ISSUES IN ANALYSIS OF A LONG-TERM INTEGRATED PEST MANAGEMENT FIELD STUDY

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ABSTRACT

A team of 14 scientists conducted a 6-year, 16-ha, integrated pest management field study in the dryland wheat production area of the Pacific Northwest. Objectives were to develop a profitable crop production system that controls weeds effectively and reduces soil erosion. Farm-size machinery was used to till, plant, and harvest crops grown in either a continuous wheat (*Triticum aestivum L.*) sequence or a 3-year crop rotation of winter wheat-spring barley (*Hordeum vulgare L.*) -spring pea (*Pisum sativum L.*) in conservation and conventional tillage systems. Main plot factor levels were two tillage systems and three rotation positions of winter wheat. Subplot factor levels were three weed management levels.

Issues in analysis of long-term field studies are discussed. Multiple objectives and complexity of the design make analysis of these studies challenging. Results of one analysis of the data as a split plot analysis of variance averaged over years showed that conservation tillage systems for winter wheat met conservation compliance on highly erodible lands of the Pacific Northwest, reduced income risks, and lessened weather related fluctuations. Wheat yield was highest in the conservation tillage, 3-year crop rotation at maximum weed management level.

1. INTRODUCTION

Agricultural production in the Palouse Region of the Pacific Northwest (PNW) is characterized by intense, high-input, high-yielding winter wheat systems that are plagued with winter annual grass weeds and soil-borne diseases. Producers use conventional tillage systems to control weeds, pathogens, and insects and to reduce heavy crop residues (Papendick and Miller, 1977). Over 84% of the wheat acreage is treated with herbicides in the PNW compared with a national average of 34% (USDA, 1992). Another characteristic of this region is the high soil erosion rates (Papendick and Miller, 1977) attributed to the topography of the area, pattern of precipitation, and winter wheat management practices (Young et al., 1995).

The 1985 Food Security Act mandates that growers comply with conservation provisions for soil erosion reduction to be eligible for farm program benefits. Soil erosion in this region can be reduced an estimated 35% if farmers use conservation tillage practices (Frazier et al., 1983). Growers have been hesitant to adopt conservation practices on wheat acreage because of low crop yields and profitability due to high incidence of root diseases and winter annual grass weeds (Boerboom et al., 1993).

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In 1993 government regulating agencies placed new emphasis on food safety issues including reduced use of pesticides and integrated pest management (IPM) farming. Regulations call for 75% of the total United States crop acreage to be farmed using IPM methods and policies by the year 2000. Very few long-term field studies have been conducted that address integrated crop/pest management in agricultural cropping systems. Information from these studies is critical for developing regulations and strategies for reduced pesticide use. These studies are expensive to conduct and require large areas of land and labor force to plant, harvest, maintain plots, and collect data. Design and analysis of these studies are challenging because of the complexity of the experiments and multiplicity of objectives.

This paper deals with some of the issues in analysis of crop rotation studies. Differences in objectives and philosophies that affect analyses will be illustrated by considering a complex, long-term, integrated pest management field study. Scientists representing eight disciplines from ARS-USDA, Washington State University, and the University of Idaho initiated a 9-year IPM project for conservation crop production systems in the Palouse Region. Farm-size equipment was used for all operations on large plots to assist growers in adopting economically feasible, conservation tillage practices.

2. MATERIALS AND METHODS

Crop rotation experiments are an important class of long-term experiments. Yates (1954) defines a rotation as, "a definite cycle of crops grown in successive years on the same land." The sequence of crops is repeated again and again (c_1, c_2, ...,c_n ; c_1 , c_2 , ... c_n , etc.). A single repetition of the sequence is termed a cycle. Sequences starting at different points in the same cycle are in different phases of the rotation. The number of possible phases is the period of the cycle which is usually the number of years in the cycle. These basic definitions are repeated by Preece (1986).

Within the class of rotation experiments there exists a wide diversity of types of experiments. Cochran (1939) identifies two main types of rotation experiments where treatments are fixed on the same plots throughout or rotate from plot to plot in successive years. Rotation experiments may be further classified as experiments on the effects of treatments to a fixed rotation of crops or experiments comparing the effects of different crop rotations. Here the different crops act as treatments. Rotation experiments may also be classified according to whether information is obtained on direct, residual, or cumulative effects of treatments. The direct effect of a treatment is a measure of the response due to that treatment in that year. Residual effects are commonly viewed as a manifestation of a treatment applied to the experimental unit at a previous time. When a treatment is applied to the same experimental unit every year cumulative effects of the treatment may be observed.

Various types of long-term experiments are illustrated in Figure 1 (Cochran 1939). In this breakdown the treatments such as cultural practices, pesticide levels, etc. are considered as different from the various crops. The layout in Figure 1 illustrates that in long-term experiments the treatments may remain on the same fixed plots or rotate from plot to plot in successive years. The type of information supplied clearly depends on the method of applying the treatments. For example, treatments applied on the same plots every year provide information on cumulative effects of treatments. Other methods of applying treatments provide information on the direct effect of the treatment on that plot or the residual effects of other treatments applied to that plot in previous years. Additional complications for long-term experiments result when either a fixed rotation of crops or successions of different crops are compared. A large number of types of long-term experiments result when the different methods of applying the treatments are combined with any of the crop classes. As Cochran (1939) states, "... the wide diversity of types of rotation experiment makes it difficult to find rules of procedure, and while some useful general advice may be given, each experiment must be considered on its own merits."

An additional issue to consider in the analysis of long-term experiments is whether years should be considered as a fixed or random effect. The distinction between fixed and random effects has generated much discussion (Mead, 1991). A factor in an experiment could be considered either fixed or random depending on the research objectives, the treatment structure, the experimental protocols, and the type of inferences to be made from the observed results (Kuehl, 1994). Years are often considered random because of the absence of any predictable pattern due to years and inferences are often made to a random set of future years. On the other hand a sample of successive years will not always be representative of future years nor can a random sample of years be selected. Also, the interpretation of other treatment effects may depend on years being a fixed effect.

Experimental factors examined in our study included two crop rotation systems, a 3-year rotation and a continuous wheat rotation; two tillage regimes, conventional and conservation (reduced/no-till); and minimum, moderate, and maximum weed management levels. The site was located on a single soil type in a 32-ha field northwest of Pullman, WA. The experiment was conducted as a randomized complete block factorial experiment in a split-plot arrangement in four blocks. The 12 main plots in each replication were a combination of tillage and crop rotation systems (Figure 2). Weed management levels were subplots (Figure 3). Treatment levels were randomized to subplots and main plots in the first year. Randomization remained constant in subsequent years. See Boerboom et al., 1993, Young et al., 1994a, and Young et al., 1994b for complete detailed descriptions of the design and experimental factors, specific procedures, and investigating disciplines.

One useful analysis of the data was as a split-plot analysis of variance repeated across years. Error terms were identified for examining year, main plot, and subplot effects. Analyses for spring barley, spring pea, and spring wheat yields were straightforward because each of these crops appeared in only one crop rotation system (Table 1). Therefore, tillage system was the only main plot factor and for these crops each main plot experimental unit was uniquely identified by specifying year and tillage system. Analysis of winter wheat yield, on the other hand, was more challenging because winter wheat appeared in both crop rotation systems. In addition, rotation position was an important factor to analyze. For winter wheat the main plot experimental units were not uniquely identified by specifying year, tillage and crop rotation systems. For winter wheat the main plot experimental units were identified by main plot number within year. For example, winter wheat was grown in main plots 1, 2, 4, 7, 8, and 10 in 1985-86 and in main plots 1, 3, 6, 7, 9, and 12 in 1986-87 (Figure 2). The form of the analysis of variance table is shown in Table 2. Comparisons of tillage systems within rotation and rotation position within tillage were made with *a priori* contrasts. For all analyses the subplot factors were the three weed management levels. When interactions between main plot and subplot factors were significant, contrasts were used to examine simple effects such as weed management levels within tillage system for a rotation position. Profitability and risk were examined for each of the twelve combinations of two crop rotation systems, two tillage systems, and three weed management levels.

3. RESULTS AND DISCUSSION

Strictly speaking, the results obtained in this study apply only to the location used for the years of the study. Full confidence in recommendations arising from this study can come only by repeating this experiment for many years at many locations in the dryland wheat production area of the Pacific Northwest. The cost and effort involved in conducting this IPM study preclude repeating the experiment. Confirmation of the validity of the results will more likely come from smaller related experiments and observation of outcomes obtained by growers in the area.

In the IPM study considered here, the cropping system treatments and the tillage regime treatments remained on the same main plots in successive years. The weed management treatments also remained the same after the initial randomization in year 1. Cochran (1939) notes that the most important rule about rotation experiments is that each crop must be grown every year. Figure 2 shows that every crop is grown every year for each main plot treatment combination.

The objectives of the long-term, IPM field study include measuring direct effects of rotation, tillage system, and weed management levels; residual effects of rotation position (previous crop for winter wheat yield); and cumulative effects of cropping system (crop rotation, tillage system, and weed management). As noted above, the analysis of residual effects of rotation position is more difficult than for direct and cumulative effects. Analyses were completed assuming all factors, including years were fixed. In this rotation study years were considered fixed because much of the interpretation of results depended on investigation of crop rotation position and tillage effects within a year. Results from one year may or may not be representative of other years.

The 6-year phase of the IPM project documented a successful, profitable, diversified conservation cropping system for PNW wheat production. One of the most significant results obtained by examining residual effects of treatments was the influence of crop rotation position on winter wheat yield (Table 3). Regardless of tillage, winter wheat yield was highest following spring dry pea compared to following spring wheat. The lowest crop yield was when winter wheat followed winter wheat in both the conventional and reduced tillage systems. Yield of conventionally tilled winter wheat following either spring pea or spring wheat was lower than no-till wheat in the same two rotation positions. The increased yield of no-till wheat following spring dry pea is due to effective weed control (Table 4), increased soil moisture (Young, F. L., 1994b) and suppression of diseases (Cook and Ownley, 1991) compared to winter wheat in other systems.

Economic viability, a combination of profitability and riskiness, is a major factor in determining if farmers will adopt new conservation cropping systems. Of the twelve cropping systems examined in this IPM study, only two were profitable (Young, D. L., et al., 1994). These two systems, the 3-year rotation with conservation tillage and either the moderate or maximum weed control were not very risky because of stable yields regardless of weather. The IPM study reports an economic trade-off between tillage and herbicide level for winter wheat and spring barley (Table 5). The increase in weed management levels was not required for spring dry pea where the moderate level was justified for both tillage systems (Young, D. L., et al., 1994).

The results reported above are indicative of the information that can be gained from long-term experiments. As noted in Table 1, information may be gained on direct, residual, and cumulative effects of treatments which means that multiple analyses may be required. Analyses over all years or for each year separately may be necessary. Analysis of yield by crop or analysis of cumulative profit over all crops may be of interest. In addition to multiple analyses, distinctions between fixed and random effects and decisions about analysis of complex interactions provide additional challenges. In this study it is now clear that each analysis was straightforward, except for the residual analysis of crop rotation that required alternate specification of treatment combinations for main plots within years.

4. SUMMARY

Cochran (1939) said, "The responsibility of the statistician who is advising on the design of the long-term experiment is a heavy one." Our investigation of issues in analysis of long-term experiments indicated that the burden of selecting appropriate analyses is also heavy. The complexity of the design and analysis requires a long-term commitment by the project statistician. Long-term experiments are more liable to mistakes than annual experiments so flexibility, creativity, and good humor are most helpful for the research team. In this example, the design, implementation, and analysis were successful in addressing the objectives of the research.

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Table 1. Sources of variation for yield of pea (barley, spring wheat) in the integrated pest management experiment.

Source
Year (Yr)
Error a [Rep(yr)]
Tillage system (TS)
Yr x TS
Error b [Rep x TS(Yr)]
Weed management level (WML)
Yr x WML
TS x WML
Yr x TS x WML
Error c [Rep x TS x WML(Yr)]

Table 2. Sources of variation for yield of winter wheat in the integrated pest management experiment.

Source
Year (Yr)
Error a [Rep(Yr)]
Main plots within year [MP(Yr)]
Error b [Rep x MP(Yr)]
Weed management level (WML)
Yr x WML
MP x WML(Yr)
Error c [Rep x MP x WML(Yr)]

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Table 3. The effect of tillage systems and rotation position on winter wheat yield (kg/ha) at Pullman, WA.[a]

Rotation position[b]	Tillage System[c]	
	Conservation	Conventional
WW/SP	6510a***	5895a
WW/SW	5305b**	4875b
WW/WW	4465c	4505c

[a] Data reprinted with permission of F. L. Young and *Agronomy Journal*.
[b] WW/SP = winter wheat after spring pea in winter wheat, spring barley, spring pea rotation; WW/SW = winter wheat after spring wheat in winter wheat, winter wheat, spring wheat rotation; WW/WW = winter wheat after winter wheat in winter wheat, winter wheat, spring wheat rotation.
[c] Within tillage systems, rotation positions with different letters are significantly different ($p<0.05$); ** and *** indicate significant differences at $p<0.01$ and $p<0.001$, respectively, between tillage systems within rotation position.

Table 4. The effect of weed management and tillage on winter wheat yield (kg/ha) following spring dry pea in the winter wheat, spring barley, spring pea rotation.[a]

WML[b]	Tillage System[c]	
	Conservation	Conventional
Minimum	5950 c	5675 b
Moderate	6699 b*	5950 a
Maximum	6980 a*	6065 a

[a] Data modified and reprinted with permission of F. L. Young and *Agronomy Journal*.
[b] WML = Weed management level.
[c] Within tillage system, WML with different letters are significantly different ($p<0.05$); * indicate significant differences at $p<0.05$ between tillage systems within WML.

Table 5. Most profitable weed management level for each integrated pest management crop and tillage system (6-yr ave.).[ab]

Crop[c]	Tillage System	
	Conventional	Conservation
WW/WW	Minimum	Moderate
WW/SW	Minimum	Moderate
WW/SP	Moderate	Maximum
Spring barley	Moderate	Maximum
Spring pea	Moderate	Moderate

[a] Modified and reprinted with permission of D. L. Young from *J. Soil Water Conserv.*
[b] Economic scenarios used were participation in the farm program for the 3-yr rotation crops (except pea) and no participation for wheat in the monoculture system.
[c] WW/WW = winter wheat after winter wheat; WW/SW = winter wheat after spring wheat; and WW/SP = winter wheat after spring pea.

Figure 1. Types of long-term experiments obtained by combining methods of applying treatments with crop.

TREATMENTS			INFORMATION	CROPS
Fixed	Applied on the same plots	Every year	Cumulative effects	Single crop
		First year	Residual effects	
		Fixed intervals	Direct and residual	Fixed rotation
Rotating	Applied on different plots in successive years		Direct and residual	Different crops

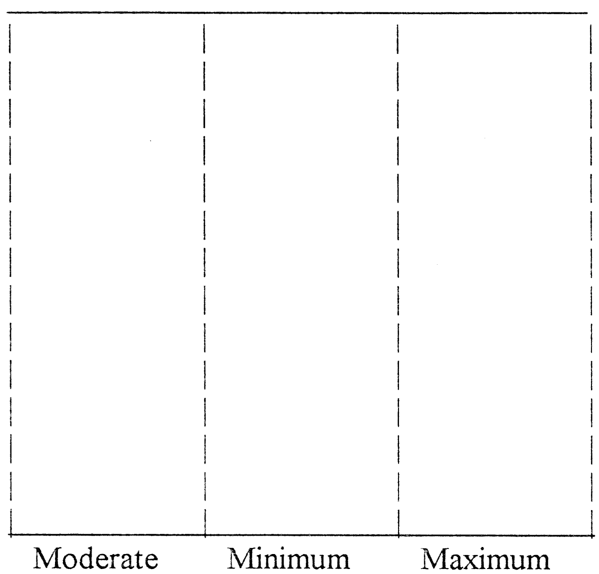
Figure 2. Crop rotation and tillage system[a] on IPM project at Pullman, WA for 6-yr period[bc]

Main Plot	Year 1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
1	WW	WW	SW	WW	WW	SW
2	WW	SW	WW	WW	SW	WW
3	SW	WW	WW	SW	WW	WW
4	WW	SB	SP	WW	SB	SP
5	SB	SP	WW	SB	SP	WW
6	SP	WW	SB	SP	WW	SB
7	WW	WW	SW	WW	WW	SW
8	WW	SW	WW	WW	SW	WW
9	SW	WW	WW	SW	WW	WW
10	WW	SB	SP	WW	SB	SP
11	SB	SP	WW	SB	SP	WW
12	SP	WW	SB	SP	WW	SB

[a] Conservation tillage for main plots 1-6, conventional tillage for main plots 7-12.
[b] Block 1 treatment assignments only; treatments randomly assigned similarly in blocks 2-4.
[c] WW = winter wheat; SW = spring wheat; SB = spring barley; SP = spring pea.

Figure 3. Subplot layout in one main plot of the IPM project at Pullman, WA.

MAIN PLOT[a]



WEED MANAGEMENT LEVEL SUBPLOTS[b]

[a.] After the initial randomization, main plots were farmed with the same tillage system in all years, but the crop grown on the main plot changed according to the rotation.
[b] Subplots received the same weed management level for all 6 years after the initial randomization.