RESEARCH SUB-PROGRAM

A LITERATURE REVIEW OF ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

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FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agri-Food Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   - **A.** Animal Manure Management (nutrients and bacteria)
   - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.

This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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The following report, approved by the Research Management Team, is reproduced in its entirety as received from the contractor, designated on the previous page.

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SCIENTIFIC AUTHORITY NOTE

Significant portions of the original hard copy version of this report are not included in this digital version because they included photocopies of numerous scientific papers.

PREFACE

In Ontario the Green Plan Program has identified a need for on-farm research to look at the field scale problems encountered by producers wanting to maintain a sustainable agricultural system on their farms. With this in mind it is anticipated that several projects will be initiated in the coming months or years. These projects will probably include a variety of study designs aimed at proving stated hypotheses and achieving specified objectives.

Research at the field scale is not new. In the past 10 to 20 years a number of research studies and demonstration projects have been reported in the literature across North America and beyond. In Ontario alone, T2000, Partners in Nitrogen, SWEEP and private industry crop variety trials all serve as examples of farm scale studies. In each case the field work is carried out in accordance with a set design and the information is then gathered, tabulated, evaluated and published.

With the initiation of the Green Plan strategy in Ontario, the science of conducting on-farm research will enter a new phase. As many workers agree, research at a systems level (whether cropping system or ecosystem) involves a wide number of variables with dynamic relationships. To ensure the most effective use of research resources it is important that the most appropriate study design be used to achieve the stated objectives. In the same manner the options for statistical analyses may not be well understood or accommodated in the study design. A review of the literature in this regard would thus allow Ontario researchers to gain a collective insight to the approaches tried by others. In this way the design and evaluation of future on-farm studies may improve with a resulting net benefit for all involved.

Initiation à la recherche agronomique sur place

La recherche agronomique en milieu réel n'est pas un phénomène nouveau. Par exemple, dans les années 40 et 50 en Amérique du Nord, on a remplacé la plupart des variétés de maïs à pollinisation libre par des hybrides à haut rendement. Au cours de cette période, comme les grandes différences de rendement entre les hybrides s'atténuaient, des comparaisons plus précises s'imposaient. Pour combler ce besoin de recherche, on a alors institutionnalisé les essais en bande au champ. Cependant, des scientifiques se sont mis à mettre en doute les mérites relatifs de ce type de recherche, par rapport à la recherche répétée et faite au hasard sur des parcelles grandement contrôlées dans quelques endroits, où la variabilité des champs était extrêmement surveillée (Duvick, 1991).

Au cours des quinze dernières années, la recherche en ferme reprend de l'importance au sein de la recherche réalisée sur les systèmes agricoles dans le but de réduire les dommages causés à l'environnement et de cerner les besoins de la société, y compris ceux des agriculteurs (Anderson et Lockeretz, 1991). La collaboration a augmenté entre les chercheurs universitaires, les agriculteurs et les organismes de producteurs, notamment grâce à un programme d'agriculture durable peu consommatrice mis en oeuvre par le ministère de l'Agriculture des États-Unis. Dans le cadre de ce programme, la collaboration est essentielle pour obtenir des fonds. Ce ministère a déjà versé des sommes considérables aux groupes qui font de la recherche en ferme (Anderson et Lockeretz, 1992).

En Ontario, c'est l'industrie agro-alimentaire qui effectue des recherches en ferme depuis quelques années, mettant l'accent sur les essais relatifs à la variété végétale et aux pesticides. Du milieu à la fin des années 80, on a entrepris en Ontario des programmes de recherche et de démonstration à long terme, notamment Tillage 2000, Partners in Nitrogen et le Programme d'évaluation et de mise au point de la technologie.

Beaucoup acquiesceront que la recherche relative aux systèmes (système de culture ou écosystème) fait entrer en jeu un nombre important de variables aux relations dynamiques. De plus, beaucoup conviendront, y compris la majorité des agriculteurs, que la recherche devient encore plus pertinente quand elle s'applique à l'échelle du champ et de la ferme. Cependant, le lien entre le lieu de la recherche et ses réalisations éventuelles n'est pas toujours bien établi. Pour que les ressources de la recherche soient bien utilisées, il importe d'employer la méthodologie qui convient pour atteindre les objectifs fixés. Par ailleurs, les options d'analyses statistiques ne sont pas toujours bien comprises ou prises en compte dans la méthodologie de l'étude.

Cet examen de la documentation sur la méthodologie de la recherche en ferme permet aux chercheurs d'avoir un aperçu des méthodes utilisées par leurs pairs et devrait contribuer à l'établissement de protocoles plus standardisés.

1.0 An Introduction to On-Farm Research

On-farm, field scale agronomic research is not a new phenomenon. For example in the 1940's and 1950's, most open pollinated corn varieties were replaced by high-yielding hybrids across North America. During this time, obvious yield differences among the hybrids became less and less apparent, requiring more precise comparisons. The field strip test was institutionalized to fill this on-farm research need. However, debate then increased among scientists as to the relative merits of conducting such research, compared with highly controlled small plot research replicated and randomized over relatively few locations with field variability tightly controlled (Duvick, 1991).

Over the past 15 years, on-farm research has received new prominence in agricultural systems research which attempts to reduce environmental damage and to increasingly serve the needs of society, including the farmer (Anderson and Lockeretz, 1991). Collaboration between university researchers, farmers and producer organizations has increased through programs such as the United States Department of Agriculture's Low-input/Sustainable Agriculture Program where such collaboration is requisite to funding approval. This agency has channelled unprecedented federal funds to groups doing on-farm research (Anderson and Lockeretz, 1992).

In Ontario, research has been carried out on farm fields for some years by agribusiness, focusing on crop variety and pesticide trials. In the mid to late 1980's, research and long term demonstration programs such as Tillage 2000, Partners in Nitrogen and the Technology Evaluation and Development Program (SWEEP) were initiated in Ontario.

Many would agree that research at a systems level (whether cropping system or ecosystem) involves a wide number of variables with dynamic relationships. Many would also agree, along with the majority of farmers, that research receives an added and a needed degree of relevance when seen to be applicable at a field and a farm scale. However, the connection between where research takes place and what it can achieve is not always clear. To ensure an effective use of research resources, it is important that the most appropriate study design be used to achieve stated objectives. Similarly, the options for statistical analyses may not be well understood or accommodated in the study design.

This review of the on-farm research methodology literature allows researchers to gain a collective insight to the approaches tried by others, and should help to streamline on-farm research techniques and efforts into more standardized protocols.

1.1 Study Objectives

The purpose of this literature review is to identify the study design and data evaluation methodologies used by on-farm researchers to date and to comment (if possible) on their potential impact on study objectives. Specific project objectives are:

1. To identify relevant sources of information with some emphasis on work carried out in North America since 1975;

2. To categorize and describe on-farm study designs and data evaluation methods, and;

3. To comment (if possible) on the potential impact of selected study design and data evaluation options on study objectives.

1.2 Methodology

Before proceeding with the study methods, it was first necessary to define the study scope. Although work on a global scale was of interest, emphasis was placed on relevant research conducted in North America since 1975. It was noted at the outset of this investigation that there is a significant amount of on-farm research conducted in developing countries, primarily due to the fact that farms in the less developed world are typically small and more labour intensive. Research institutions are often not as well established in developing countries either. While there is value in reviewing on-farm research techniques in such environments, it was decided that on-farm research methods used in developed countries, particularly in North America, would have more direct application.

The scope of this work was further defined by identifying the disciplines from which on-farm research papers would be gathered. This study focused on on-farm research which dealt with aspects of field crop production and avoided the area of livestock production. Within crop production, disciplines included: agronomy, crop science, horticulture, soil science and agricultural engineering (soil and water). Research which dealt with either production questions or environmental quality questions were eligible for inclusion in this review. On-farm surveys, if they had an environmental quality or crop production perspective were also considered as being suitable material. Both single discipline and multi-discipline research work were considered relevant if they had an on-farm component.

Definition of On-Farm Research:

For the purpose of this review a study was considered to be on-farm research if the work was located on a commercial farm where at least the potential for farmer participation existed.

As a result of the above definition, studies conducted on research stations were omitted.

While consideration of **parameter specific** data collection and sampling methodologies was not within the scope of this review, it was noted that occasionally papers would discuss sampling strategy for on-farm research. Since this is significantly influenced by the design of the study it was decided to briefly touch on this subject within the main report.

1.2.1 Identifying Relevant Researchers and Their Research

A number of methods were used to identify researchers and research papers which fell within the scope of study. The first step involved conducting an in-house search of literature compiled by the study team and located in the Ecologistics Limited library. This effort yielded a few specific papers and, more importantly, provided the study team with a number of names and contacts from which to begin the external search.

The external search began close to home initially. On-farm research known to have been conducted in Ontario and for which a report was available for public distribution (eg. SWEEP TED projects) were gathered. Contact was also made with key on-farm researchers at the University of Guelph and individuals within industry (eg. Pioneer Hi-Bred Limited) who in turn directed the team to researchers at other North American institutions involved in on-farm research. Through such networking, numerous personal contacts were made which included not only researchers, but also extension personnel, farmers and individuals and groups interested in the topic of on-farm research. The contacts described their work, provided us with material they thought would be relevant to the study as we had outlined it by phone or alternatively, directed us to the research publications in which their experience in on-farm research had been published. The advantages and disadvantages of using the on-farm environment to undertake research were discussed as well if the researchers were interested in expressing their opinions on this. A detailed listing of all individuals contacted, their affiliation and their telephone number for future reference, is provided in Appendix A.

The study team took advantage of existing information resource centres to locate relevant research work. The Soil and Water Conservation Information Bureau (SWCIB) was contacted. They performed a computer search of the AGRICOLA database and their own ASKELTON database in order to locate on-farm research. Similarly, the Ecological Agriculture Project (EAP) staff, stationed at MacDonald College in Montreal, conducted a literature search on the topic.

A simple query of databases using key words and combinations of key words such as "on-farm", "research", "experimental design", "replicated plots", "statistics", "large plot", "control plot", "multi-location" and "multi-year", often proved unfruitful. This was because papers describing an on-farm research technique used and the results obtained, for the majority of cases, did not identify themselves as being on-farm studies in the paper's title or key-word listing. The only definitive way of determining whether a paper was conducted on-farm according to the definition of this study was to actually locate the published paper and scan the paper's section outlining the methods used in conducting the research.

The following journals were reviewed as far back as 1975 in order to identify published research reports which fell within the study scope:

Agronomy Journal
Agriculture, Ecosystems and the Environment
American Journal of Alternative Agriculture
Biological Agriculture and Horticulture
Canadian Agricultural Engineering (Soil and Water section)
Canadian Journal of Plant Science
Canadian Journal of Soil Science
Crop Science (Crop Ecology, Production and Management section)
Journal of Environmental Quality
Journal of Production Agriculture
Journal of Soil and Water Conservation
Soil Science Society of America Journal (Soil Fertility and Plant Nutrition and Soil and Water Management and Conservation sections)
Transactions of the American Society of Agricultural Engineers (Soil and Water section)

In general, very few papers describing on-farm research were found before 1985 in any of these journals, indicative of the more recent interest in conducting research on-farm. Some of the older, more traditional journals had very few on-farm research studies at all. When papers were found that matched the scope of this study, they were categorized according to research type (small plot, large plot or observational) in preparation for a more detailed review.

Noting that on-farm research was a more recent trend, a review was made of the 1991 and 1992 Agronomy Abstracts to identify researchers who may be conducting on-farm research but for which results had not yet been published. The Agronomy Abstracts include presentations made at the summer meetings of the American Society of Agronomy, The Crop Science Society of America and the Soil Science Society of America. Like the literature search approach, a review of a project's abstract often did not reveal the on-farm nature of the work. Research which implied that work was being done on-farm was noted and the researcher in charge was contacted to verify the study's on-farm nature. If it was an on-farm study and a paper describing the work was available, a copy of the paper was requested.

With a collection of different on-farm research papers gathered, in the manner described above, a description and critique of the techniques used could commence. This report begins with an overview summary of on-farm research literature gathered in this study with respect to definitions and related working concepts (Section 2.0). Section 3.0 contains a summary of each type or category of on-farm research with typical examples from the literature located in Appendix B. The design and data evaluation methods used by the researcher(s) in these examples have been reviewed and comments on their approach provided. References in Appendix B have been grouped according to category on the assumption that this will make it easier for the reader to review the approaches used between and within categories. In Section 4.0 a comment is made regarding sampling strategies for on-farm research studies and the reader is referred to a few relevant examples in the literature.

2.0 Overview of Supporting On-Farm Research Literature

2.1 What is On-Farm Research and Who is Doing It?

Research that is conducted on-farm is often assumed to be related to "alternative" agriculture, because the source of such ideas is frequently the farmers themselves. One often hears that it is the farmers who encourage researchers to confirm observations or techniques that have been made or developed on farm. Lockeretz (1987) notes that "alternative" is a time-dependent concept, and that what is today's standard practice was yesterday's alternative. He continues by saying that,

> "the choice of a research site should be dictated only by the logic and the structure of the research question, and not be coupled to whether the system being investigated is or is not widely accepted."

The term "on-farm research" means different things to different people. A root definition is provided by Hildebrand and Poey (1985): "on-farm research is characterized by farmers' participation on their own land". The degree of farmer participation can vary widely, however, depending on the objectives of the particular study. It can range from traditional variety tests or fertilizer yield response trials where the farmer's involvement is limited to giving permission to use his property and performing normal field operations, to farmer-initiated and managed trials where the researcher becomes the collaborator (Anderson and Lockeretz, 1991; Hildebrand and Poey, 1985). Groups identified as conducting on-farm research include: farmer organizations created specifically for this purpose; other grass-roots organizations that do agricultural research and hire staff who are not commercial farmers; agribusiness, and; publicly-funded research administered by colleges, universities and government agencies.

The literature recognizes that farmers and researchers may well bring different expectations and objectives to on-farm research. Farmer-initiated projects tend to be short-term, tend not to focus on basic research, and move from general to specific principles about what will work on "my" farm. Conversely, researcher-initiated projects with low farmer involvement tend to move in the opposite direction, focusing on basic research and addressing the questions about what the on-farm results can say about general agricultural processes (Anderson and Lockeretz, 1991).

Gerber (1992) outlines characteristics of on-farm research that are important to farmers and researchers. For farmers, such characteristics include:

- plots of single or multiple machine widths;
- plot size large enough to make a visual impact;
- treatments that will involve only modest investments or changes in equipment;
- the possibility of improving yields or profitability; and,
- experimental conditions that represent "their" farms and farming operation.

For researchers, the following characteristics of on-farm research are generally given priority:

- valid experimental design;
- uniformity of non-treatment variables;
- accessibility of the research site, and;
- experimental conditions that represent a major production region so that results can be generalized.

Effective on-farm research can be seen as balancing the demands for high local relevance with high regional or global validity. The blending of the skills and knowledge of both farmers and researchers is essential; to have "one group call all the shots clearly is not the key to a socially desirable research system . . . both can make an important contribution to promoting true agricultural sustainability" (Lockeretz and Anderson, 1990). Partnering is clearly called for to facilitate the on-farm research process; "participatory on-farm research enables the farmer, in partnership with other experts, to conceive, design and carry out research on the farm" (Duvick, 1991).

Lockeretz and Anderson (1991) address the unwarranted assumptions that lie behind the perception that on-farm research is inferior to station research. They stress that on-farm research can have any degree of objectivity and is fully compatible with hypothesis-testing methods. It is argued that these perceptions are reinforced by non-research activities such as demonstrations and observations not being clearly distinguished from research. Demonstrations are used to communicate and persuade, whereas research seeks to answer a question which will require randomization and replication over time and/or space.

It should be recognized however that the concept of on-farm research has been accepted and used most widely among resource-poor farmers in developing countries through Farming Systems Research and Extension (FSR/E). It is an approach to technology generation, evaluation and delivery that is farmer-oriented, agro-biological and supported by the socioeconomic sciences (Hildebrand and Poey, 1985; Farrington and Martin, 1988; Petersen, 1976). Although there may be some overlap in concepts with North American-based studies, a further review of this literature is left to the reader since the focus of this review rests on relatively large scale, highly mechanized and less labour intensive farming practices.

2.2 Why and When is On-Farm Research Most Appropriate?

The clearest reason for on-farm research centres around the need for agricultural research to be relevant and applicable to production areas that are outside the "artificial" conditions inherent to research stations/experimental farms (Lockeretz, 1987; Thornley, 1990). For example, because machine-harvested, field-scale plots may miss lodged stalks, corn yields are often consistently lower than from hand-harvested station-type plots.

The literature stresses the opportunities for on-farm and on-station research to complement each other. For example, a possible sequence of research activities includes: exploratory research on-farm to determine the range of practices in use and their effectiveness; on-station research could examine why some of the most promising practices work, and screen out some of the riskier practices (eg. weed infestation problems that farmers do not want); then return to the farm context to verify the effectiveness of a smaller set of alternatives (Anderson and Lockeretz, 1991).

Lockeretz (1987) outlines situations in which working farms are particularly well-suited for research activities.

1. When obtaining data on particular soil types or other physical conditions that are not available on the experiment station.

2. When studying phenomena that must be examined on a larger tract than is available on an experimental station.

3. When analyzing systems that involve interactions among several individual enterprises or that intrinsically are of a whole-farm nature (eg. nutrient cycling, water quality impacts from surface runoff).

4. When comparing a system's performance under realistic farm conditions to its performance under experimental conditions.

5. When evaluating production techniques that are particularly sensitive to management skill.

6. When studying the long-term effects of a production method that has already been in use on a farm for a long time (eg. long-term build up of soil nutrients or organic matter).

7. When analyzing a production method or management system that is already practised by some farmers but has not received attention from researchers.

Allen (1993, pers.comm.) also adds to the above list the situation where it is desirable to compare treatments across many environments, such as when comparing the stability of cultivars across environments.

These situations are affirmed by Anderson (1992) and Shore, Auburn and Baker (1992) who also identify socio-political and communication reasons for conducting on-farm research.

The Practical Farmers of Iowa (PFI), a nonprofit educational organization, has conducted on-farm research and demonstration trials around the state since 1987 (Exner and Rosmann, no date). This organization has recognized a pressing need for an on-farm research methodology that:

- "empowers farmers to quantitatively evaluate alternative agricultural practices;
- produces results considered credible by both agronomists and other farmers, and;
- is *farmable* using existing equipment and with a minimum of additional effort."

The PFI have identified a paired-comparison research process that meets their objectives with respect to their stated on-farm research needs (discussed in greater detail in Section 3.0). The Rodale Institute and Washington State University (Cooperative Extension) have published guides to assist farmers in planning, executing and analyzing on-farm strip/paired comparison research trials (Janke et al., 1990; Washington State University, no date).

3.0 Design and Data Evaluation Methods

Three study types or categories (small plot, large plot and observational) were identified during this review. Where appropriate, sub-categories were also identified. A definition of each study type was suggested which indicates a scale and experimental unit on a relative basis.

The level of farmer cooperation in the study was rarely mentioned in the literature and as a result was not included in the category definitions.

A summary of design and data evaluation specifications per category including strengths and weaknesses follows. Examples from the literature and additional references are found in Appendices B and C.

It should be noted that the fundamental principles of experimental design are just as important in designing on-farm experiments as for research station or laboratory research (Cochran and Cox, 1957). Proper replication and randomization are necessary to ensure validity of the conclusions. Blocking and the judicious choice of covariates can dramatically increase the precision with which the experiment compares treatments. Focused study objectives are crucial in guiding the choice of an experimental design and subsequent statistical analysis.

4.0 Sampling Strategies

Once the research design is developed and before data can be evaluated the researcher must determine what sampling strategies are most appropriate for acheiving their objectives. In small plot studies individual plots within replicates may be very uniform in all aspects except the treatment. In large plot and observational studies this is rarely the case. Within one experimental (treatment) unit or plot, soil type, drainage and slope (to mention only a few) can vary significantly from one sampling location to the next. What is the strategy for ensuring that the samples are truly representative of the treatment or condition effects?

A number of authors have indicated their sampling strategies within the methods section of their papers. The reader is referred to the documents found in Appendix B and the references listed in Appendix C for further guidance. The following references may be of particular interest in this regard.

Aspinall, J.D. and R.G. Kachanoski. 1993. Tillage 2000: 1985-1990 Soil Conservation. Final Report. Ontario Ministry of Agriculture and Food. Department of Land Resource, University of Guelph, and the Ontario Soil and Crop Improvement Association and the Soil and Water Environmental Enhancement Program. 68 pp.

Battiston, L.A. and M.H. Miller. 1983. Soil Erosion and Soil Productivity in Ontario. Department of Land Resource Science, University of Guelph. Guelph, Ontario. 51 pp. (see Appendix B)

Beak Consultants Ltd. and Ecologistics Limited. 1994. Pilot Watershed Study: Final Report. Soil and Water Environmental Enhancement Program. Agriculture Canada. 7 vol.

Janke, R., D. Thompson, C. Cramer and K. McNamara. 1990. A farmer's guide to on-farm research. Rodale Institute. 21 pp.

SUMMARY

ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type:	Small Plot
Definition:	Where all treatments are applied and replicated at each field site using research plot scale equipment and techniques (i.e. non-commercial scale equipment and/or treatment application techniques).
Purpose:	To determine the effect(s) of specific individual variables or combinations thereof on one or more parameters of interest; often used to determine optimum crop production practices
Design:	
Temporal	- 1 or more years
Spacial	- 1 or more locations
Lay out	- majority are randomized complete block design (RCBD) - other lay outs include completely randomized design (CRD) and split plot design
Data Evaluation Methods:	Use methods appropriate to the study design and objectives (see example in Appendix B); the methods of analysis should not depend on where the research is conducted
Strengths:	- variables can be controlled to a greater degree - the effects of variations to one or a few factors can be determined - on-farm setting can take advantage of field conditions established over several years - a larger number of treatments and more complex treatment arrangements (e.g. factorials) can be accommodated
Weaknesses:	- treatment management may not reflect field scale management conditions - results may not extrapolate directly to field scale results - results may not be credible to producers - more effort per hectare under experiment and thus less likely to be replicated over several locations and/or years
Examples:	See Appendix B
References:	See Appendix C

SUMMARY

ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Large Plot

Definition:

Where treatments are applied using commercial scale equipment and/or treatment application techniques are representative of field scale practices.

i) Whole Field/Farm/Watershed

Where treatments are applied on the basis of a whole unit area and treatment boundaries coincide with other accepted boundaries. One whole unit area represents one treatment, applied one time.

ii) Field Strips

Where the length of the treated area equals the length of the field to facilitate field management practices but the width of the treated area is set to facilitate the needs of the study. Each treatment is applied at least once in each field.

Purpose:

To determine the effect(s) of specific individual variables or combinations thereof on one or more parameters of interest;

Complex combinations of variables may be identified as crop production systems which in turn are compared against either other;

Often used to determine optimum crop production practices to achieve either economic or environmental goals or both.

Design:

i) Whole Field/Farm/Watershed

<u>Temporal</u> - 1 or more years

<u>Spacial</u> - 1 or more locations

<u>Lay out</u> - majority are a paired comparison of two treatments; other lay outs include randomized complete block design (RCBD) involving three or more treatments

ii) Field Strips

<u>Temporal</u> - 1 or more years

<u>Spacial</u> - 1 or more locations

<u>Lay out</u> - majority are RCBD with 2 or more treatments; often involves a split plot design

...2

SUMMARY

ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Large Plot

(Large plot Cont'd)

Data Evaluation Methods:

Use methods appropriate to the study design and objectives (see example in Appendix B); the methods of analysis should not depend on where the research is conducted.

Strengths:

- on-farm setting can take advantage of field conditions established over several years
- treatment management may better reflect field scale management conditions
- results may extrapolate directly to field scale results
- results may be more credible to producers
- since these studies are often replicated across a large region, their conclusions have a broader applicability. For example herbicide trials run by an agricultural chemical firm may be replicated at 50 sites across all of western Canada.

Weaknesses:

- treatment application and some methods of data collection are generally less accurate and precise than that obtained using hand-held or small scale equipment; this may result in a greater variation in results and require the inclusion of more years and/or locations to establish trends
- a limited number of treatments (generally 2-12) can be evaluated at one time
- the size and complexity of whole field/farm/watershed studies often limits the number of whole plot replications such that the results often amount to case studies where statistical evaluations of selected parameters are performed
- treatment effects may be more likely to be confounded by other factors

Examples: See Appendix B

References: See Appendix C

SUMMARY

ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type:	Observational Plot
Definition:	Where a condition and effect relationship is examined within the boundaries of an ongoing farm enterprise. While site selection criteria may be stringent, no manipulation of the condition to suit the needs of the study is involved.
Design:	
Temporal	- 1 or more years
Spacial	- 1 or more locations
Lay out	- these studies are laid out to best observe the condition and effect; the potential variations on lay out are large
Data Evaluation Methods:	Methods are dependant on sampling structure, objective, data type and scientific knowledge. Analysis of covariance however can play a major role in the control of concomitant variation and adjustment for bias.
Strengths:	- farm setting can take advantage of field conditions established over several years - site management reflects actual field scale management conditions to producers- results may be used as direct indicators of field scale expectations - results are generally more credible to producers - site selection criteria can be used to determine comparable conditions with the resulting data- this approach is an alternative to designed studies which may be prohibitively expensive, unethical, too time consuming or simply impossible (e.g. one cannot replicate a study of the environmental impact of a nuclear power plant)
Weaknesses:	- the stringency of site selection criteria; this may result in a greater variation in results and require the inclusion of more years and/or locations to establish trends - a limited number of treatments (generally 2-12) can be evaluated at one time - the size and complexity of whole field/farm/watershed studies often limits the number of whole plot replications such that the results are often amount to case studies where statistical evaluations of selected parameters are performed - control of concomitant variation. Many other factors, other than those the investigator is interested in, are likely to vary among sampling units. Controlling these variables or properly adjusting for them is a major problem.
Examples:	See Appendix B
References:	See Appendix C

5.0 In Summary

The popularity of on-farm research continues to grow. Taken in the proper perspective on-farm research should not replace traditional methods of agricultural research but rather complement them. Partnerships with agricultural producers, when the dialogue is candid and informed, can lead to research that directly addresses the objectives of all concerned. Those responsible for choosing study type, research design and which methods of data evaluation best meet study objectives, must however be aware of the options available and the strengths and weaknesses of each approach. A review of this document, the referenced literature and/or contact with those researchers listed should assist in ensuring that the best use of resources has been accomplished.

APPENDIX A

CONTACT LIST FOR ON-FARM RESEARCH LITERATURE SEARCH

APPENDIX A

Contact List for On-Farm Research Literature Search

Name	Affiliation	Telephone
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Name	**Affiliation**	**Telephone**
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APPENDIX B
EXAMPLES OF DESIGN AND DATA EVALUATION METHODS

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B1.0 SMALL PLOTS

The following section provides examples that may assist the reader in developing their own research program.

Subsection B1.1 includes examples where the authors employed the appropriate design and data evaluation methods to meet stated objectives. These may be used as templates from which the reader may design their own study.

Subsection B1.2 includes an additional range of examples where comments are made on the methods used by the authors to achieve their objectives.

Both subsections are meant to assist the reader in understanding some of the points to consider when setting up their own research program and in no way represent an in depth critique of the work represented.

EXAMPLE B1.1

ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Small Plot

Title: Relationships between leaf nitrogen concentrations and the nitrogen status of corn (Cerrato and Blackmer, 1991)

Objective: to evaluate the sensitivity of leaf nitrogen (N) concentrations at silking as an indicator of the N status of corn

i) Variable - rate of N fertilizer (0-300 lb N/ac) applied to corn

ii) Parameters of interest
- N concentration in leaf (%)
- corn grain yield (bu/ac)

Design:

i) Temporal - 2 years; 1985 and 1986

ii) Spatial - 6 locations; 4/1985 and 2/1986

iii) Lay out - RCBD with three replications at each location; 10 fertilizer rate treatments/replication

Data Evaluation Methods:

i) Level of application
- small plots

ii) Statistical method
- regressions of yield to rate of fertilizer, leaf N to rate of fertilizer and yield to leaf N
- six regression models were used including linear, linear plus plateau, quadratic plus plateau, quadratic, exponential and square root

Were the design and statistical methods appropriate for meeting study objectives?

Yes.

Reference: Published paper follows.

EXAMPLE B1.2-1

ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Small Plot

Title: Performance of sod-seeded temperate legumes in grass dominant swards (Kunelius *et. al*. 1984)

Objective: - to determine the performance of several forage legumes when sod-seeded both in small plot (field experiments) and large-scale farm trials

i) Variable
- Field - 8 forage legume cultivars representing 5 species sod-seeded into pasture
- Farm - 4 forage cultivars representing 3 combinations of legume/grass species

ii) Parameters of interest: Field and Farm
- dry matter yield
- botanical composition
- dry matter and total nitrogen content

Design:

i) Temporal
- Field: 4 years/ Site 1: 1978 - 1981; Site 2: 1979 - 1982
- Farm: 2 years/ Sites 1,2,3: 1981-1982

ii) Spatial
- Field - 2 locations
- Farm - 3 locations

iii) Lay out
- Field - RCBD with 5 replications at each location; 7 or 8 forage legume treatments/replication
- Farm - RCBD with 2 replications at each location; 3 to 5 forage species and nitrogen treatments/replication

Data Evaluation Methods:

i) Level of application - small plots

ii) Statistical method - standard analyses for RCBD combined over 2 (or 3) locations

Were the design and statistical methods appropriate for meeting study objectives?

Yes

Reference: Published paper follows.

B2.0 LARGE PLOTS

The following section provides examples that may assist the reader in developing their own research program.

Subsection B2.1 includes examples where the authors employed the appropriate design and data evaluation methods to meet stated objectives.

Subsection B2.2 includes a range of examples where comments are made on the methods used by the authors to achieve their objectives.

Both subsections are meant to assist the reader in understanding some of the points to consider when setting up their own research program and in no way represent an in depth critique of the work represented.

EXAMPLE B2.1-1
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Large Plot

Title: The on-farm research program of practical farmers of Iowa (Thompson and Thompson, 1990)

General: This paper promotes the use of randomized replicated side-by-side comparisons on farmers' fields to document the effects of new ideas at the farm level.

i) Variable - generally production oriented e.g. nitrogen (N) management, weed control, tillage system, effects of cover crops

ii) Parameters of interest - changes with variable studied

Study Specifics:

Objective: N trials: to determine the effect of reduced N fertilizer application rates on corn grain yield
Weed control trials: to determine the effect of herbicide use on weed pressure and crop yield in the ridge tillage system

i) Variable N trials: rate of N fertilizer applied to corn
Weed control trials: use of herbicide in ridge till system

ii) Parameters of interest
N trials: grain corn yield (bu/ac)
Weed control trials: weed pressure (plants/acre), corn and soybean yield (bu/ac)

Design:

i) Temporal N trials: 3 years; 1987-1989
Weed control trials: 3 to 6 years; 1984-1989

ii) Spatial N trials: 35 trials over 22 locations
Weed control trials: 28 trials over 12 locations during 1987-1989
1 trial over 1 location during 1984-1989

iii) Lay out N trials: side-by-side comparison with 6 replications at each location; 2 treatments/replication
Weed control trials: side-by-side comparison with 6 replications at each location; 2 treatments/replication

Data Evaluation Methods:

i) Level of application - large plots i.e. field strips
ii) Statistical method - ANOVA and an F-test

Were the design and statistical methods appropriate for meeting study objectives?

Yes. Overall this appears to be a very useful and cost effective design for farmers fields, at least for some types of research.

<u>Note:</u> 1. The calculation of required sample size appears to be faulty. The paper uses $LSD = t \cdot \sqrt{2}s/\sqrt{r}$ but appears to ignore $\sqrt{r}$.
2. The Am. J. of Alternative Agriculture, vol. 6, no.2, 1991 pp 87-88 includes a comment and response regarding this paper that is worthwhile considering.

Reference: Published paper follows.

EXAMPLE B2.1-2
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Large Plot

Title: Effects of control-based adjustments on precision of large-plot yield trials (Schmitt, Openshaw and Davis, 1992)

Objective: - to investigate the effect of adjustments based on nearby control plots on the precision with which grain yield is measured in large plot trials

i) Variable - experimental design

ii) Parameters of interest
- error variances per experimental design as calculated from corn grain yield (bu/ac) data

Design: field strips replicated at each site

i) Temporal - 2 years; 1988 and 1989

ii) Spatial - 13 locations; 5/1988 and 8/1989

iii) Lay out - similar to RCBD (although not analyzed as such)
- treatments included the strip design (nonreplicated strips in which the number of strips equals the number of treatments (k)) and the tester design (nonreplicated strips having a common, systematic control treatment placed in every second or third plot in which the number of plots equals 1+(2k) if the tester is in every other plot, or 1+(5k) if the tester is in every third plot)
- see following article for diagram

Data Evaluation Methods:

i) Level of application
- large plots i.e. field strips

ii) Statistical method

The error variance for a typical strip trial is normally not estimable due to the lack of replication. However, in this study, the error associated with the area containing a nonreplicated strip design was approximated from the within-genotype variance, pooled over the four genotypes, the standard analysis used for completely randomized designs (CRD).

The error variance for the tester design was approximated as the residual error from the CRD analysis of the adjusted plot values. This estimate applies to the same area as did the corresponding estimate for the strip design.

This paper compares precision with and without adjustment using "tester" plots. It was found that in 14 of 19 sites, unadjusted values were more precise than adjusted values.

"By devoting approximately the same effort and amount of resources required for inclusion of the tester to an additional replication, error variance of the treatment means for the unadjusted strip design could have been reduced by at least one-half."

Were the design and statistical methods appropriate for meeting study objectives?

Yes. This is a useful paper for design of "on-farm" research trials.

Reference: Published paper follows.

EXAMPLE B2.2-1
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Large Plot

Title: Maize yields and soil nutrient levels with and without pesticides and standard commercial fertilizers (Lockeretz *et al.*, 1980)

Objective: 1. to obtain more reliable data on maize yields on organic vs. conventional fields by direct measurements on matched pairs of such fields
2. to compare the effects of organic and conventional practices on soil properties

i) Variable - crop management system (organic vs conventional)

ii) Parameters of interest
- grain corn yield (bu/ac) - incidence of *Diplodia* stalk rot
- stalk lodging - grain corn crude protein content
- soil organic carbon content - soil total nitrogen content
- soil available phosphorous - soil exchangeable potassium
- soil cation exchange capacity - pH

Design:

i) Temporal - 4 years; 1975-1978

ii) Spatial - Iowa, Minnesota, Illinois, Nebraska, Missouri
- 26 paired fields over space and time

iii) Lay out - paired fields, approximately 0.5 km apart

Data Evaluation Methods:

i) Level of application - field

ii) Statistical method - paired t-test

Were the design and statistical methods appropriate for meeting study objectives?

Generally yes. The authors appear to have done a paired t-test on 26 pairs but they also compared individuals pairs using subsampling. This latter approach does not seem to be useful.

Reference: Published paper follows.

EXAMPLE B2.2-2
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Large Plot

Title: Grazing reclaimed mined land seeded to native grasses in Wyoming (Schuman *et al.*, 1990)

Objective: 1) to compare the effect of 2 grazing intensities on the vegetation production, plant community response, and annual gains of yearly steers on mined land reclaimed with native grasses
2) to determine the potential of this land to meet its post-mining land use i.e. grazing by domestic livestock

i) Variable
- stocking rate
- year

ii) Parameters of interest
- forage production and use (various parameters)

Design:

i) Temporal - 6 years; 1980 - 1985

ii) Spatial - 4 sites in one area (Shirley Basin of southeastern Wyoming)

iii) Lay out
- 2 pastures - heavy stocking
- 2 pastures - light stocking

Data Evaluation Methods:

i) Level of application
- pastures as large plots

ii) Statistical method
- randomized block design using analysis of variance techniques, with reported observations over time.
- The pasture is the experimental unit. However, it is likely (but not clear) that the authors used subsampling within pastures as additional replications.

Were the design and statistical methods appropriate for meeting study objectives?

Probably. As an alternative a larger number of pastures, perhaps with less intense within pasture sampling, might have been beneficial.

Reference: Published paper follows.

B3.0 OBSERVATIONAL PLOTS

The following section provides examples that may assist the reader in developing their own research program.

Subsection B3.1 includes examples where the authors employed the appropriate design and data evaluation methods to meet stated objectives.

Subsection B3.2 includes a range of examples where comments are made on the methods used by the authors to achieve their objectives.

Both subsections are meant to assist the reader in understanding some of the points to consider when setting up their own research program and in no way represent an in depth critique of the work represented.

EXAMPLE B3.1-1
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Observational

Title: Soil erosion and soil productivity in Ontario (Battiston and Miller, 1983)

Objective:
1) evaluate the use of colour and false colour infra-red aerial photography in determining the extent and degree of soil erosion
2) determine the changes in physical and chemical soil properties that occur as a result of soil erosion on a range of Ontario soils
3) determine the magnitudes of erosion related yield reductions and relate these yield reductions to changes in physical and chemical soil properties that have occurred as a result of erosion

i) Variable - soil erosion phase within a cropped field

ii) Parameters of interest
- approx. 50 measured or derived soil and crop parameters were obtained for each plot at each site

Design:

i) Temporal - 2 years; 1982 - 1983

ii) Spatial - Wilmot and Wellesley Township, Regional Municipality of Waterloo, City of Guelph
- 14 sites in total

iii) Lay out - comparison of erosion phases (non, slight, moderate, severe, depositional). All phases to occur within a site = 6 (1982) or 3 (1983) plots per phase per site.

Data Evaluation Methods:

i) Level of application
- Observational

ii) Statistical method
- plots sampled within a field

Were the design and statistical methods appropriate for meeting study objectives?

Yes. The data do not appear to have been combined across sites (each site was regarded as an experiment). However, patterns were similar across sites.

Reference: Published paper follows.

EXAMPLE B3.2-1
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Observational

Title: Nitrate in drinking water wells in Burlington and Mercer counties, New Jersey (Murphy, 1992)

Objective: - to investigate nitrate levels in drinking water wells in several land use areas throughout 2 geographic regions in the state

i) Variable
- well depth
- fertilizer used
- distance to septic tank

ii) Parameters of interest
- nitrate
- nitrogen content of water

Design:

i) Temporal - spring 1990

ii) Spatial - 343 volunteer farms in two counties in New Jersey

iii) Lay out - random sampling within the study area but well owners were required to volunteer in response to public announcements and actively participate in the sampling

Data Evaluation Methods:

i) Level of application
- Observational

ii) Statistical method
- to determine differences in populations, a Mann-Whitney 2-sample nonmatched nonparametric test was used
- to determine correlations Spearman's rank correlation for nonparametric distributions was used

Were the design and statistical methods appropriate for meeting study objectives?

More informative methods, such as regression, are available.

Reference: Published paper follows.

EXAMPLE B3.2-2
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Observational

Title: Riparian forest communities and their role in nutrient conservation in an agricultural watershed (Fail, Hains and Todd, 1987)

Objective: - to determine the importance of riparian forest vegetation in modifying the nutrient content of water moving from agricultural areas to nearby streams

i) Variable - agricultural area contiguous or not contiguous with the riparian forests

ii) Parameters of interest
- biomass and production
- tissue nutrient concentration
- tissue nutrient pools and accretion rates

Design:

i) Temporal - Sampled at one time only

ii) Spatial - 5 study sites on one watershed

iii) Lay out - 3 test sites; 2 reference sites

Data Evaluation Methods:

i) Level of application
- Observational; sites within a watershed

ii) Statistical method
- 2 sample t-test

Were the design and statistical methods appropriate for meeting study objectives?

No. The number of sites was much too small. Better attempts at controlling variability (through pairing or using covariates) could also have been useful.

Reference: Published paper follows.

EXAMPLE B3.2-3
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: Observational

Title: Plant nutrient flow in the managed pathways of an intensive dairy farm (Bacon *et al*., 1990)

Objective: - to measure the quantity, spatial and temporal dimensions of plant nutrient flow in the managed pathways of an intensive crop and livestock dairy farm

i) Variable - not applicable

ii) Parameters of interest
- all activities and materials affecting and/or indicating nutrient levels

Design:

i) Temporal - 2 years; 1985-1986

ii) Spatial - one farm site

iii) Lay out - not applicable

Data Evaluation Methods:

i) Level of application
- Observational

ii) Statistical method
- The flow of N, P and K nutrients between fields and livestock units and on and off farm was described.

This study is in the nature of a case study since there is no real replication, nor treatments to be compared.

Were the design and statistical methods appropriate for meeting study objectives?

Yes.

Reference: Published paper follows.

B4.0 EXPOSITORY PAPERS

The following examples from the literature provide opinions on design and data evaluation methods for on-farm research.

The author's opinions often merit consideration when setting up new on-farm research programs.

EXAMPLE B4.0-1
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: General - A discussion on replicated small plot/large plot trials

Title: Experimental designs to evaluate crop response on adjacent soil mapping units (Nelson and Buol, 1990)

Objective: - to identify the design principles involved in setting up field experiments to compare the responses to different management treatments of crops grown in areas within different soil mapping units and to suggest experimental designs for this purpose.

i) Variable - not applicable

ii) Parameters of interest
- not applicable

Design: This is a theoretical paper, discussing designs when one factor is observational (soil mapping units or erosion class) and the other is randomized (treatments) and the interaction is of primary importance.

If the inferences are to apply to more than one environment and if a test of the main effect of the area represented by the soil mapping unit is desired then the following is recommended:

i) Temporal - 2 or more years

ii) Spatial - 2 or more locations

iii) Lay out - 3 variations of a split plot design, each involves a factorial arrangement of treatment x soil mapping unit

Data Evaluation Methods:

i) Level of application
- general; could be applied to small and large plots

ii) Statistical method
- The paper presents three designs which are variants of split plots and their ANOVA tables. It also discusses the combining of these experiments across locations and years.

Were the design and statistical methods appropriate for meeting study objectives?

Yes.

Reference: Published paper follows.

EXAMPLE B4.0-2
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type: General

Title: Analyzing field-measured soil-water properties (Nielson *et al.*, 1983)

Objective: - to provide a qualitative review of statistical concepts not usually covered in "aggie" statistics
- to provide an opinion of the questions future research shall answer

i) Variable - not applicable

ii) Parameters of interest
- not applicable

Design: - not applicable

Data Evaluation Methods:

This is an expository paper

The authors provide a survey of "time-series" statistical methods which can be applied to spatial auto correlation in soil and crop measurements.

Methods addressed include:
- spatial autocorrelation function
- spatial cross-correlation between two responses
- spectral and co spectral analysis of spatial responses
- semi variograms and kriging
- cross - semi variograms and co kriging between two spatial responses

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-- - scaling and stochastic equations

Were the design and statistical methods appropriate for meeting study objectives?

Author opinions are provided.

Reference: Published paper follows.

Reprinted from *Agricultural Water Management*, 6(1983), Nielsen, D.R., Patricia M. Tillotson and S.R. Vieira, Analyzing Field-Measured Soil-Water Properties, p93-109, with kind permission from Elsevier Science B.V., Amsterdam, The Netherlands

EXAMPLE B4.0-3
ON-FARM RESEARCH DESIGN AND DATA EVALUATION METHODS

Study Type:	General
Title:	On-farm experiment designs and implications for locating research sites (Rzewnicki *et al*., 1988)
Objective:	to determine whether experimental error was controlled on a wide variety of agricultural fields that used plots larger than normally used by researchers
i) Variable	- grain yields from different treatments and experiments
ii) Parameters of interest	- coefficient of variation (CV)
Design:	- not applicable

Data Evaluation Methods:

This is an *expository* paper. It argues for large farm scale plots by presenting the CV from a large number of experiments, using large scale plots. The authors argue that these CV's are not large and are acceptable to agronomists.

The authors also discuss concept of power of a statistical test and using each farm as a replication.

Were the design and statistical methods appropriate for meeting study objectives?

The authors offer an opinion.

Reference: Published paper follows.

APPENDIX C

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TABLE OF CONTENTS: Page

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