farm work, planned and activated by the researcher but taking account of apparent farmer needs and preferences.
- On-farm work, planned by the researcher but activated by the farmer.
- On-farm work, planned and activated by the farmer such that the researcher merely observes.

Publications are presented first for the general category of work, such publications forming a natural extension to the standard and commonly available statistical textbooks which present methodology applicable to a wide range of agricultural disciplines.

General statistical recommendations

The available documentation ranges from textbooks which aim to provide a complete set of advice with regard to the design and analysis of on-farm, generally

researcher planned experiments, to journal papers which include a small amount of statistical advice. The complete textbooks include Hildebrand and Poey (1985) and Steiner (1987), although both refer to quite rigid statistical designs, typically traditional on-station ones.

Gomez and Gomez (1984) contains one chapter on the design and analysis of on-farm trials but limits attention to the situation where equal numbers of plots and replicates can be achieved on each farm, a situation which is unlikely to be achieved in reality, but which facilitates statistical analysis. Mutsaers and Walker (1991) edited a valuable collection of workshop papers on design and analysis of on-farm trials. Two papers by these authors are particularly useful for the design and analysis of trials although their brevity inhibits their potential value.

Zandstra and colleagues (1981) describe typical sources of variation which need to be considered when designing trials, and list numbers of treatments and replicates that have been used in the literature but do not justify these figures; statistical analysis extends no further than simple t-tests. Hammerton and Lauckner (1984) present a manual of experimental procedures for on-farm experimentation in the Caribbean, describing rather formal field trials combined with valuable practical recommendations for their management.

Neeley and colleagues (1991) present a manual of statistical techniques for on-farm research in Africa. It is aimed at biometricians who work closely with experienced on-farm research agronomists, deals with designs which traditionally have been used on-station, and presents rather standard statistical analyses for quantitative data. Poate and Daplyn (1993) present methodology for the design of formal surveys of farms and farmers, although the analytical methods described are not extensive. Mettrick (1993) includes comments about data collection and problems of design, but presents no detailed recommendations for design or analysis.

The variability inherent in on-farm and participatory work can produce irregularity in design and the need for more flexible statistical methods than are normally available to researchers (Stroup *et al.*, 1993). The paper presents the difficult balance between the realistic design of participatory farming system studies to take account of the available facilities and the resultant necessity for complex models and statistical processes which depend upon the availability of sophisticated computer software.

Genotype by environment interaction

The very large amount of work on variety trials has generated statistical methods appropriate for multi-locational trials repeated in time (Patterson *et al.*, 1977) and thus the study of genotype by environment interaction and species stability over both sites and years. This generated methodology such as resolvable incomplete block designs and residual maximum likelihood (REML) (Patterson and Thompson, 1971), a powerful method to provide accurate analyses for incomplete block structures or data which have dependent error structure. This is appropriate for the analysis of data from developing country on-farm studies

where large variation from farm to farm may demand irregular designs and complex analysis.

Although linear regression has been used frequently to estimate patterns of stability, its value has led to much debate and various adaptations have been proposed. Dyke and colleagues (1995) refer to these types of analysis and conclude that the literature leaves much to be desired. Multivariate methods including principal components, cluster analysis and principal coordinates have also been proposed; Westcott (1986) provides a concise summary.

More recent approaches to the analysis of genotype by environment interaction data include AMMI models which model the genotype by environment interaction in a multiplicative sense rather than an additive one (Gauch, 1992). The method has been used successfully for wheat yield trials at the International Maize and Wheat Improvement Centre (CIMMYT) (Crossa *et al.*, 1991). An associated graphical method, the biplot which separates genotypic and environmental effects, has been used by Kempton (1984) and also by Cooper and Hammer (1996) for on-farm trials in developing countries.

All of these methods are powerful and flexible, but depend heavily upon availability of sophisticated computer software.

Intercropping

Available papers for studies of intercrops and mixed cropping in the tropics are, in general, relevant for both on-station and on-farm work. Design of experiments is discussed in Gomez and Gomez (1983) who promote balanced experiments of the type which were originally designed for on-station work and which can be analysed easily. However, they successfully consider sources of variability on farms and data collection procedures. Other design features for mixed species are in Mead and Stern (1980).

Several papers assess yield advantages of intercropping compared with sole cropping using indices such as the land equivalent ratio (Willey and Osiru, 1972), which led to the staple land equivalent ratio (Chetty and Reddy, 1984; Riley, 1985) and the general form of the land equivalent ratio (Riley, 1984). An alternative, yet complementary, bivariate method is promoted by Pearce and Gilliver (1978, 1979). A range of these methods is summarized and discussed in Mead and Riley (1981). This paper documents clearly the statistical methodology available at that time for intercropping research whether on-station or on-farm. A study of intercropping stability in Rao and Willey (1980) is discussed by Mead and colleagues (1986), and a statistical method proposed for determining risk of crop failure. Singh and colleagues (1988) examine the stability of mixed genotypes. Federer (1993) presents a theoretical approach to design and analysis for intercropping trials but does not consider the specific on-farm situation.

Wijesinha and colleagues (1982) describe analyses for a maize and beans intercropping experiment whilst Mutsaers and Walker (1990) provide an interesting application of a stepwise design in a maize plus cassava multi-site intercropping trial, used because a full factorial would be too large. Da Silva and

colleagues (1984) used quadratic models to determine optimum size and shape of intercropped plots of cowpea and maize.

Livestock and aquaculture work

Publications for on-farm livestock work include a number of valuable documents, although most can be classed as 'grey' literature and therefore may be obtained less easily. A paper by Quaas and Pollak (1980) examining farm and ranch beef cattle testing programmes proposes the use of mixed model methodology for weaning weight and post-weaning gain records. The methods proposed incorporate simplifications to the computations required although a complex degree of statistical work is still necessary, and users need access to powerful computer methods and confidence in interpreting the results of the analyses. Amir and Knipscheer (1989) discuss basic statistical sampling procedures and associated tests and apply them to some small on-farm animal experiments. They highlight the value of statistics and note the complexity of designs that often result from on-farm material.

A livestock systems research manual produced by the International Livestock Centre for Africa (ILCA, 1990) examines statistical aspects such as the collection of baseline data, survey methodology, analysis and presentation of results and presents analyses for standard balanced experiments. Little consideration is given to unbalanced designs apart from acknowledging that lack of balance is very likely in on-farm animal experimentation and that sophisticated statistical software is needed to handle the data from such structures.

De Wit and colleagues (1992) highlight the problems with large-scale data collection from livestock projects on small-scale farms and they propose computer software for handling such data. They also state that if participation is the main objective of a study relatively few flexible experiments will be more useful than large scale ones which generate masses of data.

Amezquita (1993) considers crossover designs and continuous treatment designs for the evaluation of forage diets for farm animals and recommends the use of both simple exploratory techniques, linear and non-linear regression, analysis of variance and cluster analysis to obtain a broad assessment of the many variables that are often collected in on-farm livestock work. Some sound recommendations with regard to designs are presented in a CARDI (Caribbean Agricultural Research and Development Institute) booklet by Lauckner (1994).

Statistical factors are noted by Scoones (1994) in a Zimbabwean browse ranking study. Ranking methods together with a scoring of important criteria provided useful planning tools for designing fodder improvement programmes with herd owners. Schoonmaker Freudenberger and Schoonmaker Freudenberger (1994) describe the use of historical matrices to demonstrate when different farming system components were introduced although no analysis of this information is done. Ghirotti (1994) describes the use of rapid rural appraisal techniques in African countries, stressing his use of statistical sampling procedures and questionnaire design to collect unbiased data, although he suggests no statistical analyses. Much aquaculture research is done on-station, the

discipline being relatively young; although some on-farm work is done, it is not yet reported in the literature. A useful paper showing the important aspects of statistics and their presentation for aquaculture studies, whether on-station or on-farm, is Riley and Darmi (1995).

Agroforestry

Agroforestry represents a relatively new discipline and one which involves considerable on-farm work, both in its study of tree–crop interactions but also in its impact upon farming communities. The International Centre for Research in Agroforestry (ICRAF) has produced considerable guidance on agroforestry and its benefits to the farmer; rather less material has appeared with regard to the design and analysis of on-farm and participatory agroforestry research. A sample of such publications includes the following: Huxley and Mead (1988) which discusses single tree experiments and on-farm trials. Roger and Rao (1990) and Rao and Roger (1990) stress the need for randomization, replication, blocking, appropriate plot size, relative species layout and design of treatment structure and plot structure. Most of these recommendations refer to standard design methodology, but are valuable nevertheless for on-farm studies. A valuable paper by Rao and Coe (1991) describes the measurement of crop yields in agroforestry studies.

Methods of recording data from agroforestry systems are presented in Riley (1988) and a study of statistical distributions of tree data from agroforestry experiments and their implications for statistical analysis is summarized in Langton and Riley (1989). Langton (1990) proposed neighbour-balanced designs to avoid edge effects in agroforestry experiments. Riley and Smyth (1993) discuss distributional properties of data from both trees and crops in a Brazilian alley-cropping experiment and show how the changes in such distributions from year to year, corresponding to fluctuating weather patterns, must be taken into account in statistical analyses.

MacDicken, Wolf and Briscoe (1991) present a small, useful manual for multipurpose tree research, although the statistical methodology is traditional and not advanced enough to deal with difficult situations where unbalanced treatment structure may be experienced. Rao and Coe (1992) and Coe (1994) present further recommendations for improved design and the evaluation of results. Hildebrand and colleagues (1993) discuss farmer criteria for evaluation and the design of trials so that they are amenable to the use of modified stability analysis.

Multidisciplinary participatory studies

The types of study which can be described as the most participatory are those typically farmer activated. A *primary* purpose of these studies is to collect information about the human component in terms of social anthropology, socio-economics or impact of different interventions upon health or livelihoods of communities. Publications are numerous and diverse in their content, some describing different approaches to study formulation, others describing actual

studies which have been done and the type of information which was generated. The studies are not rigorously structured, primarily provide information which is qualitative although quantitative data are not unknown, often give sets of data which are small in sample size and frequently are not subjected to formal statistical summary.

Some statistical advice in the multidisciplinary participatory literature can be found in parts of the following documents: van der Werf (1994), which includes descriptions of ways to collect and assess unbiased information in LEISA (low external input and sustainable agriculture) technologies and in participatory diagnoses. Tripp (1991) identifies the need to define carefully the objectives of expensive surveys, and stresses that faulty trial design under very variable conditions may provide insufficient data for interpretation. Allen (1992) states that 'intelligent use of the detail in the sample frame should give the dual advantages of greater representativeness and a smaller sample size, which implies quicker administration and analysis of survey.' Horton (1985) discusses ways of implementing formal farm surveys and encourages the use of prior informal surveys to identify key aspects of farming systems to be explored further. Chambers (1994) describes the use of formal surveys, rapid rural appraisals (RRA) and participatory rural appraisals (PRA) in some detail.

Issues with regard to quality and value of data have been raised by many research workers. Duggan (1994) highlights the massive amounts of data collected in an Indonesian RRA study and the difficulties his team experienced in handling it. Direct and indirect socio-economic indicators were collected and had to be validated by cross-checking against wealth ranking data and interview data. Both quantitative and qualitative data were needed.

Janssen and colleagues (1991) and Janssen and Ashby (1993) examine technology acceptance by producers, traders and consumers and use complex multivariate analyses to handle preference data. Van Nieuwkoop and colleagues (1994) study the value of RRA and conclude that they are valuable in identifying priorities for a formal survey. Gilling and Cropley (1993) discuss the uses of RRA and, briefly, statistical aspects such as site selection, stratification and frequency of data collection.

CONCLUSIONS

This survey has demonstrated that statistical methodology for use in participatory on-farm trials is available but is not necessarily documented in a form easily used by non-statisticians. Whilst standard methodology is widely and clearly documented, statistical techniques to handle complex design structures and some forms of qualitative data are not easily handled in short statistics training courses and are documented most frequently in the more esoteric statistical literature.

It appears also that many of the available documents appearing as institute publications are not easily accessible. Many have been written for particular disciplines, whereas the statistical methods used are valuable for others. Awareness of the availability of such literature will help in this respect and we hope that this publication will assist with this.

A common misconception is that statistical methodology refers only to the design of traditional balanced crop experiments on station with the ensuing role of formal parametric significance tests. Statistical methodology encompasses much more than this, and can offer both simple and complex methodology with the support of powerful statistical packages to add value to the quality of modern, unstructured multidisciplinary design and the summary of collected data, whether they be quantitative or qualitative.

Acknowledgements. This work is one of the dissemination outputs of the Overseas Development Administration (ODA) Policy Research Initiative Project R5979. ODA can accept no responsibility for any information provided or views expressed. The Institute for Arable Crops Research (IACR) receives grant-aided support from the Biotechnology and Biological Sciences Research Council of the United Kingdom.

REFERENCES

Allen, J. M. S. (1992). Concentric sampling in farming systems research. *Journal of Agricultural Economics* 43:104–108.

Amezquita, M. C. (1993) Diseno y analisis de ensayos para evaluacion de pasturas en fincas. In *Planeacion y Conduccion de Ensayos de Evaluacion de Gramineas y Leguminosas Forrajeras en Fincas. Documento de Trabajo No 133*:23–37. Colombia: Centro Internacional de Agricultura Tropical (CIAT).

Amir, P. & Knipscheer, H. C. (1989). Using statistics in on-farm animal research. In *Conducting On-Farm Animal Research: Procedures and Economic Analysis*. Arkansas: Winrock.

Bryan-Jones, J. & Finney, D. J. (1983). On an error in 'Instructions to Authors'. *HortScience* 18:279–282.

Chambers, R. (1994). The origins and practice of participatory rural appraisal. *World Development* 22:953–969.

Chetty, C. K. R. & Reddy, M. N. (1984). Staple land equivalent ratio for assessing yield advantage from intercropping. *Experimental Agriculture* 20:171–177.

Coe, R. (1994). Through the looking glass: 10 common problems in alley-cropping research. *Agroforestry Today* 6:9–11.

Cooper, M. & Hammer, G. L. (Eds) (1996). Plant adaptation and crop improvement. Wallingford: CAB International (in preparation).

Crossa, J., Fox, P. N., Pfeiffer, W. H., Rajaram, S. & Gauch, H. G. (1991). AMMI adjustment for statistical analysis of an international wheat yield trial. *Theoretical and Applied Genetics* 77:33–38.

da Silva, E. C., Ribeiro, V. Q. & de Andrade, D. F. (1984). The use of a quadratic model to determine the size and shape of plots in experiments with cowpea intercropped with corn. *Pesquisa Agropecuaria Brasileira* 19:1267–1270.

de Wit, J., Schiere, J. B. & Udo, H. M. J. (1992). Analyzing livestock systems in developing countries: experiences of DTAP reviewed. In *Goat Production Systems in the Humid Tropics. Proceedings of an International Workshop, Ile-Ife, Nigeria, 1992*, 146–151 (Eds A. O. Ayeni & H. G. Bosman). Wageningen, Netherlands: Pudoc.

Duggan, B. (1994). Rapid rural appraisal training for baseline data collection and target group identification. In *RRA Notes No 19 Special Issue on Training*. London: IIED (International Institute for Environment and Development).

Dyke, G. V., Lane, P. W. & Jenkyn, J. F. (1995). Sensitivity (stability) analysis of multiple variety trials, with special reference to data expressed as proportions or percentages. *Experimental Agriculture* 31:75–87.

Federer, W. T. (1993). *Statistical Design and Analysis for Intercropping Experiments Vol 1: Two Crops*. New York: Springer-Verlag.

Gauch, H. G. (1992). *Statistical Analysis of Regional Yield Trials*. Amsterdam: Elsevier.

Ghirotti, M. (1994) Rapid appraisal techniques: a tool for planning and managing animal health and production development programmes. In *RRA Notes No 20 Special Issue on Livestock*, 78–86. London: IIED (International Institute for Environment and Development).

Gilling, J., Cropley, J. P. (1993). *Needs Assessment for Agricultural Development: Practical Issues in Informal Data Collection.* Chatham, UK: Natural Resources Institute.

Gomez, A. A. & Gomez, K. A. (1983) *Multiple Cropping in the Humid Tropics. IDRC-176e.* Ottawa: International Development Research Centre (IDRC).

Gomez, K. A. & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research 2nd edn.* New York: John Wiley.

Hammerton, J. L. & Lauckner, F. B. (1984). *On-Farm Experimentation: A Manual of Suggested Experimental Procedures.* Trinidad: CARDI (Caribbean Agricultural Research and Development Institute).

Hildebrand, P. E. & Poey, F. (1985). *On-Farm Agronomic Trials in Farming Systems Research and Extension.* Colorado: Lynne Rienner.

Hildebrand, P. E., Singh, B. K., Bellows, B. C., Campbell, E. P. & Jama, B. A. (1993). Farming systems research for agroforestry extension. *Agroforestry Systems* 23:219–237.

Horton, D. (1985). *Tips for Planning Formal Farm Surveys in Developing Countries: Social Science Dept Training Document 1982-6.* Luna: International Potato Centre (CIP).

Huxley, P. A. & Mead, R. (1988). *An Ecological Approach to On-Farm Experimentation: ICRAF Working Paper No 52.* Nairobi: ICRAF.

ILCA (1990). *Livestock Systems Research Manual Vols 1 and 2.* Addis Ababa, Ethiopia: ILCA.

Janssen, W. & Ashby, J. (1993). *Technology Acceptance in a Market Setting: Theory and Application.* Colombia: Centro Internacional de Agricultura Tropical (CIAT).

Janssen, W., Ashby, J., Carlier, M. & Castano, J. (1991). Targeting new technology at consumer food preferences in developing countries. *Food Quality and Preference* 3:175–182.

Kempton, R. A. (1984). The use of biplots in interpreting variety by environment interactions. *Journal of Agricultural Science*, Cambridge 103:123–135.

Langton, S. (1990). Avoiding edge effects in agroforestry experiments; the use of neighbour-balanced designs and guard areas. *Agroforestry Systems* 12:173–185.

Langton S. D. & Riley, J. (1989). Implications of statistical analysis of initial agroforestry experiments. *Agroforestry Systems* 9:211–232.

Lauckner, F. B. (1989). A survey of the use of statistics in agricultural research journals. *Tropical Agriculture (Trinidad)* 66:2–7.

Lauckner, F. B. (1994). *On-Farm Animal Trials: Some Guidelines, Technical Bulletin No 24.* Trinidad: CARDI (Caribbean Agricultural Research and Development Institute).

MacDicken, K. G., Wolf, G. V. & Briscoe, C. B. (Eds) (1991). *Standard Research Methods for Multipurpose Trees and Shrubs.* Arkansas: Winrock.

Mead, R. & Riley, J. (1981). A review of statistical ideas relevant to intercropping research. *Journal of the Royal Statistical Society, A* 144:462–509.

Mead, R. & Stern, R. D. (1980). Designing experiments for intercropping research. *Experimental Agriculture* 16:329–342.

Mead, R., Riley, J., Dear, K. & Singh, S. P. (1986). Stability comparison of intercropping and monocropping systems. *Biometrics* 42:253–266.

Mettrick, H. (1993). *Development oriented research in agriculture: an ICRA textbook.* Wageningen: International Course for Development-orientated Research in Agriculture (ICRA).

Mutsaers, H. J. W. & Walker, P. (1990). Farmers' maize yields in S. W. Nigeria and the effect of variety and fertilizer: an analysis of variability in on-farm trials. *Field Crops Research* 23:265–278.

Mutsaers, H. J. W. & Walker, P. (Eds) (1991). *On-Farm Research in Theory and Practice.* Ibadan: International Institute for Tropical Agriculture (IITA).

Neeley, D., Matata, J. & Kisyombe, F. (1991). *Statistical Techniques for the Analysis of On-Farm Crop Trials.* Mexico: International Maize and Wheat Improvement Centre (CIMMYT).

Patterson, H. D. & Thompson, R. (1971). Recovery of inter-block information when block sizes are unequal. *Biometrika* 58:545–554.

Patterson, H. D., Silvey, V., Talbot, M. & Weatherup, S. T. C. (1977). Variability of yields of cereal varieties in UK trials. *Journal of Agricultural Science*, Cambridge 89:239–245.

Pearce, S. C. & Gilliver, B. (1978). The statistical analysis of data from intercropping experiments. *Journal of Agricultural Science*, Cambridge 91:625–632.

Pearce, S. C. & Gilliver, B. (1979). Graphical assessment of intercropping methods. *Journal of Agricultural Science*, Cambridge 93:51–58.

Poate, C. D. & Daplyn, P. F. (1993). *Data for Agrarian Development*. Cambridge: Cambridge University Press.

Quaas, R. L. & Pollak, E. J. (1980). Mixed model methodology for farm and ranch beef cattle testing programs. *Journal of Animal Science* 51:1277–1287.

Rao, M. R. & Coe, R. (1992). Evaluating the results of agroforestry research. *Agroforestry Today* 4:4–9.

Rao, M. R. & Coe, R. D. (1991). Measuring crop yields in on-farm agroforestry studies. *Agroforestry Systems* 15:275–289.

Rao, M. R. & Roger, J. H. (1990). Agroforestry field experiments: discovering the hard facts Part 2: Agronomic considerations. *Agroforestry Today* 2:11–15.

Rao, M. R. & Willey, R. W. (1980). Evaluation of yield stability in intercropping: studies on sorghum/pigeonpea. *Experimental Agriculture* 16:105–112.

Reid, H. J. A. & Asiedu, F. H. (1995). Biometrics in livestock research. In *Proceedings of the Sixth Annual Conference of the Jamaica Society for Agricultural Sciences, 31 May–1 June, 1995*.

Riley, J. (1984). A general form of the land equivalent ratio. *Experimental Agriculture* 20:19–29.

Riley, J. (1985). Examination of the staple and effective land equivalent ratios. *Experimental Agriculture* 21:369–376.

Riley, J. (1988). Data recording for agroforestry experiments. *Agroforestry Systems* 7:121–133.

Riley, J. (1994). Aspects of statistical technique and presentation. *Experimental Agriculture* 30:381–394.

Riley, J. & Darmi, M. (1995). A statistical survey for aquacultural research. *Aquaculture Research* 26:95–102.

Riley, J. & Smyth, S. (1993). A study of alley-cropping data from Northern Brazil. I. Distributional properties. *Agroforestry Systems* 22:241–258.

Roger, J. H. & Rao, M. R. (1990). Agroforestry field experiments: discovering the hard facts Part 1: Statistical considerations. *Agroforestry Today* 2:4–7.

Schoonmaker Freudenberger, K. & Schoonmaker Freudenberger, M. (1994). Livelihoods, livestock and change: the versatility and richness of historical matrices. In *RRA Notes No 20 Special Issue on Livestock*, 144–148. London: IIED (International Institute for Environment and Development).

Scoones, I. (1994) Browse ranking in Zimbabwe. In *RRA Notes No 20 Special Issue on Livestock*, 91–94, London: IIED (International Institute for Environment and Development).

Simmonds, N. (1986). A short review of farming systems research in the tropics (Farming Systems Series–Number 1). *Experimental Agriculture* 22:1–14.

Singh, M., Gilliver, B. & Rao, M. R. (1988). Stability of genotypes in intercropping. *Biometrics* 44:561–570.

Steiner, K. G. (1987). *On-Farm Experimentation Handbook for Rural Development Projects*. Eschborn, Germany: GTZ (Deutsche Gessellschaft für Technische Zusammenarbeit).

Stroup, W. W., Hildebrand, P. E. & Francis, C. A. (1993). Farmer participation for more effective research in sustainable agriculture. In *Technologies for Sustainable Agriculture in the Tropics. American Society of Agronomy Special Publication No 56*, 153–187. Madison, Wisconsin: American Society of Agronomy.

Tripp, R. (Ed.). (1991). *Planned Change in Farming Systems: Progress in On-Farm Research*. Chichester: John Wiley & Sons.

van Nieuwkoop, M., Defoer, T. & Sajidin Hussain, S. (1994). The contribution of rapid rural appraisals in the planning of on-farm research and extension activities. *Agricultural Systems* 44:201–216.

Werf, E. van der (1994). *Learning for Participatory Technology Development: a Training Guide 2 LEISA Principles and Technologies*. Leusden, Netherlands: ETC Foundation.

Westcott, B. (1986). Some methods of analysing genotype-environment interaction. *Heredity* 56:243–253.

Wijesinha, A., Federer, W. T., Carvalho, J. R. P. & Portes, T. D. (1982). Some statistical analyses for a maize and beans intercropping experiment. *Crop Science* 22:660–666.

Willey, R. W. & Osiru, D. S. O. (1972). Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population. *Journal of Agricultural Science*, Cambridge 79:519–529.

Zandstra, H. G., Price, E. C., Litsinger, J. A. & Morris, R. A. (1981). *A Methodology for On-Farm Cropping Systems Research*. Los Baños, Laguna, Philippines: International Rice Research Institute (IRRI).