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Article

A Cost–Benefit Analysis of Novel IPM-Based Approaches to Onion Thrips Management in US Dry Bulb Onions

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Abstract: Onion thrips, *Thrips tabaci* (Lindeman), is a major pest of dry bulb onion throughout the US and across the world. Yield and quality damage from thrips feeding and the expense of insecticides used for thrips management have jeopardized profitable and sustainable onion production. To improve approaches to thrips management, researchers in multiple US onion-producing regions developed novel, integrated pest management (IPM)-based strategies employing threshold-based insecticide treatments and reduced fertilization practices. The purpose of this study was to estimate the benefits from public investment in research to develop IPM-based onion thrips management techniques using a cost–benefit analysis. Benefits were extended over a 20-year timespan and were measured by reduced insecticide and fertilizer costs. The estimated net present value of benefits from improved pest management tactics will depend on the adoption and use of novel approaches to management. Using a scenario that assumes a maximum adoption rate of 58%, the estimated net present value of the research is $15.91 million, the benefit–cost ratio is 4.00, and the internal rate of return is 32%. Assuming a scenario with a maximum adoption rate of 29%, the estimated net present value of the research is $8.3 million, the benefit–cost ratio is 3.34, and the internal rate of return is 24%. Even when estimated assuming conservative adoption scenarios, results indicate a healthy return on investment in research to develop and refine new approaches to manage onion thrips and optimize dry bulb onion production.

Keywords: innovative onion management; economic impact of onion research; ROI agricultural research; action thresholds; fertilizer reduction

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1. Introduction

1.1. Onion Pests, Production, and Marketing

Onion thrips, *Thrips tabaci* (Lindeman), is a tiny, slender-bodied insect that has piercing-sucking mouthparts that attack onion and can transmit *Iris yellow spot virus* (IYSV) [1,2]. Thrips feeding and IYSV infection reduce the photosynthetic capacity of the plant [3], which results in reduced bulb size [4,5] and damages onion storage quality [6]. Thrips feeding also predisposes onion plants to fungal and bacterial diseases [2]. The level of economic damage from thrips feeding and IYSV varies, but severe epidemics can result in complete crop loss [7,8]. Persistent pressure from onion thrips, IYSV, and circumstances associated with COVID-19 pandemic-related market disruptions have intensified the need for managerial tactics that can improve the profitability and sustainability of US dry bulb onion production.

Onion production in the US is characterized by a large capital outlay and is labor- and input-intensive [9,10]. The magnitude of investment required for onion production creates a high level of risk, providing an incentive to employ judicious thrips management strategies to protect the quality and marketability of the crop. In recent production cycles, the level of risk has become more pronounced because of price volatility in key inputs, including fertilizers and insecticides. The rise in average national prices reported by the United States Department of Agriculture (USDA) prices paid index highlights the magnitude of price fluctuations. The aggregate fertilizer category, which includes nitrogen, mixed fertilizer, potash, and phosphate rose 89% from February 2020 to February 2022; insecticide prices rose 13% over the same timeframe [11,12].

The challenges of profitable onion production are not limited to input price risk. A high degree of market price risk has also jeopardized the ability to re-coup investment in onion crops. Growers in the largest western US onion-producing regions such as Idaho, Oregon, and Washington often tailor production practices to achieve larger onion bulb sizes because of price premiums [13] and marketability to the food service sector. However, the marketability of larger bulb sizes depends heavily on consumer tastes and preferences for food away from home (FAFH) driving restaurant demand for onions, a key linkage disrupted by the COVID-19 pandemic. Previous studies [14] have documented the impact of the pandemic on FAFH expenditure and visits to restaurants. Compared to the same timeframe in the previous year, a 29% reduction in average total dollars spent on FAFH in March through May of 2020 was estimated. Restaurant transactions during the week of 24 March 2020 were estimated to be 37% lower than the number of transactions reported for the same week in the previous year. During the week of 12 April 2020, restaurant transactions dropped by 47% compared to the same week in 2019. By the last week of December 2020, restaurant transactions were still 11% below the level of transactions recorded during the same timeframe in the previous year [14]. Since 40% of US onion production is estimated to be marketed to restaurants [15], the impact of the pandemic on FAFH expenditures and restaurant visits had a pronounced impact on onion markets.

Analysis of weekly shipping point price data [16] in March of 2020 further quantifies the impact of the pandemic on the marketability of ample supplies of valuable large-sized onions from the western US. Colossal-sized yellow onions produced in the 2019 crop cycle that were stored and shipped from the Columbia Basin growing region of Washington and Oregon during the height of pandemic shutdowns were priced between $2.04 and $2.95 per 22.68 kg sack lower than those shipped at the same time in the previous year. Super Colossal-sized bulbs from the Idaho and Eastern Oregon onion growing region shipped during the last weeks of March 2020 were priced between $2.49 and $2.95 per 22.68 kg sack lower than those shipped in the same timeframe in the previous year. Larger-sized bulbs produced during the 2020 crop cycle that were stored and shipped from the western US throughout 2020 and 2021 were also impacted by lower pricing throughout the marketing year compared to non-COVID-19 circumstances [16]. In the western US, the 2021 production cycle did not provide an opportunity for producers to rebound from market disruptions. Haze from western wildfires and hot growing conditions contributed to bulb yields that were 25–30% lower than those recorded in the 2020 production cycle, which further exacerbated the financial challenges of onion production [17,18].

Onion production systems across the US and worldwide are characterized by diverse and unique growing conditions that are influenced by region-specific climate conditions and soil properties, yet the development of more economical and sustainable strategies for thrips management has represented a unified and ongoing research need [9,19–26]. In the US, the primary tool for thrips management in major onion-growing regions has been the use of multiple insecticides typically applied on a calendar-based schedule. Costs for season-long insecticide application programs for the management of thrips will vary, but typical spray regimes have been estimated to range from $469 to $815 per hectare [25,27,28].

In addition to expense, thrips management is challenged by evolving tolerance and resistance to classes of insecticides [27–34]. Utilization of action-based thresholds is one technique that may slow the development of resistance and reduce costs. The action threshold for onion thrips is defined by the number of thrips per plant that will cause economic damage if managerial action is not taken [35]. When action thresholds are used, insecticide applications are not executed until thrips populations reach or exceed the threshold, creating the potential to reduce the overall number of insecticide applications needed to protect the crop throughout the season. The need to develop more holistic, integrated approaches to management has also motivated the exploration of an improved understanding of the interaction between fertilization practices and thrips populations. However, the impact of different fertilization strategies has been mixed depending on the production region [24,36–38].

1.2. Field Research

As part of an integrated project to address the most serious pests and diseases threatening the US allium industry, researchers in major onion-growing regions sought to determine if concomitant strategies employing action threshold-based insecticide treatments and reduced fertilization could improve the management of thrips without affecting the yield of dry bulb onions. Field studies were conducted over three years (2019–2021) in Malheur County, Oregon, and throughout western and central New York. Results from Malheur County are assumed to be applicable to other major onion growing regions in western US because of similarities in climate and thrips management techniques [8,39].

Field studies conducted in Malheur County, Oregon, produced varying results pertaining to best management practices for delivering insecticide applications. In 2019, there was a lack of thrips damage, which may have been caused by an uncharacteristically cool and wet spring [40]. The lack of early-season thrips, and damage in general, inhibited the ability to draw accurate conclusions regarding optimal insecticide use in 2019 [41]. Results from 2020 provided evidence to support the use of action-based thresholds to optimize profit [42] and yield of bulbs grading in the super colossal and colossal size classes [43]. Using action-based thresholds also resulted in one less application of insecticide being made compared to a calendar-based insecticide application program [43].

In 2021, the greatest total marketable yield and profit were achieved using a calendar-based insecticide application schedule [42]; however, the calendar-based program did not produce the greatest yield of bulbs grading in the larger colossal and super colossal size classes [41]. Even though profit was maximized from the greater overall marketable yield achieved by the calendar-based application program, the higher profit was driven by uncharacteristically high prices for the jumbo-size class [16]. Since the value of individual size classes will vary from year to year, the profit achieved from the threshold-based program could have outperformed the profit achieved from the calendar-based program under more typical market conditions. In 2021, the use of action-based thresholds resulted in two fewer applications of insecticides compared to the calendar-based program [41].

Data from 2020 and 2021 supported the use of action-based thresholds as an effective technique for thrips management, but reductions in the number of insecticide applications varied. In order to avoid overestimation of the benefits achieved from employing action threshold-based thrips management tactics, benefits are estimated based on the assumption of reducing the number of insecticide applications by one. The results of nitrogen fertilization practices were conclusive across all years of the study. Rates of fertilization were not found to impact onion thrips populations [41]. Standard fertilizer programs based on soil and tissue tests outperformed reduced fertilization programs, optimizing profit in all years of the study [42].

Research from New York [38] indicated the concomitant strategy of reductions in fertilizer and the use of action-based thresholds for the execution of spray applications as an effective managerial tactic for more profitable production of dry bulb onions. Results were consistent across all three years of the study and suggested an average reduction of 2.3 insecticide applications per season could be achieved if threshold-based application methods were used. The ability to reduce insecticide applications by a greater number in New York onion-growing regions compared to western regions was expected because of differences in climate and overall thrips and virus pressure. Like the research conducted in the western US, fertilizer rates did not impact thrips populations; however, in the eastern US, the yield was not impacted by a reduction in fertilizer use. The lack of yield response to a reduction in fertilizer may be attributable to the rich muck soils characteristic of New

York onion-producing regions. Results from field studies indicate growers in New York could reduce nitrogen, phosphorous, and potassium fertilizer use by 43%, 36%, and 60%, respectively, without impacting yield [38]. To evaluate the return on public investment in the development and use of novel approaches to the management of dry bulb onions, a cost–benefit analysis was conducted.

1.3. Objective

The ability to make more informed decisions regarding the necessity of fertilizer use and the execution and timing of insecticide applications targeting onion thrips could improve the sustainability and profitability of onion production systems across the US. The objective of this study was to analyze returns to society from public investment in agricultural research resulting from the development of novel IPM-based approaches to manage onion thrips in dry bulb onions. The benefit–cost ratio, net present value, and internal rate of return (IRR) were used as metrics for evaluation. The analysis estimated benefits that could be achieved through a reduction in the use of synthetic fertilizers and insecticides in onion-growing regions of New York, and reductions in insecticide use in major onion-growing regions of the western US, including the Treasure Valley region of western Idaho and eastern Oregon, and the Columbia Basin onion growing region of Washington and Oregon.

1.4. Previous Studies

Cost–benefit analyses can be used to evaluate alternative investments by comparing different flows of costs against projected benefits over a specific period [44]. Cost–benefit analysis of IPM for a variety of crops, research protocols, and timeframes are documented in the domestic and international agricultural sectors. An important contribution to the literature [45] considers how returns to investment in IPM research could differ depending on the level of stakeholder collaboration. When evaluating the adoption of IPM-based spray application programs to replace calendar-based spray application schedules in mango production, public–private partnerships were found to be especially important for garnering the adoption of IPM-based practices and maximizing returns from investment. The analysis addressed a key factor for consideration when projecting the adoption of IPM-based approaches to management, but narrowly defined public–private partnership by only considering monetary investment as a research contribution [45]. As a result, the impact of the important contributions of in-kind investments in research, such as time or space, were omitted from consideration in the IPM adoption process.

Another important aspect of investment in agricultural research involves the evaluation of the feasibility of positive returns when long-run investments for the development of IPM practices are required [46]. Consideration of the length of time required to develop IPM-based approaches for challenging and evolving pests offers critical insight as to how the monetary investment required to revise IPM recommendations impacts overall returns. In the case of leaf beetles, the investment in research exceeded a 30-year timespan yet still produced a positive result, yielding an internal rate of return of 7.5% [46].

In the US, no research has been conducted to estimate returns on investment in IPM and novel approaches to the management of onion crops. However, investment in IPM and improved management practices for potatoes, a crop similar in capital and input intensiveness [9], has been evaluated. The economic impacts of investments in breeding and genetics that would reduce pesticide use were estimated by employing an ex-ante cost–benefit analysis. Return from investment in the Pacific Northwest potato variety development program was estimated to be 35% [47]. Returns from investment in IPM decision support tools for potato psyllid management in the Pacific Northwest states of Idaho, Oregon, and Washington have also been evaluated [48]. The benefits of decision support tools were estimated based only on reduction in the use of spirotetramat, an active ingredient commonly applied for the management of psyllids. The estimated internal rate of return was dependent on the adoption rate and was projected to range between 8% and 14% [48].

2. Materials and Methods

The costs and benefits of the research were evaluated at the farmer level, the institution level, and from the perspective of society over time using assessment guidelines for economic evaluation of IPM projects as a framework [44]. The net present value, benefit–cost ratio, and internal rate of return were used as evaluation metrics. Consistent with previous studies on the adoption of agricultural innovations in high-value vegetable crops [47,49,50], the estimated benefits will be probabilistic because they depend on the successful adoption of new approaches to management.

Mathematical Model

The methodology used in previous research [48] was employed for the estimation of the gross annual benefits resulting from fewer insecticide applications and reductions in the use of synthetic fertilizers.

The benefits per hectare were summed over all hectares currently treated with insecticides and fertilizer as:

$$\sum_{j=1}^{N} (\beta_{jt}) = \sum_{j=1}^{N} H_j{}^i(I) + H_j{}^f(F) \quad (1)$$

Where

β_{jt} = the dollar value of benefits achieved from reducing the number of insecticide applications and fertilizers in the jth region in year t.

$H_j{}^i$ = hectares currently treated with insecticides in the jth region

$I =$ net decrease in insecticide costs ($/hectare) due to the adoption of threshold-based spray application programs

$j =$ the regions considered in the study

$H_j{}^f$ = hectares currently treated with fertilizer in the jth region

F = net decrease in fertilizer costs ($/hectare) due to adoption of new fertilization practices

The gross annual benefit β_{jt} is probabilistic since it depends on the probability of the rate of adoption $P(A_k)$. We define the expected value of β_{jt},

$$\sum_{j=1}^{n} E(\beta_{jt}) = \sum_{j=1}^{n} \sum_{k=t}^{t+T} \beta_{jt} P(A_k) \quad (2)$$

Where:

$k =$ the period when the benefits are achieved

$T =$ the total duration of time over which benefits are accrued in region j

To estimate the net present value (NPV) of the flow of benefits, we discount the right side of Equation (2)

$$\sum_{j=1}^{n} PE(\beta_{jt}) = \sum_{j=1}^{n} \sum_{k=t}^{t+T} \frac{\beta_{jt} P(A_k)}{(1+r)^k} \quad (3)$$

Where $PE(\beta_{jt})$ is the present value of the expected dollar value of benefits achieved from reducing insecticide and fertilizer applications in the jth region in year t. The social discount rate is represented by r; we apply a rate of 2.5%. This is the risk-free rate reported for 20-year bonds by the Office of Management and Budget for use in cost–benefit analysis of federal programs [51]. The adoption rate used is discussed in the Results Section.

The flow of costs resulting from the development of IPM is represented as

$$C_k = \sum_{t=0}^{\pi} (D_t + M_t + O_t) \quad (4)$$

C_k represents the total costs required to research and develop IPM approaches for the management of dry bulb onions, maintain extension and outreach activities, and implement new management tactics on the farm. D_t *is* the direct cost of conducting field research to develop and refine new approaches for the management of thrips. M_t is the cost required to maintain extension and outreach activities in support of IPM-based thrips management strategies. O_t is the operational cost required to implement IPM-based approaches to management on the farm.

The net present value of the expected flow of gross annual benefits is estimated by subtracting the costs estimated in Equation (4) from the benefits in Equation (3)

$$\sum_{j=0}^{n} PE(\beta_{jt}) = \sum_{j=1}^{n} \sum_{k=t}^{t+T} E(\beta_{jt}) - C_k/(1+r)^k \quad (5)$$

The internal rate of return (IRR) is found by solving the following equation:

$$\sum_{k=t}^{t+T} \left\{ \left(E(\beta_{jt}) - C_{kt} \right) / (1 + IRR)^k \right\} = 0 \quad (6)$$

3. Results and Discussion

3.1. Adoption of Agricultural Innovations

Adoption of agricultural innovations can be impacted by multiple factors such as the type of innovation or economic forces [52], and a variety of techniques can be used to estimate the adoption and diffusion patterns of new agricultural practices. Producer surveys are straightforward and widely used techniques for the estimation of the adoption of innovations in agriculture [53]. However, one of the key limitations of survey-based approaches to assessing adoption is a potential lack of familiarity with the new practice [54]. The specific practices evaluated in this analysis have only been field-tested in three crop cycles and pandemic precautions in the early years of the study limited usual face-to-face outreach activities such as field days that would assist in enhancing grower awareness of new approaches to management. As a result, we assumed limited awareness of the new practices and expected limited success from the use of survey methodology.

The technique broadly referred to as the historical trends approach [55] projects the adoption of a new agricultural innovation based on past adoption rates of similar innovations. However, the success of the historical trends approach is dependent on the availability of relevant data [56]. In the case of dry bulb onions, time series data on a national scale pertaining to the adoption of new innovative approaches to management are limited. USDA pest management surveys that would improve understanding of the diffusion of IPM-based practices are reported as an aggregate measure that encompasses 22 vegetable crops [57]. As a result, the ability to draw inferences regarding the adoption and diffusion of new approaches to management specific to onion crops is difficult.

To account for data limitations, we modeled the adoption of new managerial tactics for dry bulb onions by combining the Bass diffusion model with recent data documenting the adoption of similar pest management strategies [25]. Previous research indicated that the Bass model can be successfully applied in agricultural settings [48,58,59] and Bass-type modeling can be a flexible, mathematically robust method for estimating sigmoid-shaped curves [60].

The basic equation takes the form:

$$n(t) = (p + qN(t))(m - N(t))$$

Where:

$n(t)$ = percent of adopters during time t
p = coefficient of innovation
q = coefficient of imitation
$N(t) = \sum_{j=0}^{t} n(j)$ percent of adopters at time t
m = maximum adoption rate

The exact innovation or imitation parameters for the adoption of new management practices in onions are not known. However, previous researchers [48] have successfully utilized averages to estimate innovation and imitation parameters when the availability of data was limited. Consequently, the average values for the coefficients of innovation and imitation reported in a meta-analysis of 213 sets of diffusion models examining a variety of innovations were used as proxies [61]. The average value for the coefficient of innovation was 0.03; the average value for the coefficient of imitation reported in the same study was 0.38. Both parameters are important because the adoption of IPM practices will be driven by innovators and imitators. Innovators will adopt new production practices due to external influence from sources such as extension, while imitators will adopt an agricultural innovation as a result of farmer-to-farmer communication [59]. The simplifying assumptions subject the estimates to error because the average parameters may not accurately capture the unique factors contributing to the adoption of new approaches to the management of dry bulb onions.

Adoption is assumed to begin at the time the new practice or technology would be available for use 55]. Our model assumes growers could begin using action-based thresholds and reducing fertilizer applications in the year 2022. In scenario I, adoption is assumed to begin at 1% in 2022 and reaches a maximum adoption rate of 58% in the year 2041 (Table 1). The maximum adoption rate is taken from previous research that evaluated the adoption of insecticide resistance management practices (IRM) in dry bulb onions [25]. While the adoption of IRM practices does not establish the adoption and use of action-based thresholds or reduced fertilization practices, in the absence of any other data, it does provide a reasonable proxy for estimation. We applied this scenario to all regions considered in the analysis. A sensitivity analysis was performed to allow for the evaluation of a less optimistic adoption scenario. Scenario II assumes that adoption begins at 1% in 2022 and reaches a maximum adoption rate of 29% in 2041, half of the adoption rate estimated in Scenario I (Table 1).

Table 1. Projected adoption profile scenarios.

Year	Projected Adoption Profile (%) Scenario I	Projected Adoption Profile (%) Scenario II
2022	1%	1%
2023	3%	2%
2024	6%	4%
2025	9%	6%
2026	14%	8%
2027	19%	11%
2028	25%	14%
2029	32%	17%
2030	38%	20%
2031	43%	23%
2032	48%	25%
2033	51%	26%
2034	54%	27%
2035	55%	28%
2036	56%	28%
2037	57%	29%
2038	57%	29%
2039	58%	29%
2040	58%	29%
2041	58%	29%

3.2. Estimation of Baseline Hectares Treated with Insecticides and Fertilizer

Baseline estimates of the number of hectares treated with insecticides in major onion-growing regions in the western US and New York are calculated using the USDA chemical use survey for onions and USDA estimates of area planted. In the western US states of Oregon and Washington, 100% of planted hectares were reported to be treated with insecticides [62]. Since the chemical use survey for onions was not conducted in Idaho and the major dry bulb onion-growing region in the state is adjacent to Oregon's major onion-growing region, we assume the estimates reported for Oregon are an accurate proxy for Idaho. As a result, 100% of planted hectares in Idaho are assumed to be treated with insecticides. The chemical use survey for New York indicates that 98% of onion hectares were reported to be treated with insecticides [62]. The USDA data did not consistently report the number of applications of each active ingredient assessed in the survey for all states of interest. As a result of limited reporting, we rely on previous research to provide perspective on the frequency of thrips-targeted insecticide applications. Regardless of region, estimates suggest between five and nine insecticide applications are typically used to manage thrips in a typical growing season [39,63,64].

Baseline estimates of the number of hectares treated with nitrogen, phosphorous, and potassium fertilizers in New York onion-growing regions are calculated using the USDA fertilizer use survey for onions and USDA estimates of area planted. Fertilizer use was not reported in 2020, thus data reported in 2018 were used as a proxy. An estimated 99% of planted hectares were treated with nitrogen-, phosphorous-, and potassium-based fertilizers in 2018 [65]. When data for hectares treated were combined with data for planted hectares, a total of 3125 hectares of New York onions were estimated to be treated with fertilizer. Baseline estimates of the number of hectares treated with fertilizer in western US onion-growing regions were omitted based on the assumption that reduced fertilization practices would not be adopted in the region. Research results suggested that reductions in fertilizer use could jeopardize yield of valuable large-sized onion bulbs in the western US, reducing overall profit [42].

3.3. Estimation of Gross Annual Benefits

An example from 2022 illustrates how the gross annual benefits are calculated. A total of 21,448.37 hectares were estimated to be treated with insecticides in the major dry bulb onion-growing regions located in western US. If one insecticide application [43] valued at the three-year average price of $89.06 per hectare [10,66,67] is eliminated on 1% of hectares currently treated with insecticides, $19,101.20 in benefits would be achieved. In New York, a total of 3093.42 hectares of dry bulb onions were estimated to be treated with insecticides. If an average of 2.3 insecticide applications [38] with an estimated three-year average price of $204.83 per hectare are eliminated on 1% of New York hectares currently treated with insecticides, an estimated $6336.26 in benefits would be achieved.

No benefits from reductions in fertilizer were assumed to be achieved in onion-growing regions located in the western US. However, in New York, additional benefits from the dollar value of savings from reducing nitrogen, phosphorous, and potassium fertilizer applications would accrue. A total of 3125 hectares of dry bulb onions were estimated to be treated with the three key fertilizer components used in New York onion production. The three-year average prices of nitrogen, phosphorous, and potassium fertilizers were estimated to be $1.20, $1.30, and $0.97 per kilogram, respectively [10,66,67]. The maximum recommended rates for nitrogen, phosphorus, and potassium fertilizers required to produce onions in New York are 140 kg per hectare, 168 kg per hectare, and 168 kg per hectare, respectively. If an average of 60 kg of nitrogen per hectare was eliminated (43% reduction), the estimated savings would be $71 per hectare. If an average of 61 kg of phosphorous per hectare was eliminated (36% reduction), the estimated savings would be $79 per hectare. Eliminating the use of 100 kg of potassium per hectare (60% reduction) would result in savings of $87 per hectare. The combined savings from a reduction in the use of nitrogen, phosphorous, and potassium fertilizers would total $236.92 per hectare. If fertilizer use valued at $236.92 per hectare is eliminated on 1% of New York hectares currently treated with each key fertilizer component, an estimated $7413.12 in benefits would be achieved. The benefits from reductions in input use in each US onion-producing region would combine for a total gross annual benefit of $32,850.58 in 2022 (Table 2). The gross annual benefits are expected to expand each year as more growers adopt new approaches to management. If the projected adoption rates in scenario I are achieved, gross annual benefits would exceed $1.9 million annually by the year 2041. If the adoption rates projected in Scenario II (Table 3) are achieved, the gross annual benefits would accrue to $951,230.18 by the year 2041 (Table 3).

Table 2. Estimated costs and benefits of novel IPM-based approaches to onion thrips management: scenario I.

Year	Direct Cost	Maintenance Cost	Operational Cost	Total Cost	Gross Annual Benefit	Net Benefits
2018	$125,096.00			$125,096.00	$0.00	−$125,096.00
2019	$172,947.00			$172,947.00	$0.00	−$172,947.00
2020	$186,422.00			$186,422.00	$0.00	−$186,422.00
2021	$126,952.00			$126,952.00	$0.00	−$126,952.00
2022		$20,000.00	$6450.50	$26,450.50	$32,850.58	$6400.08
2023		$20,000.00	$19,889.78	$39,889.78	$101,293.08	$61,403.29
2024		$20,000.00	$37,673.27	$57,673.27	$191,859.36	$134,186.09
2025		$20,000.00	$60,641.23	$80,641.23	$308,828.76	$228,187.53
2026		$20,000.00	$89,354.47	$109,354.47	$455,057.20	$345,702.73
2027		$20,000.00	$123,742.89	$143,742.89	$630,187.77	$486,444.88
2028		$20,000.00	$162,724.18	$182,724.18	$828,708.53	$645,984.35
2029		$20,000.00	$204,006.83	$224,006.83	$1,038,949.48	$814,942.65
2030		$20,000.00	$244,361.20	$264,361.20	$1,244,462.97	$980,101.76
2031		$20,000.00	$280,462.06	$300,462.06	$1,428,314.50	$1,127,852.44
2032		$20,000.00	$309,954.33	$329,954.33	$1,578,510.36	$1,248,556.02
2033		$20,000.00	$332,082.93	$352,082.93	$1,691,205.09	$1,339,122.16
2034		$20,000.00	$347,526.21	$367,526.21	$1,769,853.34	$1,402,327.14
2035		$20,000.00	$357,714.54	$377,714.54	$1,821,739.65	$1,444,025.11
2036		$20,000.00	$364,170.80	$384,170.80	$1,854,619.61	$1,470,448.80
2037		$20,000.00	$368,152.94	$388,152.94	$1,874,899.52	$1,486,746.58
2038		$20,000.00	$370,566.85	$390,566.85	$1,887,192.88	$1,496,626.03
2039		$20,000.00	$372,014.44	$392,014.44	$1,894,565.07	$1,502,550.62
2040		$20,000.00	$372,876.87	$392,876.87	$1,898,957.16	$1,506,080.29
2041		$20,000.00	$373,388.65	$393,388.65	$1,901,563.51	$1,508,174.86
Total	$611,417.00	$400,000.00	$4,797,754.99	$5,809,171.99	$24,433,618.41	$18,624,446.43
					IRR	32%

Table 3. Estimated costs and benefits of novel IPM-based approaches to onion thrips management: scenario II.

Year	Direct Cost	Maintenance Cost	Operational Cost	Total Cost	Gross Annual Benefit	Net Benefits
2018	$125,096.00			$125,096.00	$0.00	($125,096.00)
2019	$172,947.00			$172,947.00	$0.00	($172,947.00)
2020	$186,422.00			$186,422.00	$0.00	($186,422.00)
2021	$126,952.00			$126,952.00	$0.00	($126,952.00)
2022		$20,000.00	$6450.50	$26,450.50	$32,850.58	$6400.08
2023		$20,000.00	$14,235.59	$34,235.59	$72,497.84	$38,262.26
2024		$20,000.00	$24,418.31	$44,418.31	$124,355.61	$79,937.29
2025		$20,000.00	$37,365.44	$57,365.44	$190,291.67	$132,926.23
2026		$20,000.00	$53,219.10	$73,219.10	$271,029.94	$197,810.84
2027		$20,000.00	$71,704.29	$91,704.29	$365,169.79	$273,465.50
2028		$20,000.00	$91,968.35	$111,968.35	$468,368.96	$356,400.61
2029		$20,000.00	$112,587.39	$132,587.39	$573,375.95	$440,788.56
2030		$20,000.00	$131,855.24	$151,855.24	$671,501.69	$519,646.45
2031		$20,000.00	$148,299.25	$168,299.25	$755,246.41	$586,947.16
2032		$20,000.00	$161,140.35	$181,140.35	$820,642.53	$639,502.18
2033		$20,000.00	$170,404.03	$190,404.03	$867,819.88	$677,415.85
2034		$20,000.00	$176,670.97	$196,670.97	$899,735.63	$703,064.66
2035		$20,000.00	$180,712.88	$200,712.88	$920,319.92	$719,607.04
2036		$20,000.00	$183,235.09	$203,235.09	$933,164.84	$729,929.75
2037		$20,000.00	$184,775.36	$204,775.36	$941,009.00	$736,233.64
2038		$20,000.00	$185,703.26	$205,703.26	$945,734.55	$740,031.29
2039		$20,000.00	$186,257.61	$206,257.61	$948,557.66	$742,300.06
2040		$20,000.00	$186,587.11	$206,587.11	$950,235.74	$743,648.63
2041		$20,000.00	$186,782.38	$206,782.38	$951,230.18	$744,447.80
Total	$611,417.00	$400,000.00	$2,494,372.48	$3,505,789.48	$12,703,138.36	$9,197,348.88
					IRR	24%

3.4. Research Costs

The direct costs corresponding to the field research and data analysis required to evaluate the new approaches to thrips management were estimated to be $125,096 in year one, $172,947 in year two, $186,422 in year three, and $126,952 in year four. The cost to maintain extension outreach programs, support farm field days, refine approaches to novel IPM-based practices, and disseminate information to stakeholders was estimated to be $20,000 per year (Tables 2 and 3). Farmers would incur increased operational costs to implement new approaches to thrips management and fertilization practices (Tables 2 and 3). Scouting for pests is a practice that has been documented to be widely used in vegetable crops [57]; however, we assume that those who adopt threshold-based management practices would monitor crops more intensively. The additional costs associated with increased scouting efforts are derived from adjusting estimates of willingness to pay for scouting reported in previous research [25] and are estimated to be $24.71 per hectare. Additionally, we assume that New York growers adopting reduced fertilization practices would engage in more judicious soil nutrition monitoring and allocate $12.36 per hectare [67] to implement additional soil tests.

3.5. Limitations of the Analysis

The gross annual benefits of novel approaches to manage onion thrips and optimize dry bulb onion production are estimated using the assumption that the use of action-based thresholds could facilitate a reduction in insecticide application in onion-growing regions of the western US. In the eastern US, benefits are estimated based on the assumption of reduced insecticide applications and fertilizer use. The adoption profiles estimated in this analysis were scenario-based. The most optimistic adoption scenario assumed that adoption began at 1% and reached a maximum adoption rate of 58%. The second scenario was more conservative, assuming that adoption began at 1% and reached a maximum adoption rate of 29%. The use of different adoption scenarios would result in different evaluation outcomes.

The actual coefficients of innovation and imitation for the adoption of novel approaches to dry bulb onion management are not known. The use of the averages of the coefficients of innovation and imitation as proxies for adoption also subjects the estimates to error. Further, we do not know how public–private partnerships in the form of in-kind contributions such as the provision of land by commercial onion growers for conducting field research in New York impact the coefficient of imitation. It is possible that such in-kind contributions will improve the adoption and diffusion of public research, enhancing returns to society. This analysis assumed that maintenance costs were constant; however, changes associated with staff salaries or operating budgets would alter evaluation outcomes. The benefits of the adoption of new approaches to onion thrips management and optimization of dry bulb onion production are estimated to span 20 years; however, spreading the benefits over a different period would also change the evaluation metrics.

The estimation of benefits was based only on the value of reductions in fertilizer and insecticide use. Benefits from changes in yields or quality resulting from the adoption of new management approaches in dry bulb onions were not considered in the analysis. However, the assumption of no change in yields or quality could lead to underestimation of the benefits of utilization of action-based thresholds for insecticide applications because the ability to better time applications of insecticides could improve yields. Our analysis also used historical three-year average prices to estimate the dollar value of benefits from reductions in input use. However, this approach could have led to an underestimation of benefits due to the rapid rise in farm input costs [12].

4. Conclusions

We performed a cost–benefit analysis of novel, IPM-based approaches to onion thrips management in major dry bulb onion-growing regions across the US. In our model, benefits were measured by the dollar value of savings resulting from reductions in fertilizer and insecticide use. The results of our analysis highlight the potential impact of new management tactics that could reduce fertilizer use and improve the ability to make informed decisions regarding the timing and execution of insecticide applications through the utilization of action-based thresholds. Using a scenario that assumed a maximum adoption rate of 58%, the estimated net present value of the research was estimated to be $15.91 million, the benefit–cost ratio was estimated to be 4.00, and the internal rate of return was 32%. Assuming a scenario with a maximum adoption rate of 29%, the estimated net present value of the research was $8.3 million, the benefit–cost ratio was 3.34, and the internal rate of return was 24%. Even when conservatively estimated, investment in research to develop and refine new approaches to manage onion thrips and optimize dry bulb onion production illustrated a healthy return on public investment in research. Future research after sufficient time has elapsed is needed to evaluate the actual adoption of new production practices and to identify any barriers to the adoption of new practices. Additional research is also required to improve understanding of how public–private partnerships in the form of in-kind contributions such as land for conducting field trials impact the adoption of new agricultural practices.

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