TECHNICAL AND ECONOMIC COMPARISONS OF ALTERNATIVE FARMING SYSTEMS

by

D. Peter Stonehouse

Department of Agricultural Economics and Business
University of Guelph
Guelph, Ontario
N1G 2W1
CANADA

for

Presentation

at the

Australian Agricultural Economics Society, Inc.
Annual Meeting

at

Victoria University,
Wellington
New Zealand

8-10 February 1994

Problem situation and objectives

In response to growing public and farming sector concerns about sustainability, resource degradation and environmental damage, many new policies and programs with an environmental orientation have been introduced by all levels of Canadian government, especially since the early 1980s (Stonehouse and Bohl, 1990). These policies and programs rely heavily on well-established voluntary compliance approach to solving conservation problems in agriculture. One such program launched in 1988 by the Ontario government, entitled "Food Systems 2002 - Pest Management Research Program (1988-1993)", aimed to reduce the use of chemical pesticides in Ontario agriculture by one-half by the year 2002. The inherent challenge was to find ways to farm profitability without being quite so heavily dependent upon chemical inputs. Interest in this study focused on investigating alternative farming systems with varying degrees of dependence on chemicals for weed control purposes.

Three alternative systems each with different implications and consequences both on and off the farm, were examined. "Conventional" systems (i.e. farms that follow Ontario Ministry of Agriculture and Food recommendations for routinely broadcasting all herbicides) may be extremely effective in controlling weeds and in achieving high crop yields (Stemeroff et al., 1988), but may also result in trace residues in ground-water or downstream watercourses. Equal or superior results, mostly in terms of profitability, can be achieved with reduced rates of herbicide applications (Musser et al., 1981, Lybecker et al., 1984; Snipes et al., 1984; Bridges and Walker, 1987; Baldwin et al., 1988; Lybecker et al., 1988), and these so-called "Reduced-input" systems may decrease pollution costs and health hazards to farm operators (Madden, 1988). Reduced-input systems employing both herbicides and cultivations to control weeds are examples of flexible strategies that have generally been found to produce fewer variations in net returns with varied input and product price assumptions (e.g. Snipes et al., 1984; Wilcut et al., 1987a; wilcut et al., 1987b; monks, 1989).

A number of studies have concluded that reduced-input systems based on integrated pest management or "Organic" (zero-herbicide) approaches to farming and weed management appear to be superior to conventional methods (e.g. King and Robinson, 1984; Bridges and Walker, 1987; Goldstein and Young, 1987). Other studies have reported exactly the opposite (e.g., Berardi, 1978). Some studies reported non-statistically significant differences among alternative methods (e.g., *Helmers et al., 1986; Sahs et al., 1989*). Organic farming systems must rely on crop rotations, smother crops, tillage and timeliness of field operations for weed control, and these systems reduce the potential for ground and surface-water pollution and health hazards from synthetic herbicides to zero. There have been no reports so far in Canada of empirically-based comparisons across alternative farming systems, either for weed control or for other specific or more general purposes.

The main objective of this study was to provide a scientific basis for making comparisons across alternative farming systems in order to furnish some preliminary results under Ontario conditions. Specifically the objectives were to: 1) compile resource usage, crop yield and financial data for weed management in field crops, but with special emphasis on corn, beans and fall cereal grains, the principal field crops in Ontario, for three alternative farming systems (conventional, reduced-input, and organic) representing different levels of dependence on herbicides for weed control; 2) evaluate these data from technical and economic viewpoints; 3) provide technical comparisons (in terms of crop yields and resource input use rates) and economic comparisons of productivity, efficiency, and profitability.

Research procedures

In the absence of any secondary data for farming systems comparisons under Ontario conditions at the time of initiating this study in 1989, it was decided to approach farmers for their cooperation in providing data about their conventional, reduced-input or organic systems of weed control in commercial settings. It was fully recognized that an approach using commercial farm data may not provide completely objective results because of differences among farms in: 1) natural resource endowments (climate, soil, topography, etc.); 2) combinations of crop and livestock enterprises; 3) size and scale of operation, degree of indebtedness, and other economic aspects; 4) human capital endowments, in terms of information available and used, management skills and abilities, etc., as well as differences in weed management procedures. Nevertheless, such an approach is able to provide first-round data from which analyses can provide some useful preliminary conclusions. In addition, all farms were selected on the basis of having: 1)at least 35 hectares tillable land (owned or rented, not necessarily all devoted to cash crops); 2) some tillable land allocated to at least one of grain corn, beans (e.g., soybeans, white beans, kidney beans), and fall cereal grains (e.g., winter wheat, rye, spelt); 3) heat units received on the farm that lie between 2500 and 2900; 4) five years of data related to crop production and weed control procedures, including resource usage rates and costs, crop yields and prices.

Twenty-five cooperators were selected for the analysis - nine conventional, nine reduced-input, and seven organic farmers. Data were collected through an on-farm interview and an in-depth questionnaire. Enterprise budgets were used to provide gross margins (gross revenues less all direct costs of production) per hectare for each of corn, beans, and fall cereal grains for each of the three groups of farms. The budget data were used for focus crop comparisons across the three farming systems. Mathematical programming techniques were used to compare net farm incomes across farming systems, based on a subset of 12 farms randomly selected from each parent group with four farms in each system alternative. Net farm incomes provide a more comprehensive basis for comparisons by including all crop and livestock enterprise gross margins and all farm overhead costs (except returns to management, risk and equity capital in this study).

Empirical results and discussion

Conventional farms operated the largest land base, at 260.70 ha average per farm, followed by Reduced-input farms at 214.86 ha. and Organic farms with 151.11 ha. (Table 1). Both Conventional and Reduced-input systems recorded between 90 and 95 percent on average of their total land bases as tillable land, considerably greater than the 79 percent recorded for Organic farms. This implicitly endowed advantages on the Conventional and Reduced-input systems in terms of both quantity and quality of land base. Intensive row crops such as corn and beans comprised a much higher proportion of the tillable land base on both Conventional and Reduced-input farms than on Organic farms, because of the tendency of Conventional and Reduced-input farms to specialize in fewer enterprise lines. In contrast, Organic farms typically carried a much wider range of crops, and had greater allocations of land to pasture and hay crops. This may reflect any one or all of a) an approach to weed management that relied on crop rotations, and other substitutes for synthetic herbicide methods; b) a response by Organic farmers to niche market opportunities in specialty crop areas; c) the overall philosophy of Organic farmers, to rely more heavily on diversified enterprise mixes and flexible resource usage for reasons of resource stewardship, long-term sustainability of operations, and risk avoidance

Table 1: Land base and focus crop hectarages of participating farms (average by system) 1989

	Conventional	Reduced-input	Organic
Number of Farms	9	9	7
Total Land Base (Average # Ha.)	260.70	214.86	151.11
Tillable Land Base (Average # Ha.)	244.72	195.14	119.89
Focus Crop Hectarages			
Grain Corn (Average # Ha.)	99.10	65.89	7.47
Beans (Average # Ha.)	47.36	50.81	2.31
Fall Cereal Grains (Average # Ha.)	42.78	31.19	29.70
Proportion of Tillable Land Under Focus Crops	77.3%	75.7%	32.9%

Several differences among farming systems for weed control methods are worth noting (Table 2). Organic farmers relied more heavily on cultivations and hand weeding than the other two types of farmers. Organic farmers were the only ones to compost manure (with the objective of destroying disease organisms as well as weed seeds); the other two types of farmers applied untreated manure. Conventional and Reduced-input farmers employed herbicides, while Organic farmers applied none. Organic farmers committed more labour resources to weed control than the other two types of farmers.

Higher total weed control costs reflected the heavier applications of resources to weed control on the Organic farms, despite the zero expenditures on herbicides. In contrast, other direct production costs were lower on Organic farms, due mainly to lower seed costs, and to zero fertilizer and (non-herbicide) synthetic pesticide materials and applications costs. This rendered overall direct production costs lowest on Organic farms for all three focus crops (Table 2).

Crop yield differences were not great among the three farming systems (Table 2). Highest average yields were achieved on Reduced-input farms for corn and cereal grains, and on Organic farms for beans. With small yield differences, but with premium prices for products and lower total direct production costs, Organic farms enjoyed highest gross margins for all three focus crops. This gross margin advantage needs to be correctly interpreted. The lower production costs were far more critical than the higher product prices. With premiums on product prices eliminated, gross margins on Organic farms would have averaged \$491.99 ha^{-1} for corn, \$527.53 ha^{-1} for beans, and \$170.05 ha^{-1} for cereal grains. Organic farms would therefore have continued to obtain gross margin advantages for two of three focus crops.

Given the focus of this study on alternative weed management systems, the comparisons made above on a gross margin ha^{-1} basis would seem appropriate, but incomplete. A more complete analysis can be afforded by comparisons on a net farm income basis whereby gross margins are aggregated to the enterprise level, gross margins for all enterprise lines are included, and overhead costs plus imputed costs of operator and unpaid family labour are accounted for . Despite problems with comparing heterogeneous entities, whole farm analyses were conducted across systems, using LP modelling techniques. Only 12 farms - four from each system - were modelled, because of lack of time to model all 25 farms surveyed. The 12 farms were selected completely randomly, ignoring all factors for selection that may have reduced the degree of heterogeneity across farms and systems Illustrative example results are presented

Table 2: Weed control method and costs, crop yields and enterprise gross margins, by farming system and by focus crop (averages by system), 1989.

	Corn			Beans			Fall Cereal Grains		
	Conventional	Reduced input	Organic	Conventional	Reduced input	Organic	Conventional	Reduced Input	Organic
Number of Farms	9	9	4	7	8	3	9	8	6
Pre plant Cultivations[a] ($ ha⁻¹)	34.06	30.98	45.71	33.22	34.79	48.60	22.41	6.19	45.92
Post plant Cultivations[a] ($ ha⁻¹)	6.55	14.62	53.93	5.06	21.18	54.72	0.73	12.93	0.54
Manure Composting[b] ($ ha⁻¹)			20.00				-	-	-
Herbicides ($ ha⁻¹)	55.04	51.30		58.96	72.21	-	4.62	19.77	-
Weed Scouting ($ ha⁻¹)	3.92	4.35	2.32	3.17	3.09	1.84	1.33	3.00	2.74
Hand Weeding ($ ha⁻¹)		0.47	1.49		0.47	14.85	0.55		2.80
Total Weed Control Costs[c] ($ ha⁻¹)	99.57	101.70	123.45	100.41	116.32	120.01	29.54	28.97	52.80
Total Weed Control Labour (hr ha⁻¹)	2.08	2.07	6.21	1.75	1.61	6.20	0.91	0.64	2.37
Other Direct Production Costs[d] ($ ha⁻¹)	339.60	319.18	180.67	219.93	200.71	188.16	308.90	239.56	207.83
Total Direct Production Costs ($ ha⁻¹)	489.17	420.88	304.12	320.34	317.03	308.17	338.44	268.53	260.63
5-year Average Yield (t ha⁻¹)	6.32	7.13	6.62	2.37	2.50	3.03	3.50	4.02	2.84
5-year Average Gross Revenue ($ ha⁻¹)	753.41	864.80	971.15	646.27	697.33	877.49	528.26	612.53	612.79
5-year Average Gross Margin ($ ha⁻¹)	264.24	443.92	667.03	325.94	380.30	569.32	189.82	344.00	352.16

a - Includes machinery operating costs and labour costs. 100% of cultivation costs attributed to weed control
b - 100% of manure composting costs attributed to weed control
c - Materials costs only
d - Include all materials, labour, and machinery operating costs

here, for reasons of space and time shortage. These portray actual 1989 situations (Simulation Run) and maximum potential net returns situations (Open Run).

For the Conventional systems farmer, actual net farm income generated in 1989 was $18,354 (Table 3), based on a 19 ha. - to - 36 ha. - to - 25 ha. division of tillable land among corn, soybeans, and cereal grains (fall- and spring-seeded), respectively. The unrestricted use of available resources in the open LP model run led to increases in corn, to decreases in soybeans, and barley, and to elimination of winter wheat. This land use pattern would have raised 1989 net farm income to $19,757 from $18,354. Clearly there are some implications for land stewardship here through changing crop rotational patterns, but because no costs have been included in these models for land degradation (or benefits through conservation), these considerations were ignored. The dual prices on activities across crop enterprises for the simulation run were in accordance with changing land use patterns for the open model run. For example, the lowest dual price (on winter wheat of $368.07/ha) was an indication that this crop would have been the least preferred on economic grounds in 1989. Grain corn carried the highest dual price, so that more land would presumably have been allocated to this corp in the open LP model run but for constraints on operator labour during the crucial fertilizer and corn herbicide application period of May 31 to June 13. Very high shadow prices were generated in the open LP model run for land ($375.59/ha) and May 31-June 13 operator labour ($98.81/hr), indicating the critical nature of these resource scarcities.

Table 3: LP Results for the Conventional Farmer

	Simulation Run	Open Run
Gross Margin	39,139	40,542
Overhead Expenses	20,785	20,785
Net Farm Income	18,354	29,757
Corn (ha.)	19.22	28.18
Soybeans (ha.)	36.06	35.51
Winter Wheat (ha.)	6.62	-
Barley (ha.)	19.09	17.31
Shadow Values (Marginal Value Products)		
Land ($/ha.)		375.59
Operator Labour, May 31 - Jun 13 ($/hr)		98.81
Dual Prices On Actvities		
Corn ($/ha)	635.16	
Soybeans ($/ha)	451.68	
Winter Wheat ($/ha)	368.07	
Barley ($/ha)	381.52	

The results for all four Conventional farms modelled in general showed that resource reallocation and improved efficiency potential is low, in part reflecting high levels of enterprise specialization, plus built-in inflexibilities with respect to cost structures particularly for overhead charges such as depreciation and interest in the short run, and production procedures. Only one of these farms displayed potential, albeit unrealistic on technical grounds, to improve net farm income over actual 1989 achievement levels.

In contrast, the results for the four Reduced-input farms modelled displayed somewhat better potential for improving efficient resource use and profitability of farm business, by concentrating resources on the most profitable crops. In most cases this would have resulted in increased risk loadings, an important consideration for most farmers who are thought to be risk-averse. Also the increased profitability may only have been obtained at the expense of natural resource conservation and good environmental stewardship.

The example Reduced-input farm shown (Table 4) may not have caused much if any increase in environmental damage because the open model run called for continued dependence on diversification and rotations of crops, but with a distinct bias toward the crop(s) with highest inherent profitability - corn, white beans and winter wheat. The increase in expected net farm income of $7,380 ($2,973 to $10,353) for this farmer may have been worth trading off against presumably higher risk. Of special note were the shadow values attached to scarce resources in the open LP model run (Table 4, column 2). As in the case of the Conventional farm, land scarcity generated a very high economic rent at $346.99/ha, but perhaps of greater interest were the economic rents attached to labour resources, both owner-operator and hired, in specific time periods.

Table 4: LP Model Results for the Reduced-Input Farmer

	Simulation Run	Open Run
Gross Margin	84,211	91,591
Overhead Expenses	81,238	81,238
Net Farm Income	2,973	10,353
Corn (ha.)	37.65	54.70
Soybeans (ha.)	46.96	0.79
White Beans (ha.)	50.00	58.18
Winter Wheat (ha.)		58.18
Shadow Values (Marginal Value Products)		
Land ($/ha.)		346.99
130 hp Tractor, May 1-15 ($/hr.)		
Operator Labour, May 31-June 13 ($/hr.)		286.63
Hired Labour, Jul 12-30 ($/hr.)		34.18
Dual Prices on Activities		
Corn ($/ha.)	544.77	
Soybeans ($/ha.)	346.99	
White Beans ($/ha.)	691.56	
Winter Wheat ($/ha.)	898.86	

Results for the four Organic farms modelled were similar in some important respects to those obtained for the Reduced-input farms. Organic farms were characteristically diversified in their enterprise mixes and resource usages presumably for risk avaoidance reasons, but more critically for pest and disease control and land management reasons. Crop rotations, cultivations, careful nurturing of soil organic matter and plant nutrients, and mixed livestock-crop enterprise strategies were all relied upon to supplant the use of synthetic pesticides and fertilizers. These strategies were largely retained in the open LP model runs by maintaining livestock numbers at constant levels, and by maintaining the need for forage feed self-sufficiency.

The Organic farm showed relatively little potential for improving net farm income (Table 5). An increase in net farm income of about $21,000 over the actual 1989 level would have been possible by consolidating cropland into spelt, corn, mixed grain, hay and pasture, and divesting oats and rye. Risk loading may not have increased substantially by adopting the open LP model plan, given that the cropland would still have been allocated among five different crops.

Table 5: LP Model Results for the Organic Farmer

	Simulation Run	Open Run
Gross Margin	128,608	150,115
Overhead Expenses	62,288	62,288
Net Farm Income	66,320	87,827
Spelt (ha.)	18.62	44.75
Corn (ha.)	10.98	10.40
Mixed Grain (ha.)	48.56	47.70
Oats (ha.)	13.76	-
Rye (ha.)	10.93	-
Hay (ha.)	29.54	29.54
Pasture (ha.)	10.12	10.12
Dairy Cows (head)	85	85
Shadow Values (Marginal Value Products)		
Dairy Cows ($/head)	1,364.28	1,056.42
Operator Labour, Aug 16-29 ($/hr.)		28.29
Operator Labour, Aug 30-Sept. 12 ($/hr.)		310.02
Dual Prices on Activities		
Spelt ($/ha.)	905.77	
Corn ($/ha.)	456.22	
Mixed Grain ($/ha.)	62.15	
Oats ($/ha.)	61.28	
Rye ($/ha.)	-188.24	
Hay ($/ha.)	-275.19	
Pasture ($/ha.)	-120.98	

The summary results from 12 farms analyzed with LP model techniques indicated a net farm income advantage to Organic farms (Table 6). Net farm income on Organic farms averaged $32,292, 28% higher than that on Reduced-input farms at $25,232, while Conventional farms averaged a negative net farm income of $10,253.

It was apparent that both Organic and Reduced-input farms in the sample enjoyed greater profitability than Conventional farms because of the greater range of enterprises found on the Reduced-input and Organic farms, and particularly due to the inclusion of livestock enterprises on every Organic farm. Despite the large differences among the three types of farms in average land base and enterprise mix, relatively small differences were recorded in average overhead expenses across the three types. No claim is being made here about the general applicability of these summary findings, because of lack of knowledge about the representatives of the 12-farm sample of the general population. All results recorded here are preliminary only, based on small sample, case study analyses.

Conclusions

Although only a small sample of 25 farms has been analyzed in this study, some preliminary conclusions can be drawn from the results obtained. First, Conventional farms in this study tended to be more specialized operations with a smaller range of crop enterprises than either Reduced-input or Organic farms, but also tended to operate larger hectarages of tillable land and land in total. Second, overall costs of weed control and labour requirements for weed management were highest on Organic farms in the sample, but have likely been overestimated in this study, by virtue of attributing 100% of cultivation (and, on Organic farms, manure composting) costs to weed control. Third, there were equivocal rankings among farming systems on a crop yield basis, with Reduced-input systems in the sample outranking other systems for both grain

Table 6: Summary LP Model Results for 12 Farms' Net Farm Incomes

		Conventional		Reduced-Input		Organic
1989 Simulated Run	Farm 1	$-33,708	Farm 5	$ 8,372	Farm 9	$27,795
	2	18,354	6	2,973	10	66,320
	3	-9,945	7	6,871	11	53,756
	4	-15,713	8	82,713	12	-18,704
	Mean	-10,253	Mean	25,232	Mean	32,292
Open Run	Farm 1	-30,385	Farm 5	63,851	Farm 9	81,088
	2	19,757	6	10,353	10	87,827
	3	16,067	7	26,162	11	105,520
	4	-15,568	8	96,274	12	1,003
	Mean	-2,532	Mean %	49,135	Mean %	68,860
	% Change from 1989 Simulated Mean to Open Run Mean	75.3	Change from 1989 Simulated Mean to Open Run Mean	94.7	Change from 1989 Simulated Mean to Open Run Mean	112.3

corn and fall cereal grains, but Organic systems in the sample ranking first in bean yields. However, this conclusion is the more tentative because only three Organic farms reported producing bean crops. Fourth, despite higher weed control costs on a per-ha basis, Organic farming systems in the sample generated higher gross margins on a per-ha basis across all crop enterprises evaluated than the other two systems. While some of the superior gross margins outcomes were due to product price premiums earned by Organic farmers in the market place, total direct crop production costs were lower on the Organic farms - especially in the case of grain corn. Using identical crop prices across systems, Organic farmers would still have generated superior gross margins for corn and bean crops on a per-ha basis. The inferior performance of Organic farms in fall cereal grains using identical product prices can be partially attributed to the lower crop yields expected from both spelt and rye, which were emphasized more than winter wheat on the Organic farms. Fifth, net farm incomes on a whole farm basis were highest on the Organic farms, being 28% higher than those on Reduced-input farms, and considerably higher than those on Conventional farms, despite the much smaller land base employed on Organic farms. Much of the superior net returns performance on Organic farms can be attributed to the wider range of enterprise lines, and in particular, to the livestock enterprises that invariably comprise a part of the enterprise mix on Organic farms. An additional factor was the lower levels of direct costs of production on Organic farms, particularly for those inputs purchased from off the farm, such as fertilizers, pesticides, and feed additives.

The preliminary results and conclusions recorded above imply that there is potential to reduce rates of synthetic fertilizers and pesticides in Ontario agriculture without jeopardizing crop yields or adversely affecting farm profitability. This further suggests that the goals of government programs such as the Ontario Ministry of Agriculture and Food's "Food Systems 2002" have been realistically set, and should be attainable. The full extent of that attainability must await more definitive results from further research work. Future research efforts should also address the off-farm benefits and costs of alternative farming systems being adopted (e.g. impacts on the ecology and the environment at large), and broader on-farm issues such as agricultural sustainability, in addition to farm profitability.

References Cited

1. Baldwin, L.R., R. Oliver and T.N. Tripp. 1988. "Arkansas experience with reduced rate herbicide recommendations." In: Environmental Legislation and its Effect on Weed Science. Proceedings of the 41st Annual Meetings of the Southern Weed Science Society; January 1988; Nashville, Tennessee.

2. Berardi, G.M. 1978. "Organic and conventional wheat production: Examination of energy and economics." Agro Ecosystems 4:367-376.

3. Bridges, D.C. and R.H. Walker. 1987. "Economics of sicklepod (Cassia obtusifolia) management." Weed Science 35:594-598.

4. Colvin, D.L., B.J. Brecke and W.L. Currey. 1986. "Weed control and economic evaluation of full season-double cropped, conventional and minimum tillage peanuts." In Proceedings: Southern Weed Science Society. 39th Annual Meeting. Weed Science and Risk Assessment. Nashville, Tennessee.

5. Goldstein, W.A. and D.L. Young. 1987. "An agronomic and economic comparison of a conventional and low-input cropping system in the Palouse." American Journal of Alternative Agriculture. 2(2):51-56.

6. Helmers, G.A., M. Langemeier and J. Atwood. 1986. "An economic analysis of alternative cropping systems for east-central Nebraska." American Journal of Alternative Agriculture. 1(4):153-158.

7. King, R.P. and L.J. Robinson. 1984. "Risk efficiency models." In Risk Management in Agriculture. Peter J. Barry (ed.) The Iowa State University Press. Ames, Iowa.

8. Lybecker, D.W. E. Schweizer and R.P. King. 1988. "Economic analysis of four weed management systems." Weed Science. 32(1):846-849.

9. Lybecker, D.W., R.P. King, E.E. Schweizer and R.L. Zimdahl. 1984. "Economic analysis of two weed management systems for two cropping rotations." Weed Science. 32(1):90-94.

10. Madden, P. 1988. "Low-input sustainable agricultural research and education - challenges to the agricultural economics profession." American Journal of Agricultural Economics. 70(5):1167-72.

11. Monks, C.D. 1989. "Economic comparison of snap bean control systems." In: Weed Science and Risk Assessment. Proceedings of the 39th Annual Meeting of the Southern Weed Science Society; Nashville, Tennessee.

12. Musser, W.N., B.N. Tew and J.E. Epperson. 1981. "An economic examination of an integrated pest management production system with a contrast between E-V and stochastic dominance analysis." Southern Journal of Agricultural Economics. 13(1):119-125.

13. Sahs, W.W., G.A. Helmers and M.R. Langemeier. 1989. "An economic comparison of the profitability of organic and conventional production systems for east-central Nebraska." Paper presented at the National Conference on Organic/Sustainable Agriculture Policies, Washington, D.C., March 16-17.

14. Snipes, C.E., R.H. Walker, T. Whitwall, G.A. Buchanan, J.A. McGuire and N.R. Martin. 1984. "Efficacy and economics of weed control methods in cotton (Gossypium hirsutum)." Weed Science 32:95-100.

15. Stemeroff, M., C.J. Swanton, A.S. Hamill and R.H. Brown. 1988. "Economics of herbicide use on corn (Zea mays) and soybeans (Glycine max) in Ontario." Weed Technology 2:466-472.

16. Stonehouse, D.P. and M.J. Bohl. 1990. "Land degradation issues in Canadian agriculture." Canadian Public Policies 16(4):418-431.

17. Wilcut, J.W., G.R. Wehtge and M.G. Patterson. 1987a. "Economic assessment of weed control systems for peanuts (Arachis hypogaea)." Weed Science .35(3):433-437.

18. Wilcut, J.W., G.R. Wehtge and R.H. Walker. 1987b. "Economics of weed control in peanuts (Arachis hypogaea) with herbicides and cultivations." Weed Science .35(5):711-715.

19. Zavaleta, L.R., B. Eleveld, M. Kogan, L. Wax, D. Kulman, and S.M. Lim. 1984. "Income and risk associated with various pest management levels, tillage systems, and crop rotations: An analysis of experimental data." Agricultural Economics Research Report, Department of Agricultural Economics, Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.