Integrating novel technologies for cabbage IPM in the USA: value of on-farm research

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Abstract

Integrated pest management (IPM), particularly for high-value crops, is often viewed by growers as a more risky approach compared to their current (conventional) pest control practices. In this article we present the results of a 3-year on-farm trial, which documents the expected benefits, and risks of IPM and a conventional pest management system for cabbage. In Minnesota, USA, *ca*. 500 ha of cabbage and cole crops are produced each year. Despite relatively few hectares, the high value of the crop (≈9,000 US$/ha), and high insecticide use (5-9 sprays/season), continues to create a demand for alternative pest management programs. Throughout the Midwestern states, cabbage is attacked by three important lepidopteran pests: *Pieris rapae*, *Plutella xylostella* and the cabbage looper, *Trichoplusia ni*. In the absence of insecticide resistance, as well as high parasitism rates of *P. xylostella* (80-90%), *T. ni* is often the most common, and most difficult insect pest to control. Much of our focus over the past 8 years, has been to: a) evaluate rapid presence/absence (binomial) thresholds that account primarily for *T. ni*, b) validate thresholds for use with "reduced-risk" insecticides such as SpinTor® (spinosad) and Proclaim®, with pyrethroid use as needed (e.g., lambda-cyhalothrin; Warrior®), and c) measure and communicate the value of IPM in on-farm trials.

Use of a 10% action threshold and the reduced-risk insecticides, consistently provided a lower proportion of plants infested with late-instar *T. ni* larvae and a higher percentage of marketable heads for the 3-year study (1998-2000), compared with a conventional system. The conventional system used by the grower included pest scouting only to determine the first spray. Thereafter, sprays were applied approximately every 10 days or when convenient. The IPM program resulted in the highest percentage of marketable heads, while reducing the number of insecticide applications in 1998 and 1999 (43-66%). Despite a slight increase in sprays in 2000 (3.0 vs. 2.6) for the IPM program, net profits were still highest for the IPM program in each of the three years, ranging from 16 to 107% over the conventional program. Expected utility analysis also revealed that the IPM program provided the highest expected net revenue ($973/ha) with the least risk, compared with the conventional strategy and untreated check. In summary, these results confirmed the economic benefit of an IPM approach by careful measurement of the benefits and risks of IPM and has been well-received by Minnesota growers.

Introduction

Integrated pest management (IPM) is a concept and practice that has the potential to improve productivity and/or reduce pesticide use for a variety of commodities in agriculture and forestry, as well as in schools, buildings and landscape settings within urban and residential areas. Essentially, IPM is a *management framework* that can be used by growers and consultants to employ all possible complementary pest control tactics to manage arthropod, pathogen, weed and vertebrate pests in a way that provides economic sustainability, is environmentally sound and is socially compatible. The IPM concept and components of IPM have received considerable research attention over the past 40 years (Kogan 1998). However, the research emphasis, often by necessity such as crises created by exotic pest outbreaks, has focused primarily on pest biology, economic injury levels, or the discovery and development of novel pest control tactics (e.g. Kogan 1998, Radcliffe & Hutchison 2002).

By contrast, there has been relatively little acknowledgement within the pest disciplines that the implementation of IPM *is a management, and specifically, a decision-making activity* (e.g. Carlson 1970, Moffitt *et al*. 1983, Plant & Stone 1991). Consequently, the benefits and risks of IPM are not always carefully measured or communicated to growers or end-users. As with other areas of agriculture, decision-making for pest control occurs with considerable uncertainty and risk, due to variable pest pressure, weather, crop price, etc. (Fleisher 1990). In addition, IPM is often more knowledge intensive than conventional systems and the burden to implement IPM is often left with the grower who must integrate new

IPM components with existing production systems (Plant & Stone 1991). Not too surprisingly, many growers, and those with high-value crops, often view IPM as a more risky option vs. conventional methods, which can include a substantial reliance on pesticide applications.

IPM risk-reward tradeoff

As one approach to illustrating the cost-benefit, or risk-reward value of an IPM approach, we adopted an economic risk analysis (Carlson 1970, Moffit *et al*. 1983) to analyse the results of a three-year on-farm implementation trial for cabbage IPM in Minnesota. Cabbage, broccoli and cauliflower continue to be important vegetable crops for Midwestern U.S. growers, for both processing and fresh-market (Eastman *et al*. 1995). Annually, approximately 500 ha of cabbage and cole crops are produced in Minnesota for fresh-market (grocers and roadside stands, WDH, unpublished data). Despite relatively few hectares in Minnesota, the high value of the crop (≈$9,000/ha) and traditionally high insecticide use of 5-9 applications/season, continue to create a demand for alternative insect management programs. In Minnesota, and throughout the Midwestern U.S., cabbage is attacked primarily by three lepidopteran pests: imported cabbageworm (ICW), *Pieris rapae*; diamondback moth (DBM), *Plutella xylostella* and the cabbage looper (CL), *Trichoplusia ni* (Eastman *et al*. 1995, Hines 1998). DBM is usually most abundant on early-season plantings, with ICW and CL becoming the dominant pests in late June to August. In the late 1960s to early 1970s, ICW was the dominant lepidopteran cabbage pest in Minnesota (Weires & Chiang 1973). However, throughout the 1990s, CL has become the most dominant insect pest (Hines & Hutchison 2001). In the absence of insecticide-resistant DBM, as well as high parasitism rates of DBM by *Diadegma insulare* (typically 80-100%; Hines 1998), our experience has been that CL is often the most difficult pest to manage in Minnesota. Thus, much of our focus over the past 8 years, has been to a) evaluate action thresholds that account primarily for CL and ICW, b) use simple-to-implement presence/absence thresholds (% of plants infested with one or more lepidopteran larvae), c) validate the thresholds for use with “soft” insecticides such as *Bacillus thuringiensis,* SpinTor®, and Proclaim®, and finally, d) assess the use, implementation and value of IPM in on-farm trials.

SpinTor® was initially selected as the primary alternative insecticide because of its known efficacy against CL (Liu *et al*. 1999) and the potential reduced impact on the diversity of natural enemies (predators and parasitoids) of the entire lepidopteran pest complex (Sparks *et al*. 1998). SpinTor® (spinosyns) is derived from the *Actinomycete* bacterium, *Saccharopolyspora spinosa* (Sparks *et al*. 1998).

In this article, we summarize an economic risk analysis for several novel, biologically-based insecticides, including SpinTor 2SC® (i.e. spinosad, Success®, Dow AgroSciences) and Proclaim® (Syngenta Corp.). Moreover, we also use these results to document the expected profits as well and economic risk (variability in profit) associated with the on-farm implementation of the Minnesota Cabbage IPM Program.

Materials and methods

Given the positive results from previous action threshold validation studies in 1996-1997 (Hines 1998, Hines & Hutchison 2001), we developed and implemented an IPM program with Pahl’s Markets, one of the leading fresh-market growers in Minnesota. Our purpose was to compare an IPM program, based on previous experiment station (small plot) research, with conventional grower practices. The Pahls allowed us to use small sections of several commercial fields. During each of the three years (1998-2000) we established 6 commercial field sites (replications), with 3 treatments in each: IPM, Conventional and Untreated Check (= "Do Nothing strategy"). During each year of the study, plot size for each replication of each treatment was 390 m^2 (0.35 ha). All data were initially analysed using a randomised complete block design and one-way Analysis of Variance (SAS 1988). The 3-year data set was also analysed using expected utility analysis to determine average (expected) gross and net profit/ha, as well as the standard deviation of gross and net revenue/ha, as a measure of the risk associated with the IPM and Conventional pest management systems (Moffitt *et al*. 1983; Burkness *et al*. 2002).

The IPM program included the use of: presence/absence action threshold, the biologically based insecticides SpinTor 2SC® and Proclaim® (2000 only) early in the season to conserve natural enemies, and pyrethroids during late-season, in response to excessive insect pest pressure. Unlike previous threshold systems used in the U.S. and Canada, adjusted for pest species or vegetative vs. head growth stages (e.g. Eastman *et al*. 1995), we used a season-long action threshold of 10% of the plants infested with one or more CL early instar larvae/plant (Hines 1998). Despite this conservative threshold, validation studies indicated that because CL is the most difficult pest to control, the threshold worked well for CL as well as DBM and ICW

(Hines & Hutchison 2001). As noted in the current Minnesota guidelines, if CL is not present, and either DBM or ICW are present, we used the thresholds of 50% of the plants infested with larvae (early instars for ICW) until heading, then a 10% larval infestation from heading to harvest (Hines & Hutchison 2001).

All plots were monitored twice/week during July and August of each year, when pests were most active. For each replication of each treatment, a minimum of 30 heads was selected at random and examined for larvae of each pest species. The percentage of plants infested with one or more eggs and/or larvae for each pest was recorded. To better anticipate increasing CL infestations, the number of CL eggs was also noted. Pest monitoring and decision-making for the IPM plots was done independently of the grower, making every effort to not influence decision making by the grower. Every effort was made to keep the IPM decision-making confidential (blind test). The grower was responsible for all decision-making and spraying of the conventional plots. When treatment was necessary in the IPM plots, sprays were applied by one of the authors (ECB) using a back-pack sprayer fitted with a 3-m boom and 6 nozzles over 3 rows of cabbage (2 nozzles/row). This system was calibrated to apply 187 L water/ha. When treatments were necessary in the Conventional plots, one of the authors (GP) made the necessary applications using a tractor-mounted 19.3-m boom, with 38 nozzles. This system also included 2 nozzles/row and was calibrated to deliver 187 L water/ha.

At harvest, 10 heads/replication of each treatment were randomly selected, weighed and evaluated for marketability using a standard 1-6 scale (Greene *et al*. 1969), where: 1 = no damage; 2 = minor feeding damage on wrapper or outer leaves; 3 = moderate insect feeding on wrapper or outer leaves with no head damage; 4 = moderate insect feeding damage on wrapper leaves and minor head damage; 5 = moderate to heavy feeding on wrapper and head leaves with head having numerous scars, over 30% of leaf area eaten; and 6 = considerable insect feeding on wrapper and head leaves with head having numerous feeding scars, over 30% of leaf area eaten. These data were also analysed by one-way ANOVA.

Results and discussion

Use of the 10% action threshold and the biologically-based insecticides, SpinTor® (1998-2000) or Proclaim® (2000), in the IPM program, consistently provided a lower proportion of plants infested with late instar CL larvae (Figure 1, Table 1) and statistically higher marketability ratings (lower the number the better; usually <2.1) over the 3-year study (Table 1). Yields were significantly higher in the IPM plots vs. Conventional in 2000 only. The percentage of marketable heads, a function of both marketability rating and head weight, was more variable and not statistically different between the IPM and Conventional systems. However, the numerical differences in percent marketable heads, as illustrated in the frequency histogram (Figure 2) occur more consistently at the high end for the IPM program (3 years combined). Head contaminant levels were significantly lower in both the IPM and Conventional systems compared with the untreated check, for all 3 years of the study (Table 1).

Seasonal mean summaries of the impact of the IPM program, compared with the Conventional system are summarized in Table 2. Because of unique pest pressure each year, the number of sprays and control costs were variable, having a combined effect on final yields, marketability and profit. Despite higher control costs in 2000 for the IPM program, marketable yield was the highest ever (18.5% more than the Conventional). Subsequently, we observed the highest increase in net revenue in 2000, 107% higher than the Conventional system. Increases in net profit for the IPM program in 1998 and 1999, at 15.8 and 58.6%, respectively, are also notable. As noted in the 2nd row of Table 2, the IPM program incurs an annual, additional cost of $30/ha for scouting (pest monitoring fee). The added profits accrue despite this added cost, and the fact that the biologically based insecticides (SpinTor® and Proclaim®) are about three times more expensive than the pyrethroid (Warrior®) used by our grower.

We attribute the increased profit of the IPM program to more frequent, consistent scouting (twice per week), the use of a knowledgeable crop consultant (M.S. Entomology with 5 years vegetable IPM experience), and the ability to immediately apply an insecticide (within 24 h), when needed. To review, the Conventional system in this case relies on grower-based decisions (B.S. Agronomy; 20 years production experience), where scouting is typically employed only for the first spray; subsequent sprays are made every 10 days, or at times, when convenient for the grower. A good example of excellent timing, in a relatively low pest pressure year, was 1999, where only one IPM spray was applied (SpinTor®, Figure 1, Table 2).

Table 1. Mean (±SE) of seasonal infestation levels and yield and marketability data for the three-year on-farm trial; Apple Valley, Minnesota, U.S.A., 1998-2001

	1998			1999			2000		
	IPM	**Conv.**	**Check**	**IPM**	**Conv.**	**Check**	**IPM**	**Conv.**	**Check**
Cumulative season larval infestation[1]	4.29 ± 0.84 a	10.46 ± 1.51 b	21.04 ± 2.51 c	1.46 ± 0.28 a	11.41 ± 1.37 b	15.75 ± 1.97 b	3.44 ± 0.71 a	5.06 ± 0.83 a	10.33 ± 1.49 b
Marketability rating[2]	1.17 ± 0.04 a	1.53 ± 0.06 b	2.21 ± 0.08 c	1.47 ± 0.05 a	1.89 ± 0.08 b	4.02 ± 0.08 c	2.12 ± 0.08 a	2.67 ± 0.10 b	3.59 ± 0.09 c
Yield (kg/5 heads)	4.59 ± 0.22 a	4.28 ± 0.25 a	4.10 ± 0.21 a	4.91 ± 0.15 a	4.79 ± 0.21 a	4.93 ± 0.16 a	5.15 ± 0.17 a	4.49 ± 0.27 b	4.81 ± 0.20 ab
% Marketable heads[3]	97.83 ± 1.14 a	96.33 ± 1.96 a	87.33 ± 5.14 b	96.00 ± 1.84 a	91.00 ± 2.38 a	27.00 ± 6.06 b	81.83 ± 6.07 a	63.33 ± 10.78 a	38.33 ± 13.46 b
Contaminants[4]	0.00 ± 0.00 a	0.01 ± 0.01 a	0.11 ± 0.03 b	0.04 ± 0.03 a	0.03 ± 0.02 a	0.51 ± 0.16 b	0.09 ± 0.04 a	0.18 ± 0.06 a	0.77 ± 0.19 b

ANOVA based on 6 replications; means in a row, for each year, followed by same letter are not significantly different; REGWQ (P=0.05). Mean percentage of late instar cabbage looper and marketable heads were transformed using the arcsine transformation; contaminant counts were transformed using the square root transformation prior to ANOVA and mean separations using REGWQ (P=0.05); back transformed means are presented.

[1]Percentage of plants infested with late instar cabbage looper.

[2]U.S. 1-6 scale (Greene *et al*. 1969); 1 = no damage; 2 = minor feeding damage on wrapper or outer leaves; 3 = moderate insect feeding on wrapper or outer leaves with no head damage; 4 = moderate insect feeding damage on wrapper leaves and minor head damage; 5 = moderate to heavy feeding on wrapper and head leaves with head having numerous scars, over 30% of leaf area eaten; and 6 = considerable insect feeding on wrapper and head leaves with head having numerous feeding scars, over 30% of leaf area eaten.

[3]Number of marketable heads per 30 heads.

[4]Number of larvae and/or pupae per head (one or more pest species).

Table 2. Mean impact of the Cabbage IPM Program on number of sprays, control costs, marketable yield and increase in net revenue (profit), during three-year on-farm trial, Apple Valley, Minnesota, 1998-2001

	1998			1999			2000		
	Conv.	**IPM**	**Chk**	**Conv.**	**IPM**	**Chk**	**Conv.**	**IPM**	**Chk**
Number of sprays	7	4	--	3	1	--	2.67	3	--
Control costs $ /ha (spray/sampling costs)[1]	302/0	227/30	0/0	130/0	94/30	0/0	87/0	202/30	0/0
Marketable yield (%)[2]	--	+1.50	-9.00	--	+5.00	-64.00	--	+18.50	-25.00
Reduction in sprays (%)	--	43	--	--	66	--	--	+12	--
Reduction in control costs (%)	--	15	--	--	5	--	--	+167	--
Increase in net revenue (%)[3]	--	15.8	--	--	58.6	--	--	107.3	--

[1]Insect management costs for sprays is calculated using the following prices for Insecticides: SpinTor 2SC® (15 oz./ha) = $67.35/ha; Proclaim® (7.9 fl oz/ha) = $66.0/ha; Warrior® T (8 oz./ha) = $21.28/ha; Lannate® SP (2.5 lbs./ha) = $60.00/ha; and Surfactants: Bond (12 oz./ha) = $2.65/ha; Dyne-Amic (32 oz./ha) = $16.33/ha; Kinetic (8 oz./ha) = $5.45/ha; multiplied by the appropriate number of sprays. A $10.00/ha application fee was added for each application.

[2]Marketable yield refers to the increase or decrease in yield compared to the conventional plots.

[3]Increase in net revenue is calculated by comparing overall net revenue of a conventional system to an IPM system.

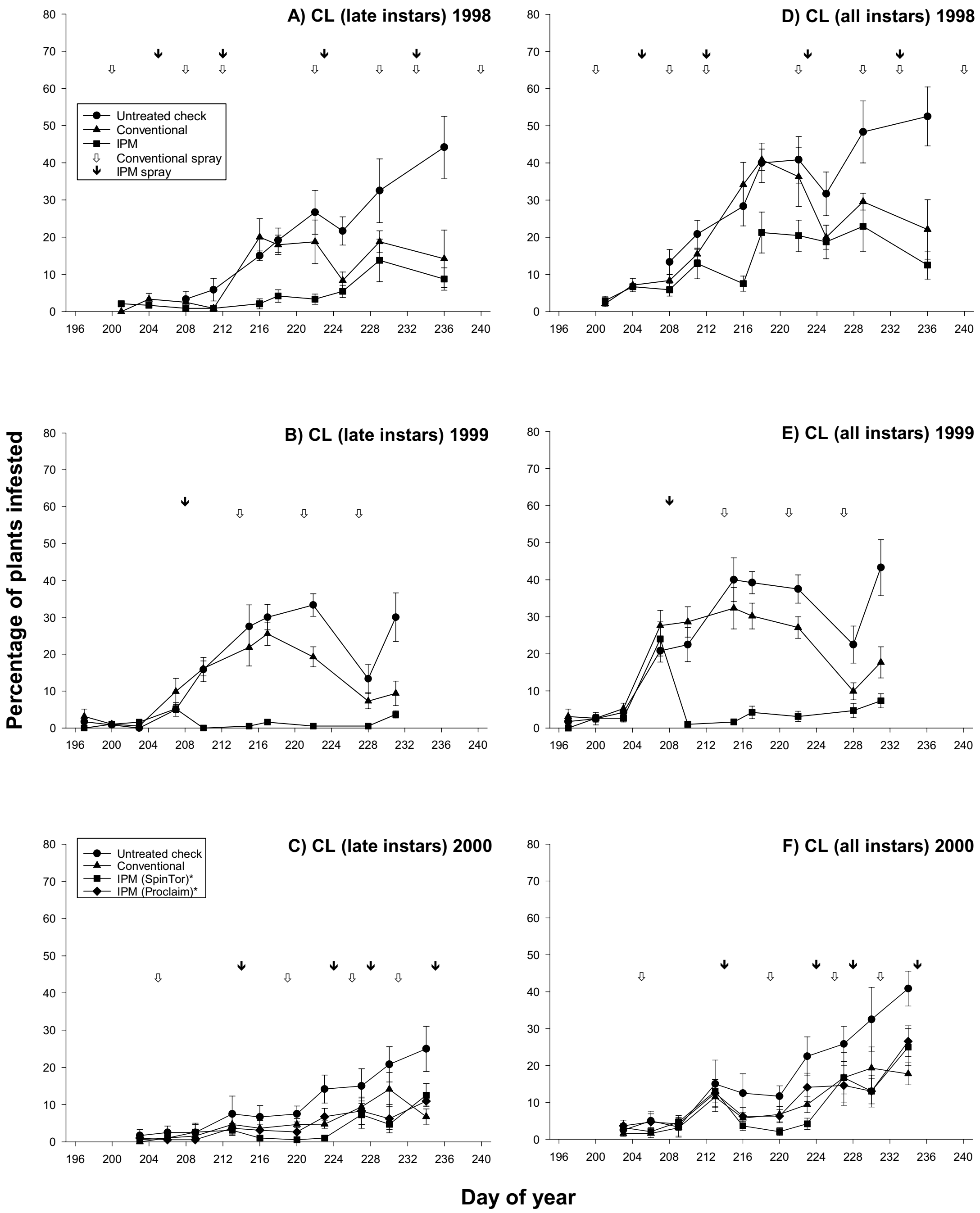

Figure 1. Phenology of cabbage looper (*Trichoplusia ni*) infestations for each management system, 1998-2000 (arrows refer to timing of sprays for each system, each year).

IPM risk-reward tradeoff

In addition to the traditional measures of economic impact, expected utility (Carlson 1970) and stochastic dominance (Moffitt *et al*. 1983, Burkness *et al*. 2002) methods were used to assess the overall risk of the IPM vs. Conventional programs. This type of analysis allows for a comparison of IPM and conventional control strategies, which incorporates economic benefits and a measure of risk (i.e. standard deviation and coefficient of variation of the expected value). This analysis (Table 3) revealed that the IPM program provides 6.4X higher profits ($973/ha) over the Conventional system ($151/ha). Moreover, the IPM program has about 46% less risk (lower standard deviation) over the Conventional system (Table 3). The untreated check, which reflects a “do nothing” strategy, shows that on average a grower would lose $2,949/ha by ignoring insect pests.

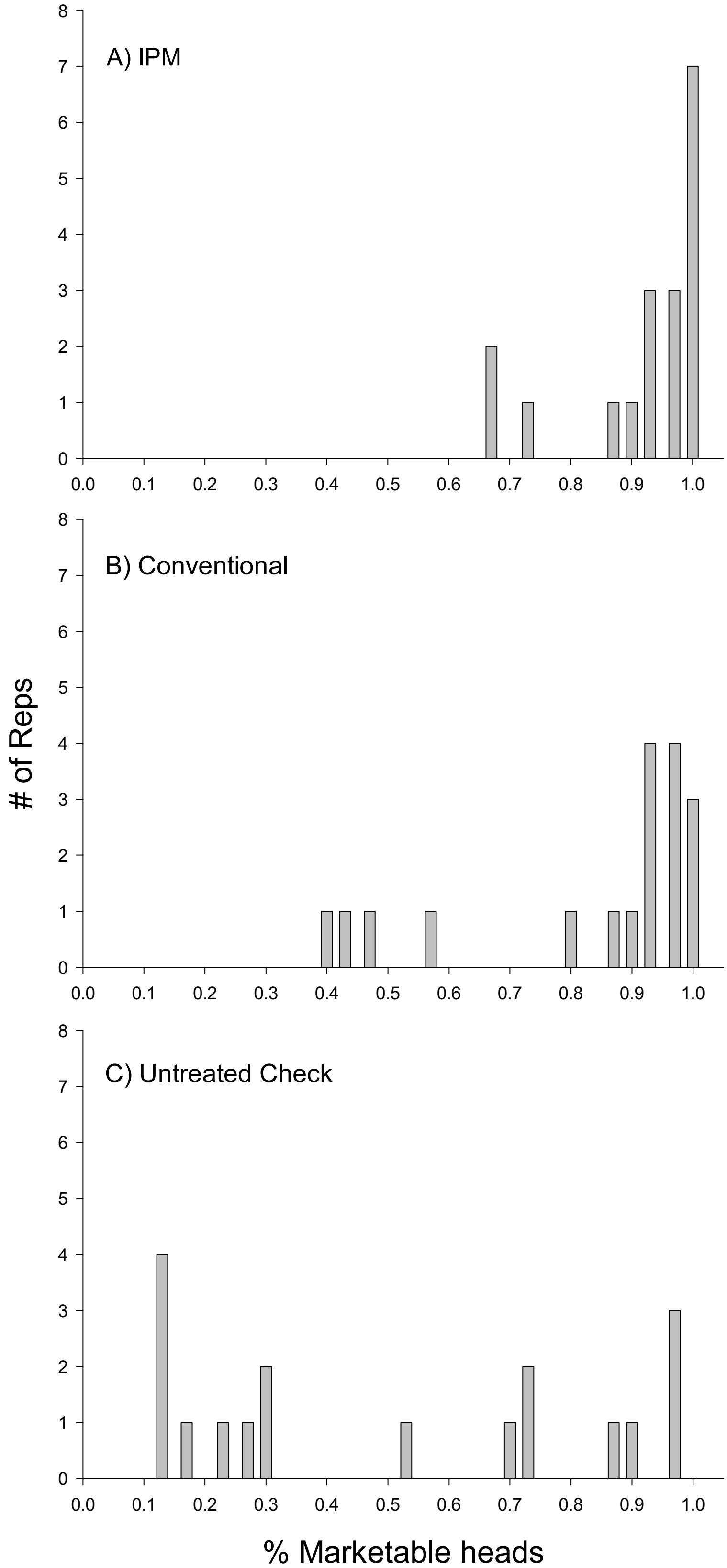

Figure 2. Frequency of marketable cabbage heads for three management systems, 1998-2000.

Table 3. Expected utility and standard deviation (risk) ($/ha) for various pest management strategies, cabbage on-farm trial, Apple Valley, Minnesota, USA, 1998-2000

	Expected value[1] (US$/ha)	**Standard Deviation[1] (US$/ha; Risk)**	**Coefficient of Variation**
Gross Revenue			
IPM	9,258	1109	0.12
Conventional	8,418	2062	0.25
Untreated Check	5,133	3317	0.65
Net Revenue			
IPM	973	1040	1.07
Conventional	151	1944	12.90
Untreated Check	-2,949	3285	1.11

[1]Expected value (utility) and standard deviation calculated according to the formula of Carlson (1970) and Burkness *et al*. 2002.

In addition to the expected utility results, we used the pooled 3-year data set to further assess the variability in percentage marketability (Figure 2) for each pest management system. These data were then used to calculate the distribution of gross and net revenue for each system. Here, we present the cumulative probability distribution functions (CDF) for gross and net revenue per ha (Figure 3). Formally, this analysis is known as stochastic dominance (Moffitt *et al*. 1983) and simply incorporates the variability (risk) of each system, for every possible revenue outcome. The results for this study indicate first degree stochastic dominance (FSD), with no overlap or intersection of the CDFs for each strategy. Thus, the CDF that is farthest to the right-hand side of the graph (IPM system) is the preferred, most profitable system.

Given these results, expected utility theory therefore suggests that both risk-averse and risk-taking growers should be very motivated to adopt an IPM approach for cabbage (e.g. Fleisher 1990). If the IPM approach had higher net revenue but also high risk (i.e., standard deviation greater than the Conventional), most risk-averse growers might be inclined to stay with the Conventional system. With this example, incorporating the field and pest infestation variability over three seasons, the risk and reward analysis is clearly in favour of the IPM program, with both the highest expected net profit and lowest profit risk.

In summary, the IPM program provided the highest expected profit with the least profit risk (net revenue variability) compared with the Conventional strategy and untreated check (Table 3). These results confirm that the economic benefits of an IPM approach for cabbage are sustainable over time, despite variable pest and weather dynamics. As a key component of this analysis, the results also highlight the value of having an experienced crop consultant involved with IPM decision-making. In this system, much of the consulting value was attributed to advanced IPM knowledge, but also availability (scouting twice per week when needed). The grower was often too busy with other production and marketing activities to devote the time necessary for pest monitoring. The initial, preliminary response by Minnesota vegetable growers to these results has been very positive. The results tend to fit their perspective on production risks, providing answers to questions like, …“IPM is too risky and crop consultants cost too much; how can I experience a profit?” or,… “how often will I see increased profits?” Via new outreach efforts, including field days and easy-to-use brochures, we plan to use this information to better communicate the value of IPM and further the adoption of cabbage IPM in the Midwestern U.S.

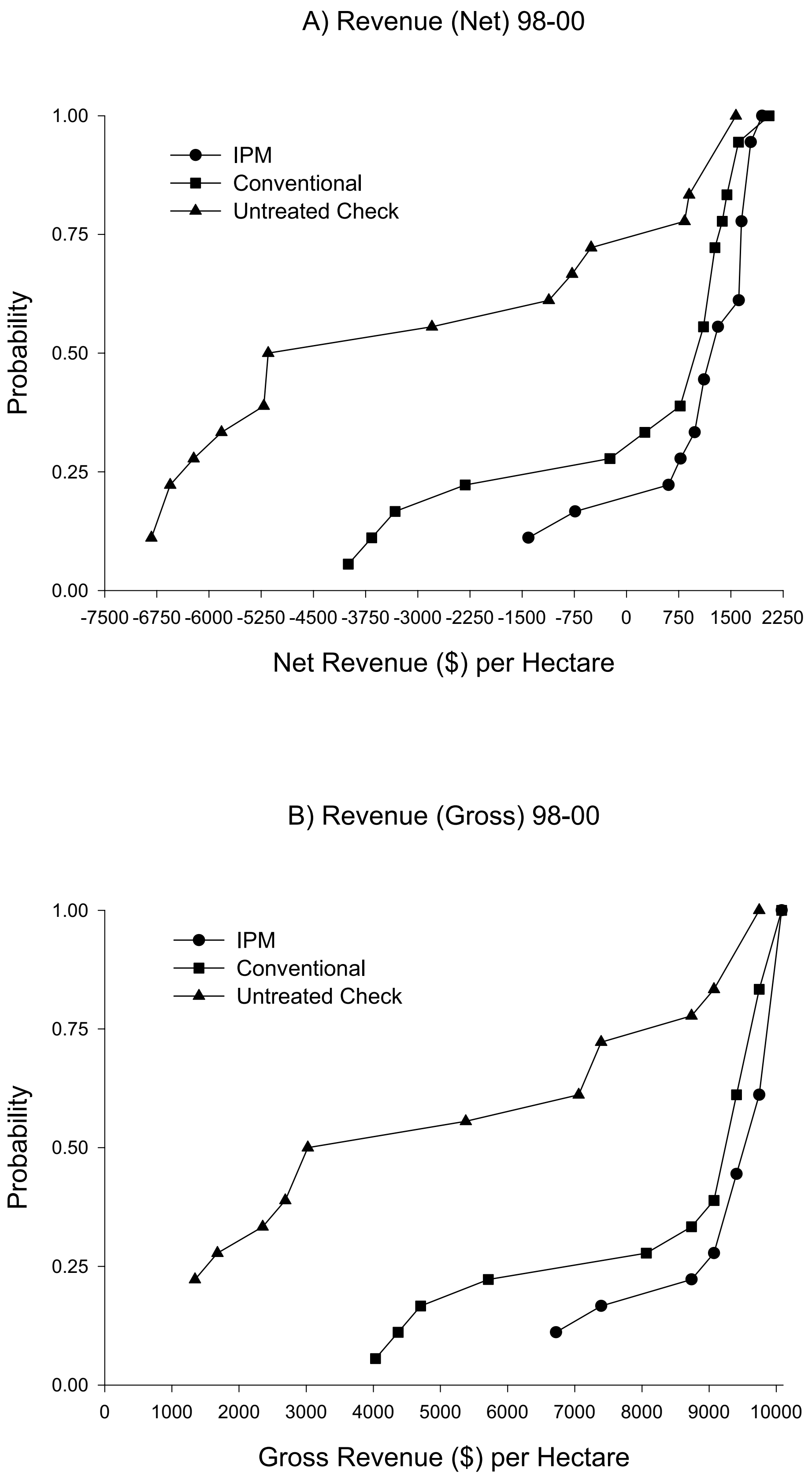

Figure 3. Cumulative probability distribution functions (CDF) for net and gross revenue based on observed frequency histograms for each cabbage management system, 1998-2000.

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References

Burkness EC, Hutchison WD, Weinzierl RA, Wedberg JL, Wold S & Shaw JT. 2002. Efficacy and risk efficiency of sweet corn hybrids expressing a *Bacillus thuringiensis* toxin for Lepidopteran pest management in the Midwestern U.S. *Crop Protection* **21,** 157-169.

Carlson GA. 1970. A decision theoretic approach to crop disease prediction and control. *American Journal of Agricultural Economics* **52**, 216-223.

Eastman C, Mahr S, Wyman J, Hoy C & Oloumi-Sadeghi H. 1995. Cabbage, broccoli, and cauliflower. In: *Vegetable insect management with emphasis on the Midwest*. (eds R Foster & B Flood). Meister Publishing Co., Willoughby, OH, pp. 99-110.

Fleisher B. 1990. *Agricultural risk management*. Lynne Rienner Publishers, Inc. Boulder, CO.

Greene GL, Genung WG, Workman RB & Kelsheimer EG. 1969. Cabbage looper control in Florida – a cooperative program. *Journal of Economic Entomology* **62**, 798-800.

Hines RL. 1998. Biologically intensive integrated pest management of the lepidopteran pest complex in Minnesota cabbage. M.S. Thesis, University of Minnesota, St. Paul, Minnesota.

Hines RL & Hutchison WD. 2001. Evaluation of action thresholds and spinosad for lepidopteran pest management in Minnesota cabbage. *Journal of Economic Entomology* **94**, 190-196.

Kogan M. 1998. IPM: Historical perspectives and contemporary developments. *Annual Review of Entomology* **43**, 243-270.

Liu T-X, Sparks Jr. AN, Hendrix III WH & Yue B. 1999. Effects of SpinTor (Spinosad) on cabbage looper (Lepidoptera: Noctuidae): toxicity and persistence of leaf residue on cabbage under field and laboratory conditions. *Journal of Economic Entomology* **92**, 1266-1273.

Moffitt LJ, Tanigoshi LK & Baritelle JL. 1983. Incorporating risk in comparisons of alternative pest control methods. *Environmental Entomology* **12**, 1003-1011.

Plant RE & Stone ND. 1991. *Knowledge-based systems in agriculture*. McGraw-Hill, Inc., New York, NY.

Radcliffe EB & Hutchison WD eds. 2002. *World IPM textbook*. World Wide Web URL:http://ipmworld.umn.edu University of Minnesota, St. Paul, MN.

SAS Institute. 1988. SAS user's guide: statistics. SAS Institute, Cary, NC.

Sparks TC, Thompson GD, Kirst HA, Hertlein MB, Larson LL, Worden TV & Thibault ST. 1998. Biological activity of the spinosyns, new fermentation derived insect control agents, on tobacco budworm (Lepidoptera: Noctuidae) larvae. *Journal of Economic Entomology* **91**, 1277-1283.

Weires RW & Chiang HC. 1973. Integrated control prospects of major cabbage insect pests in Minnesota: based on the faunistic, host varietal, and trophic relationships. *University of Minnesota, Agricultural Experiment Station. Technical Bulletin* **291**, pp. 40-42.