Understanding Growers' Decisions to Manage Invasive Pathogens at the Farm Level

Annemarie Breukers, Marcel van Asseldonk, Johan Bremmer, and Volkert Beekman

First and second authors: LEI, part of Wageningen UR, P.O. Box 8130, 6700 EW, Wageningen, The Netherlands; and third and fourth authors: LEI, part of Wageningen UR, P.O. Box 29703, 2502 LS, The Hague, The Netherlands.
Accepted for publication 23 February 2012.

ABSTRACT

Breukers, A., van Asseldonk, M., Bremmer, J., and Beekman, V. 2012. Understanding growers' decisions to manage invasive pathogens at the farm level. Phytopathology 102:609-619.

Globalization causes plant production systems to be increasingly threatened by invasive pests and pathogens. Much research is devoted to support management of these risks. Yet, the role of growers' perceptions and behavior in risk management has remained insufficiently analyzed. This article aims to fill this gap by addressing risk management of invasive pathogens from a sociopsychological perspective. An analytical framework based on the Theory of Planned Behavior was used to explain growers' decisions on voluntary risk management measures. Survey information from 303 Dutch horticultural growers was statistically analyzed, including regression and cluster analysis. It appeared that growers were generally willing to apply risk management measures, and that poor risk management was mainly due to perceived barriers, such as high costs and doubts regarding efficacy of management measures. The management measures applied varied considerably among growers, depending on production sector and farm-specific circumstances. Growers' risk perception was found to play a role in their risk management, although the causal relation remained unclear. These results underscore the need to apply a holistic perspective to farm level management of invasive pathogen risk, considering the entire package of management measures and accounting for sector- and farm-specific circumstances. Moreover, they demonstrate that invasive pathogen risk management can benefit from a multidisciplinary approach that incorporates growers' perceptions and behavior.

Globalization causes increasing exposure of plant production systems to invasive (also called nonnative) pests and pathogens (10,46). Well-known examples from the past decades include outbreaks of citrus canker (caused by *Xanthomonas citri* subsp. *citri*) in, among others, the United States and Australia (18,22); the advance of western corn rootworm (*Diabrotica virgifera virgifera*) in Europe (35); and the spread of *Phytophthora ramorum* in North American and European nurseries and natural and semi-natural environments (21). International regulations exist to prevent the introduction and further spread of invasive organisms (12,13). The list of regulated pests and pathogens grows steadily, and entails increasing expenses on inspections of imported and traded plant products and of production sites. Yet, such measures could, at best, prevent further spread through intervention, and their effectiveness is the result of intensity and frequency—and, thus, the costs—of inspection.

Stakeholders involved in plant production chains, growers in particular, can provide an important contribution to the management of invasive pests and pathogens. For instance, the likelihood of introduction of harmful organisms at the farm scale can be significantly reduced by using certified seed or planting material, restraining visitors' access, or requiring contract workers to use clean machinery. Regular scouting will support early detection, if an introduction on the farm has nevertheless occurred. Taking suitable quarantine measures may then prevent further spread within the farm and to other farms and, thus, minimize the impact of an outbreak. Farm-level measures reduce risks for the entire production chain, as a result of which monitoring intensity can be relaxed; which, in turn, leads to lower management costs. Thus, sharing responsibilities in invasive pest and pathogen risk management between government and production sector offers mutual benefits.

Although this conclusion seems obvious, in practice, large differences in farm-level risk management exist both within and between plant production sectors. The consequences of an outbreak of an invasive pest or pathogen often transgress the infested farms, causing sector-wide invasive pest and pathogen risk management to become a collective effort. Therefore, it is important that all growers in a production sector are able and willing to take their responsibility. Achieving this requires insight into growers' motivations regarding whether or not to apply management measures. Once the incentives and barriers growers experience in applying farm-level risk management measures are understood, effective intervention strategies can be designed to further improve risk management at the farm level.

A growing public concern regarding invasive plant pests and pathogens has boosted scientific research on analysis and management of the risks they impose. Much research is devoted to qualifying and quantifying risks (4,20,27,31,40,44) to improve the process of pest risk assessment that underlies decisions to control a pest (14). Also, methodologies are developed and applied to select cost-effective risk management strategies (7,9,11,37). Although these studies are important in the development of risk management strategies and tools, they usually do not address risk management at the level of individual growers. Moreover, they are based on the assumption that growers always make rational decisions based on objective risk assessment (34). Yet, it is well known that a person's assessment of the likelihood of an adverse event (e.g., the introduction of an invasive pest or pathogen) is, by definition, subjective and biased by heuristics such as familiarity with a pathogen or the ease with which previous outbreaks are remembered (43). Moreover, along with expected profit, factors

Corresponding author: A. Breukers; E-mail address: Annemarie.breukers@wur.nl

http://dx.doi.org/10.1094/PHYTO-06-11-0178

such as risk aversion and social pressure also determine human behavior (1,28).

Studies on farmers' behavior regarding other management issues (33,41,45) illustrate that accounting for people's subjective perceptions and beliefs can greatly improve the effectiveness of risk management. Yet, as far as behavioral aspects have been studied in the domain of plant health (15,24,32,42), they tend to focus on risks *following* from plant health management (e.g., environmental and health risks) rather than on risks *requiring* plant health management. In line with this, their aim is to reduce undesirable but common behavior, whereas nonnative pest and pathogen risk management concerns the stimulation of desirable but (still) unadopted behavior.

Public health research, as opposed to plant health research, commonly deals with the behavioral component in risk management. Examples of risks frequently addressed in relation to human behavior are pandemics, AIDS, cancer, obesity, and car accidents (6,23,25,38,39). A frequently applied method in this field of research as well as in other disciplines is the Theory of Planned Behavior (TPB), a cognitive model for studying human action in which a person's intention to perform a particular behavior is determined by attitude, subjective norms, and perceived behavioral control (1,2). Another widely used theory that studies human health-related behavior is the Health Belief Model (HBM), which considers the perceived threat imposed by a disease as a motivation to perform protective behavior (26). Heong and Escalada (24) modified the HBM framework into a Pest Belief Model to explain insecticide spray behavior of rice farmers, showing its applicability in disciplines other than public health.

The present study focuses on the growers' perspective toward invasive pest and pathogen risk management. More specifically, it aims to provide insight into the decision-making process of growers with respect to voluntary management of the risk associated with invasive pests and pathogens at the farm level. We present an analytical framework, which is structured according to the TPB, extended with a risk perception component as included in the HBM. We used this framework in an empirical analysis of survey information from Dutch growers of various horticultural crops. In doing so, we (i) tested the applicability of the TPB in explaining growers' invasive pest and pathogen risk management, (ii) identified factors affecting growers' risk management, and (iii) analyzed whether and how growers' risk perception relates to their risk management. In the remainder of this article, the term "invasive pathogens" refers to both pathogens and pests.

MATERIALS AND METHODS

Analytical framework. The analytical framework is based on the TPB, a theory that aims to explain or predict human behavior in specific contexts (1). According to the TPB, a person's intention to perform a particular behavior follows from three determinants: attitude, subjective norms, and perceived behavioral control (Fig. 1). Attitude toward the behavior refers to the degree to which a person has a favorable or unfavorable evaluation of the behavior in question. Subjective norm refers to the perceived social pressure on performing the behavior. Finally, perceived behavioral control (pbc) refers to the extent to which one expects to be able to perform the intended behavior. Each determinant follows from personal beliefs (i.e., perceived advantages and disadvantages, other people's opinions, and impeding or facilitating factors) and the evaluation of these beliefs in terms of importance (i.e., the extent to which the beliefs play a role in the person's decision-making). In summary, behavioral intention is determined by the extent to which a person considers oneself willing, allowed, and able to perform the behavior in question.

If the behavior in question concerns risk mitigation, as is the case with invasive pathogen risk management, a person's risk perception may play a significant role in individual behavior. This hypothesis is supported by the HBM, in which behavior depends on two variables: the *perceived* threat of becoming ill, and the *perceived* likelihood of being able to reduce that threat (26). Therefore, risk perception was included as a fourth determinant in our analytical framework. Risk is defined here as the product of the probability of an (adverse) event and its potential consequences (36). Therefore, perceived risk refers to a person's subjective personal assessment of the probability and consequences of experiencing the particular event. According to HBM, risk perception affects behavior directly. However, we hypothesize that risk perception may, instead, have an indirect effect on behavior, via attitude. The reasoning behind this is that perceived benefits of risk management measures and, thus, attitude increase as the perceived risk increases.

People perceive risks differently for a number of reasons. One of the factors that is believed to affect a grower's risk perception is previous experience. People estimate the likelihood of an event by the ease with which they can imagine or recall past instances of the event, suggesting a positive relation between previous experience and risk perception (43). On the other hand, lack of experience has been reported to increase people's risk perception, implying a negative relation (5). Another factor for which both positive and negative correlations with risk perception have been found is knowledge (17). Knowledge and previous experience are likely to be interrelated, because information and skills acquired by a grower through experiencing an outbreak might have enhanced the knowledge on this specific subject.

In the empirical analysis presented below, the behavior of interest was "applying management measures on the farm to reduce invasive pathogen risk". We tested the descriptive value

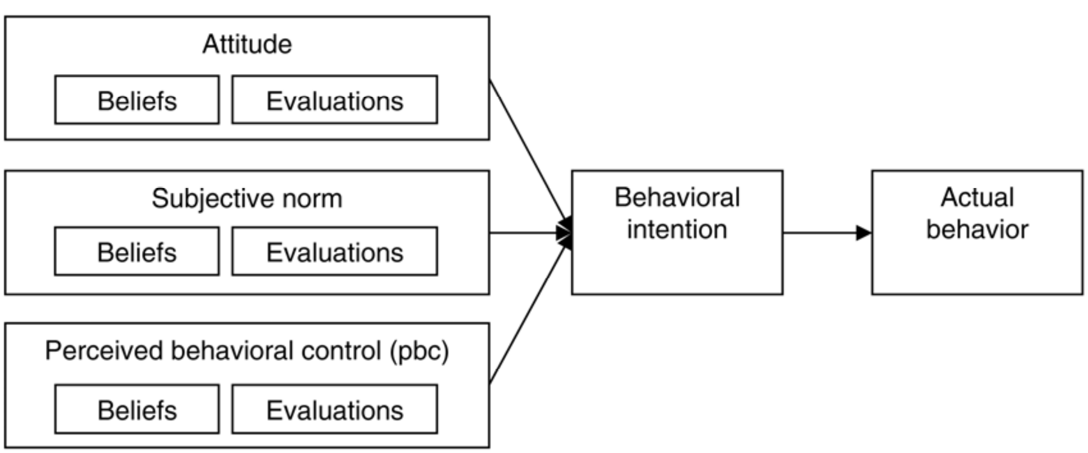

Fig. 1. Structure of the Theory of Planned Behavior. Adapted from Ajzen (1).

and practical applicability of the TPB in this context. Also, we evaluated whether perceived risk of invasive pathogens affects grower's risk management. Because the position of risk perception in the analytical framework is uncertain, both hypotheses (i.e., direct effect on behavior or indirect effect via attitude) were tested. Furthermore, we investigated the presumed correlations between risk perception and past experience and knowledge of invasive pathogens. Finally, cluster analysis was performed to identify farm-specific characteristics that explain why growers act differently with respect to management of invasive pathogen risk.

Data and measurements. A survey was conducted among growers in three distinct horticultural (case) sectors (i.e., the tomato, tulip bulb, and strawberry production sectors). Participating tomato growers produced final product (tomato fruit), while tulip bulb growers grew tulip bulbs for propagation purposes. The participating strawberry growers produced strawberry as planting material, strawberries, or both. Three case organisms were selected per production sector (Table 1), which were illustrative for invasive pathogen risk. Selection criteria were (i) quarantine status or similar nature (i.e., low probability and high potential impact) (13), (ii) at least some familiarity in the respective production sector, and (iii) at least to some extent manageable by farm-level management measures. For the tomato production sector, *Clavibacter michiganensis* subsp. *michiganensis* (causing bacterial canker), *Tomato yellow leaf curl virus* (TYLCV), and *Tuta absoluta* (tomato leaf miner) were selected. Selected tulip bulb pathogens were *Ditylenchus dipsaci* (stem and bulb eelworm), *Tulip virus X* (TVX), and *Arabis mosaic virus* (AMV). For the strawberry production sector, *Xanthomonas fragariae* (the angular leaf spot pathogen), *Phytonemus pallidus* subsp. *fragariae* (strawberry mite), and *Phytophthora fragariae* or *P. cactorum* (red stele or crown rot) were chosen.

The survey was conducted by means of Computer-Assisted Personal Interviewing. The questionnaire used in the interviews started with a section on structural characteristics, describing the specific circumstances of the farm and grower. The following information was collected: production acreage, production region (province), soil types or growth medium, land use condition (owned versus hired land), estimated number of other tomato (or tulip bulb or strawberry) farms within a 10-km distance, production aim (propagation material, plants for planting, and end product), main activity in terms of labor investment, origin of planting material, cooperation with other colleagues (e.g., shared machinery or personnel), use or performance of contract work, participation in networks (e.g., study group or growers' union), presence of organic crop production, and future perspective (still active within 5 years from now or not).

Subsequent questions aimed at quantification of the elements in the analytical framework and are summarized in Table 2. The grower's "risk perception" for each case organism was quantified by measuring his expected frequency of having an infestation on the farm and the expected potential consequences of an infestation. Both elements were measured on ordinal scales, the product of which was used as a risk perception score for one case organism. It is generally agreed that someone can only perceive risk when one is aware of its existence. Therefore, the grower's risk perception was only measured for case organisms he had heard of before. Values for these organisms were averaged to determine overall risk perception. For the other organisms, risk perception was treated as a missing value.

"Knowledge" was quantified in two ways: recognition of symptoms and knowledge of sources of introduction on the farm. Recognition of symptoms was tested by means of nine pictures, six of which could be associated with one of the case organisms and the other three representing injuries caused by other pests or diseases, or symptoms of deficiencies. Scores for each case organism were calculated as the total number of pictures correctly associated with the organism, weighted by the sum of pictures that should be associated, pictures incorrectly associated (false positives), and pictures incorrectly not associated (false negatives) with the organism. Scores could range between 0 and 1, and the average over all three case organisms represented overall recognition. Knowledge of sources of introduction was measured as a binary variable indicating whether a grower was self-reportedly aware of the most important sources or not. Further quantification of this variable was not possible, because sources considerably vary in importance, some of which even experts are uncertain about. "Past experience" was measured as a binary variable, a grower either having encountered an infestation with a case organism in the past or not.

Although behavioral intention is the dependent variable in the TPB, we measured growers' actual "behavior" to avoid socially desirable answers. This is justified by the fact that, in all three production sectors, relevant circumstances have not recently changed (i.e., no outbreaks, new emerging risks, or changes in risk management options). Actual behavior was measured on the basis of 17 risk measures. These were formulated in cooperation with sector experts and divided over five categories: farm hygiene, crop plan, scouting, logistics, and intervention in case of an outbreak. The categories and number of management measures per category were the same for the three production sectors; the measures, however, were sector specific (Table 3). The score per category could range between 0 and 1 and was calculated by dividing the number of management measures actually taken by the total number of measures in the respective category. Overall behavior was quantified on a continuous scale from 0 to 1 as the average of all category scores, all categories having equal weights.

Questions for quantification of "attitude", "subjective norm", and "pbc" were designed according to the guidelines for designing a TPB questionnaire as defined by Francis et al. (16). Each determinant was measured by means of three or four propositions (Table 2). Growers were asked to indicate how much they agreed or disagreed with these propositions. Answers were measured on a seven-point Likert scale, which is a bipolar symmetric scaling method commonly used to measure opinions. A four was considered neutral; higher values were associated with agreement, while lower levels implied disagreement. Questions phrased in a negative way were recoded in the analysis by mirroring the scale. Answers to the propositions were then averaged to obtain a value for attitude, subjective norm, and pbc. In addition, growers were asked about their beliefs and evaluations regarding seven aspects (variables) associated with the respective determinant. These variables were selected on the basis of outcomes of a qualitative exploration preceding the survey, in which personal and group interviews with stakeholders of horticultural production chains were held. The product of a grower's

TABLE 1. Selected case study organisms per production sector

Organism	Tomato	Tulip bulb	Strawberry
A	*Clavibacter michiganensis* subsp. *michiganensis* (bacterial canker)	*Ditylenchus dipsaci* (stem and bulb eelworm)	*Xanthomonas fragariae* (angular leaf spot)
B	*Tomato yellow leaf curl virus* (TYLCV)	*Tulip virus X* (TVX)	*Phytonemus pallidus* subsp. *fragariae* (strawberry mite)
C	*Tuta absoluta* (tomato leaf miner)	*Arabis mosaic virus* (AMV)	*Phytophthora fragariae* or *P. cactorum* (red stele or crown rot)

belief and evaluation regarding a variable provided an indicator of its perceived importance in determining the grower's attitude, subjective norm, or pbc. Beliefs and evaluations were both scored on seven-point Likert scales, one of which ranged from –3 to +3 to differentiate not only between important and unimportant variables but also between positively and negatively rated variables.

Data analysis. SPSS 17.0 was used for the statistical analyses. The reliability of the measures for attitude, subjective norm, and pbc was tested, using Cronbach's Alpha as an indicator. This coefficient determines the inter-item correlation (i.e., the internal consistency of the set of propositions comprising each measure).

Overview and comparison of production sectors regarding elements of the TPB. By means of analysis of variance (ANOVA), the three production sectors were tested for significant differences in behavior, attitude, subjective norm, and pbc. Although the three determinants of behavior are essentially ordinal variables, it has been shown that the *F* test is robust to violations of the interval data assumption and that ANOVA can be applied to Likert-scale type of data with no resulting bias (8).

TABLE 2. Questions used for quantification of the elements in the analytical framework

Questions	Possible answers	Type and range of variable
Risk perception		
How high do you estimate the average frequency of an infestation with organism X on your farm per year?	0 (never); <1; 1; >1	Ordinal (0–3)
What do you consider the possible consequences of an infestation with organism X on your farm? (multiple answers possible)	Loss of turnover; (temporary) crop growth restrictions or extra measures; trade restrictions; reputation damage; bankruptcy. Consequences can occur at farm, sector, or both	Ordinal (0–10)
Knowledge		
Are you aware of the most important sources of infestation with organism X in your crop?	Yes; no	Nominal
Which associations do you have with the following photo? (9 photos in total)	Organism A; Organism B; Organism C; other disease, pest or deficiency; don't know	Nominal
Past experience		
Have you had an infestation with organism X in your crop in the past?	Yes; no	Nominal
Behavior		
Do you apply measure Y on your farm?	Yes; no	Nominal
Attitude		
I consider the application of measures to manage harmful organisms…	Very much disagree–Very much agree	Ordinal (1–7)
Important		
Fair		
Useless (recoded)		
The measures I apply…	Very unlikely–Very likely	Ordinal (1–7)
Reduce the likelihood of infestation		
Reduce the consequences of an infestation		
Increase product quality		
Increase my farm profit		
Improve the reputation of my farm		
Contribute to farm continuity		
Contribute to the reputation of my sector		
I consider… (e.g., reducing the probability of infestation):	Very unimportant–Very important	Ordinal (–3 to +3)
Subjective norm		
I'm expected to…		
Most people who are important to my farm think I should…		
I feel pressure to…		
apply measures to manage harmful pathogens	Very much disagree–Very much agree	Ordinal (1–7)
The following people or institutions want me to apply measures to manage invasive pathogens:	Very much disagree–Very much agree	Ordinal (–3 to +3)
Buyers		
Advisors		
Colleagues in the neighborhood		
Colleagues I cooperate with		
Collective (e.g., growers organization, sector organization)		
My employees		
Suppliers		
In deciding on the application of measures to manage invasive pathogens, I consider the opinion of … (e.g., buyers) … important	Very much disagree–Very much agree	Ordinal (1–7)
Perceived behavioral control		
I'm convinced that, if I wanted to, I'd be able to …		
It is difficult for me to … (recoded)		
It is not completely up to me whether or not I… (recoded)		
It's out of my control whether or not I… (recoded)		
apply measures to manage harmful pathogens	Very much disagree–Very much agree	Ordinal (1–7)
The measures that are advised to manage invasive pathogens …	Very much disagree–Very much agree	Ordinal (1–7)
Are not always effective on my farm		
Go together with high costs		
Require specific facilities on my farm (e.g., space, equipment)		
Require specific knowledge		
Require much time from me		
Do not always have an obvious merit to me		
Sometimes conflict with legislation		
Applying measures to manage invasive pathogens becomes more difficult for me if… (e.g., they are not always effective) (recoded)	Very much disagree–Very much agree	Ordinal (–3 to +3)

Relationships between the elements of the TPB, including risk perception. The association between behavior, attitude, subjective norm, pbc, and risk perception was measured by means of Spearman's correlation coefficient (ρ), which is a nonparametric correlation measure based on rankings of the variables. Next, the relations between different elements of the TPB were analyzed with the following (multiple) linear regression model: $Y(\text{behavior})_j = \beta_0 + \beta_1 \times \text{attitude}_j + \beta_2 \times \text{subjective norm}_j + \beta_3 \times \text{pbc}_j + \varepsilon_j$, where β_0 is a constant, j refers to the respondent, β_i is a vector of parameters to be estimated, and ε is the residual (or error term), assumed to follow a standard normal distribution.

The regression model was estimated for each production sector as well as for the entire survey population. In the latter analysis, two sector dummy variables were included (the strawberry production sector being the reference group) to account for structural differences between the production sectors. The normality assumption behind the regression analyses was confirmed by means of normal probability plots of the residuals.

Risk perception in relation to knowledge and past experience. Differences in risk perception between the three production sectors were investigated using the Mann-Whitney U test. This nonparametric test compares ranks of the variable of interest between two populations to determine whether they have significantly different distributions or not. The same test was used to analyze whether growers with previous experience or self-reported knowledge about sources of introduction (both binary variables) differed in risk perception from growers who had not. Spearman's correlation coefficient was used to test whether recognition of symptoms was correlated to risk perception.

Effect of farm-specific characteristics on behavior. Cluster analysis was applied to partition the general population of growers per production sector into segments with different farm-specific characteristics. A two-step cluster algorithm in SPSS was applied, which handles both continuous and categorical variables. The log-likelihood distance measure was used. The number of clusters was fixed at three, as a compromise between too much variation within one cluster and cluster sizes too small to interpret cluster characteristics. Clusters were composed on the basis of farm variables that met the following criteria: (i) relevance for the particular production sector and (ii) a reasonable level of variation within the sector (in order to be able to distinguish between groups of farms). Due to these criteria, the final set of cluster variables varied per sector.

RESULTS

The questionnaire was completed by 304 growers in total. In each production sector, the survey population was compared with the entire sector population in terms of population size, geographical distribution, and farm size (Table 4). On the basis of these three structural characteristics, the survey populations were considered representative for their respective sectors.

Growers' management of the risk of pathogen invasion. Average scores for behavior were similar among the three production sectors, the tulip bulb growers performing slightly poorer than the other two types of growers (Table 5). However, large differences existed regarding the type of management measures taken (Fig. 2). Whereas tomato growers performed rather well with respect to on-farm prophylactic measures, the average tulip bulb or strawberry grower implemented less than half of the corresponding management measures. The opposite was true for farm logistic measures. In each production sector, 75% of all management measures or more were adopted by at least 50% of all growers. Yet, the average score for behavior was <0.7 (i.e., 70%) in most categories of measures, suggesting that the actual set of adopted measures varied considerably among growers.

Growers' attitude, subjective norm, and pbc toward invasive pathogen risk management. Reliabilities of the measures

TABLE 3. Risk management measures per sector included in the survey

Category	Tomato sector	Tulip bulb sector	Strawberry sector
1. Farm hygiene	Use of disinfection mats at entrances and corridors	Weekly cleaning of processing areas and machinery	Use of disinfection mats at entrances and corridors
	Restricted access to greenhouse	Restricted access to farm and fields	Restricted access to farm and fields
	Obligatory special clothing for personnel and visitors	Contract workers enter the field with cleaned machinery	Obligatory special clothing for personnel and visitors
	Employees not working on other tomato farms	Employees not working on other tulip bulb farms	Employees not working on other strawberry farms
	Disinfection of knifes at the end of each row	Each lot is stored in disinfected crates, boxes etc.	Each lot is stored in disinfected crates, boxes etc.
2. Crop plan	Disinfection of greenhouse, equipment and irrigation system at crop rotation	Machinery is disinfected in between two fields	Machinery and equipment is disinfected in between two fields/zones
	Crop debris is removed at the time of crop rotation	Crop debris is removed after harvest	Crop debris is removed after harvest
3. Scouting/monitoring	At least once a week thorough scouting	At least once a week thorough scouting in field	At least once a week thorough scouting
	Instructions to personnel about symptoms of pests and diseases	Instructions to personnel about symptoms of pests and diseases	Instructions to personnel about symptoms of pests and diseases
	Regular testing of soil or plant samples	Regular testing of soil or plant samples	Regular testing of soil or plant samples
4. Logistics	Incoming and outgoing product streams are separated	Strict separation of own and purchased planting material, also during planting	Separated production of propagation material from plants for planting and strawberry production
	Presence of a hygiene corridor with possibility for disinfection	Soil and sludge from sorting and washing is returned to field of origin	At maximum, 2 successive years of propagation material on the same field; next 5 years, other crop
5.Timely intervention	Suspicious lots are isolated, in greenhouse and at harvest	Suspicious lots are isolated, in the field and during storage	Suspicious lots are isolated, in greenhouse or field and at harvest
	Inspection authority is informed in case of suspicion of an infestation	Inspection authority is informed in case of suspicion of an infestation	Inspection authority is informed in case of suspicion of an infestation
	Infested plants and plant products are removed	Infested plants and plant products are removed	Infested plants and plant products are removed
	Always the same employees working in an infested zone	Always the same employees working in an infested zone	Always the same employees working in an infested zone
	A (potentially) infested zone is always treated last	A (potentially) infested field is always treated last	A (potentially) infested zone is always treated last

for attitude, subjective norm, and pbc were mostly 0.6 to 0.7, with two exceptions (0.44), implying that the consistency of propositions comprising attitude, subjective norm, and pbc was acceptable for their intended use.

Average scores for attitude were high (Table 5), which means that growers generally acknowledged the relevance of farm-level management of invasive pathogen risk. Looking at the variables associated with attitude (Fig. 2), growers particularly valued the perceived positive side effect of risk management measures on farm continuity, whereas a positive effect on farm and sector reputation were less important in their decision whether to apply measures.

TABLE 4. Representativeness of survey populations for their respective production sectors, in terms of population size, geographical distribution, and farm size[a]

Production sector	Number of growers (%)[b]	Geographical distribution (distribution of entire sector) (%)				Farm size (sector) (ha)[c]
		South	North	West	East	
Tomato	100 (31)	36 (35)	5 (3)	58 (59)	1 (3)	5.5 (4.9)
Tulip bulb	103 (10)	3 (3)	3 (5)	73 (74)	21 (18)	17.3 (11.5)
Strawberry	101 (22)	70 (70)	0 (2)	5 (11)	25 (17)	7.7 (6.9)
Greenhouse	71 (25)	45 (37)	0 (1)	5 (9)	19 (14)	1.2 (0.9)
Field	83 (26)	64 (55)	0 (1)	0 (4)	17 (9)	8.5 (9.1)

[a] Strawberry production sector is further divided into greenhouse and field production.
[b] Number of growers in survey (percentage of sector).
[c] Average number of hectares per farm (sector average).

TABLE 5. Average scores for the elements of the Theory of Planned Behavior and risk perception for the entire survey population and sector subpopulations[a]

Variable	Tomato	Tulip bulb	Strawberry	Total
Behavior, average	0.67[2]	0.61[1,3]	0.67[2]	0.65
Attitude, direct	6.59	6.37	6.52	6.50
Subjective norm, direct	5.54[2,3]	4.93[1]	5.02[1]	5.16
Perceived behavioral control, direct	5.40[2]	4.79[1,3]	5.27[2]	5.16
Risk perception, average	2.02[2]	3.89[1,3]	2.25[2]	2.68

[a] Superscripts indicate significant difference ($P < 0.05$) compared with tomato (1), tulip bulb (2), or strawberry (3) production sector.

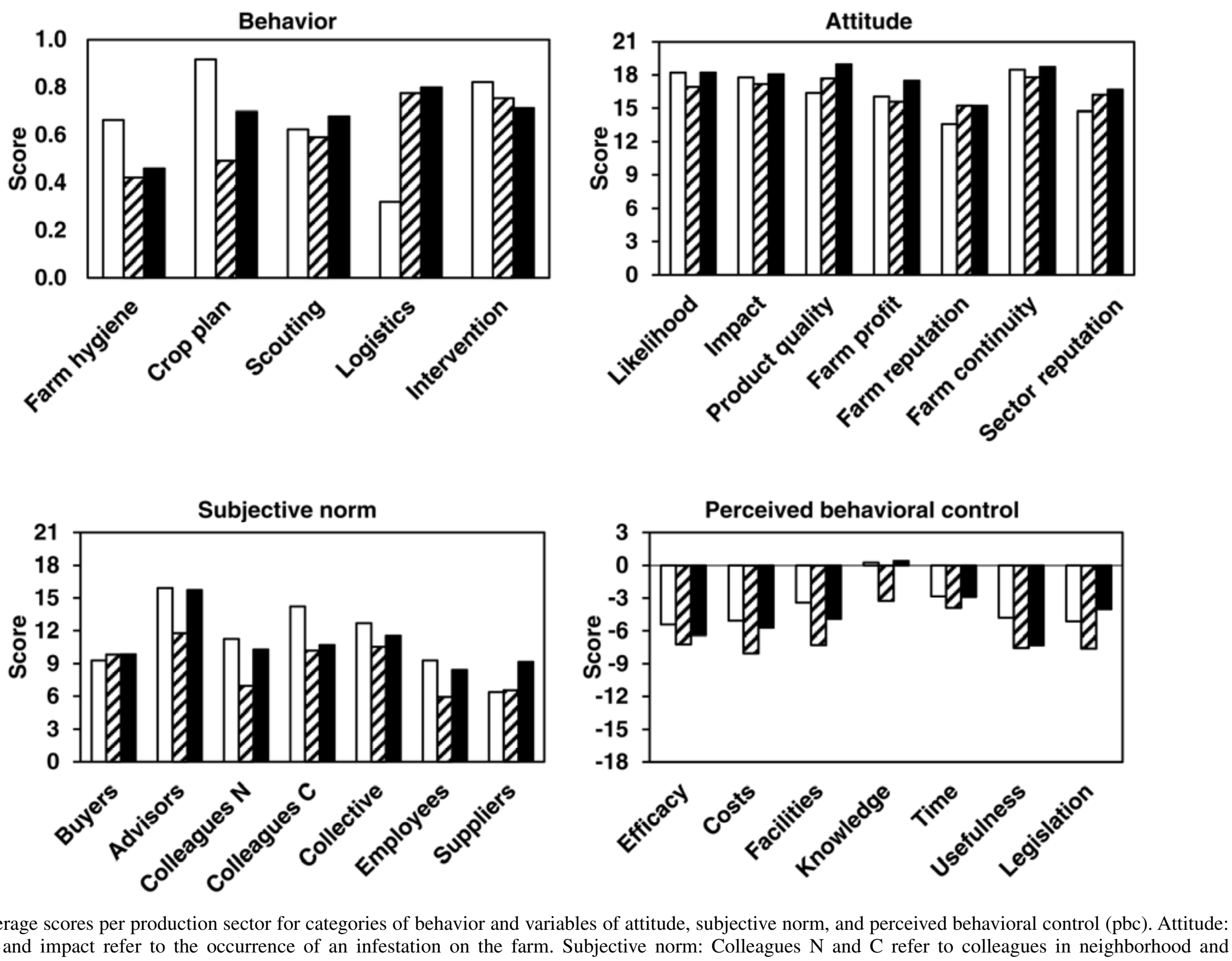

Fig. 2. Average scores per production sector for categories of behavior and variables of attitude, subjective norm, and perceived behavioral control (pbc). Attitude: likelihood and impact refer to the occurrence of an infestation on the farm. Subjective norm: Colleagues N and C refer to colleagues in neighborhood and colleagues the grower cooperates with, respectively. Pbc: legislation refers to conflict with application of measures; other variables refer to requirements for application of measures. Explanation of bar patterns: white = tomato sector, shaded = tulip bulb sector, black = strawberry sector.

Tomato growers had the highest subjective norm (Table 5), indicating that they perceived much pressure from third parties and persons, as opposed to tulip bulb growers, who had the lowest subjective norm. In all production sectors, advisors were considered to be most important, followed by collectives and colleagues growers cooperate with (Fig. 2). Tulip bulb growers perceived comparatively less pressure from most parties, except from buyers. This illustrates the upstream position of tulip bulb growers in the supply chain as suppliers of propagation material.

Of all interviewed growers, tulip bulb growers perceived the lowest behavioral control (Table 5). Particularly, high costs and conflicting legislation were considered important restricting factors (Fig. 2); the latter can be explained by their dependency on crop protection chemicals. In all production sectors, nearly all variables were scored negatively on average, implying that they were perceived as restrictive. Generally, knowledge and time were considered the least restrictive, whereas limited efficacy and uncertainty about the merit of available risk management measures were considered most restrictive. Other variables perceived as restrictive were costs (tulip bulb production sector) and conflicting legislation (tulip bulb and tomato production sector).

Relationships between the elements of the TPB. For the total survey population, behavior correlated significantly and positively with all three determinants in the TPB model (Table 6). Mutual correlations between the determinants were also observed. This is a rather common observation, because the three determinants are partly based on the same information (e.g., the effect of a particular management measure). Investigating behavior in more detail showed that attitude correlated with all categories of management measures but one, although coefficients were smaller than for the aggregated behavior. Subjective norm and pbc correlated with two or three categories of measures. The hygiene and crop plan management categories correlated with all three determinants. For the individual sectors, correlations between the three elements and behavior were only partly confirmed by the data. In the tomato production sector, no correlations between determinants and behavior were observed.

Regression analysis showed that, for the total survey population, attitude and subjective norm contributed to the description of behavior but pbc did not (Table 7). One of the sector dummy variables was significant, implying that invasive pathogen risk management is sector dependent. The regression model had a low R^2 (i.e., the determinants described only a small fraction of the variance in behavior). At the sector level, the descriptive value of the model was even lower, and behavior was significantly associated with only some of the considered determinants.

Growers' risk perception, knowledge, and past experience. Familiarity of growers with the case study organisms varied considerably (Table 8). Although most organisms were widely known, one out of five tomato growers had never heard of TYLCV before, and >25% of all tulip bulb growers was unaware of the existence of AMV. Even growers who were aware of a particular harmful organism were often unable to assess the likelihood of its introduction on their farm. This applies particularly to the tulip bulb production sector, where an additional 19 to 32% of all growers could not provide an estimate of the likelihood of introduction for a particular organism. The average risk perception scores for case organisms roughly varied from 1 to 5, which is rather low on a scale that runs from 0 to 30. Tulip bulb growers had, on average, a higher risk perception than growers in the tomato and strawberry production sector. This was mainly due to the fact that they expected more severe consequences, including trade restrictions and reputation damage.

A negative correlation was found between risk perception and both attitude and behavior, the latter being stronger than the former (Table 6). Growers who had encountered an outbreak of a

TABLE 6. Rank correlations between the elements of the analytical framework (using Spearman's correlation coefficient), with behavior further specified into its five categories[a]

					Categories of behavior				
Variable	Att	Sn	Pbc	Behavior	Hygiene	Crop plan	Scouting	Logistics	Intervention
Total population									
Rp	–0.13*	–0.06	–0.09	–0.19*	–0.14*	–0.24*	–0.18*	0.05	–0.07
Att	…	0.31*	0.39*	0.26*	0.15*	0.22*	0.18*	0.04	0.17*
Sn	…	…	0.06	0.18*	0.20*	0.25*	0.09	–0.14*	0.14*
Pbc	…	…	…	0.13*	0.18*	0.17*	0.10	–0.07	0.05
Tomato growers									
Rp	–0.03	–0.00	0.02	–0.02	0.10	0.05	–0.15	–0.03	0.03
Att	…	0.42*	0.31*	0.15	0.13	0.13	0.06	0.03	0.18
Sn	…	…	0.12	0.03	0.17	0.09	0.02	–0.02	–0.04
Pbc	…	…	…	0.10	0.07	0.18	0.03	–0.09	0.12
Tulip bulb growers									
Rp	–0.12	0.06	–0.05	–0.18	–0.13	–0.03	–0.11	–0.02	–0.11
Att	…	0.32*	0.38*	0.27*	–0.03	0.19	0.22*	0.20	0.14
Sn	…	…	0.06	0.16	–0.07	0.16	0.17	0.04	0.07
Pbc	…	…	…	–0.09	–0.09	–0.09	0.06	–0.13	0.00
Strawberry growers									
Rp	–0.17	–0.10	–0.09	–0.31*	–0.15	–0.21*	–0.29*	–0.33*	–0.12
Att	…	0.19	0.42*	0.28*	0.27*	0.23*	0.22*	0.09	0.17
Sn	…	…	–0.05	0.22*	0.30*	0.20*	0.10	–0.04	0.26*
Pbc	…	…	…	0.20	0.33*	0.06	0.12	0.19	–0.03

[a] Asterisks (*) indicate significant correlations ($P < 0.05$). Abbreviations: Rp = risk perception; Att = attitude, Sn = subjective norm, Pbc = perceived behavioral control.

TABLE 7. Unstandardized regression coefficients of the determinants of behavior and sector dummy variables, assuming a linear relationship with behavior[a]

Parameter	β_0 (Con)	β_1 (Att)	β_2 (Sn)	β_3 (pbc)	Tomato dummy	Tulip bulb dummy	R^2 adjusted
Total population	0.29*	0.04*	0.02*	0.01	–0.02	–0.06*	0.07
Tomato growers	0.41*	0.04	0.00	0.01	…	…	–0.01
Tulip bulb growers	0.24	0.07*	0.02	–0.03	…	…	0.10
Strawberry growers	0.18	0.04	0.03*	0.02	…	…	0.10

[a] Asterisks (*) indicate significant correlations ($P < 0.05$). Abbreviations: Con = constant, Att = attitude, Sn = subjective norm, Pbc = perceived behavioral control.

case study organism on their farm in the past had a significantly higher risk perception than growers that hitherto had not been personally affected (average score of 3.06 versus 2.01). Moreover, previously affected growers were better capable of recognizing symptoms of infection with any of the case study organisms (average score of 0.51 versus 0.33). Recognition of symptoms and risk perception were also positively correlated in both the entire survey population ($\rho = 0.13$) and in the tomato, tulip bulb, and strawberry production sector ($\rho = 0.26$, 0.22, and 0.36, respectively). Yet, for subpopulations of growers with either experience or not, this correlation was no longer significant. This suggests an indirect correlation between knowledge of symptoms and risk perception, via past experience. A correlation between growers' knowledge about possible sources of introduction and risk perception could not be quantified objectively, because growers who self-reportedly did not know of such sources also frequently had not heard of the organism before, resulting in few quantified risk perceptions in this category of growers.

Farm-specific characteristics affecting behavior. Results of the cluster analysis are summarized in Table 9. In the tomato sector survey population, clusters were categorized as "small-scale production, no outbreaks thus far" (cluster 1); "large-scale production, with or without outbreaks in the past" (cluster 2); and "small- and medium-scale production in regions with a concentration of greenhouse horticulture, with outbreaks in the past" (cluster 3). Risk management was highest in cluster 2, while growers in cluster 3 perceived the highest risk. The differences in risk management and risk perception between the clusters suggest that not only past experience (via risk perception) but also large-scale production positively affects risk management. This reasoning is supported by the observation that growers in cluster 2 were the only ones who considered efficacy and merit of measures, both variables of pbc, on average, as stimulatory factors in risk management.

The tulip bulb clusters were categorized by "medium- to large-scale production, tulip bulbs mostly being the main crop, sometimes with production on contract for or by other growers" (cluster 1); "small-scale production, completely on owned land, tulip bulbs mostly being not the main crop" (cluster 2); and "medium-scale production, no share of machinery or personnel" (cluster 3). Whereas, in the tomato production sector, production scale tended to be positively related to behavior, the opposite seems to be the case in the tulip bulb production sector, cluster 2 having the highest average score for risk management. Yet, most growers in this cluster produced main crops other than tulip bulbs, causing the tulip bulb acreage to be less representative for production scale. Also, production on owned land may have stimulated these growers to apply management measures because the management of soilborne pathogens has direct long-term benefits for them.

Strawberry growers were classified into the following clusters: "focus on (small-scale) greenhouse production, sometimes organic" (cluster 1); "large-scale field production, sometimes combined with greenhouse production, focus on production of strawberries" (cluster 2); and "medium-scale, often combined greenhouse and field production, including production of planting material" (cluster 3). Growers in cluster 1 had a high risk perception, while scoring relatively high on behavior. Having a closer look at risk

TABLE 8. Average scores for risk perception, knowledge, and previous experience, per sector and case organism

Sector–organism combination	Risk perception	Recognition of symptoms	Growers unaware of introduction sources (%)	Growers with past experience (%)
Tomato production sector				
Clavibacter michiganensis subsp. *michiganensis*	2.30	0.35	4	27
Tomato yellow leaf curl virus	1.51	0.45	38	7
Tuta absoluta	1.76	0.47	5	11
Tulip bulb production sector				
Ditylenchus dipsaci	3.32	0.48	5	11
Tulip virus X	4.81	0.32	13	40
Arabis mosaic virus	3.03	0.15	47	7
Strawberry production sector				
Xanthomonas fragariae	2.29	0.51	4	49
Phytonemus pallidus subsp. *fragariae*	1.08	0.68	4	42
Phytophthora fragariae or *P. cactorum*	3.43	0.56	2	91

TABLE 9. Characterization of clusters per production sector on the basis of farm characteristics[a]

	Tomato clusters			Tulip bulb clusters			Strawberry clusters		
Farm characteristics[b]	1	2	3	1	2	3	1	2	3
Cluster size (number growers)	53	11	36	32	14	55	26	39	38
Production (ha) in									
Field[2,3]	n/a	n/a	n/a	20.25	6.31	18.31	1.99	13.69	7.18
Greenhouse[1,3]	4.09	15.42	4.69	n/a	n/a	n/a	0.73	1.05	1.53
Farms (%) with production in									
Field	n/a	n/a	n/a	n/a	n/a	n/a	23	44	24
Greenhouse	n/a	n/a	n/a	n/a	n/a	n/a	35	20	8
Field & greenhouse	n/a	n/a	n/a	n/a	n/a	n/a	42	36	68
Predominant regions[1,2,3]	W, S	D	W, S	W, E	W, E	W	E	S, W	S
Growers (%) with									
Past experience[1,2]	0	36	100	34	50	60	96	90	95
Shared use of machinery[2]	4	9	8	56	29	0	11	5	13
Closed production system[2]	n/a	n/a	n/a	41	43	40	n/a	n/a	n/a
Production only on owned land[2]	n/a	n/a	n/a	0	100	0	n/a	n/a	n/a
Production of plants for planting[3]	n/a	n/a	n/a	n/a	n/a	n/a	54	8	97
Average score for									
Risk management	0.64	0.74	0.69	0.59	0.67	0.60	0.68	0.70	0.62
Risk perception	1.33	2.33	2.91	4.35	3.54	3.72	2.42	1.99	2.39

[a] Abbreviation: n/a means that the variable is not applicable to the respective production sector; W = west, S = south, D = diverse, and E = east.

[b] Superscripts indicate the variables used for clustering of tomato growers (1), tulip bulb growers (2), or strawberry growers (3).

perception revealed that growers mainly perceived strawberry mite as a threat. Growers in cluster 3, on the other hand, gave higher scores to *X. fragariae*. These differences reflect the differences in production environment among clusters: strawberry mite is considered a greenhouse pest, while *X. fragariae* mainly causes problems in field production. Production environment also affected the types of management measures applied by growers; for instance, growers in cluster 1 more consistently removed crop waste after production than growers in other clusters, while growers in cluster 3 performed better on isolation of potentially infested plant material.

DISCUSSION

In this article, we have developed and empirically tested an analytical framework for understanding growers' management of invasive pathogen risk, based on the TPB (Fig. 3). The results showed that the TPB is applicable in this respect, although with some ramifications. Overall, attitude, subjective norm, and pbc affected behavior, either directly or indirectly. At sector level, the relations were weaker. The explanation is that within-sector variation was too large in relation to the population size to measure significant correlations. In the total population with a larger number of observations, these correlations were significant.

Although all growers applied at least some measures to manage risks of invasive pathogens, considerable differences among growers existed in the combination of management measures taken between production sectors. These observations coincide with the ease of implementation of particular types of measures in different production sectors. For instance, growers with outdoor production are more dependent on weather circumstances and, thus, more likely to experience time pressure, shifting priorities away from activities such as cleaning equipment. Also, keeping incoming and outgoing product streams separate is common practice for most tulip bulb growers but more difficult to achieve in greenhouses, where activities are spatially and temporally less separated. Also, within the production sectors, considerable differences between growers were observed. This calls for development of sector-specific intervention strategies that focus on the package of management measures rather than on individual measures. Moreover, it reflects the complexity of the investigated behavior, which complicates the applicability of the TPB. Farm-level management of invasive pathogen risk was represented by a scale variable (as opposed to a binary variable), based on 18 management measures that a grower could have adopted or not. Latent variables like this one are less pure and more difficult to interpret, because a particular value cannot be linked to a unique activity. In addition, adoption of certain management measures involves changes in overall farm management, leaving less flexibility to the grower on deciding whether to apply them or not. This is particularly true for logistic measures, such as "presence of a hygiene corridor" or "keeping a field registration system".

The difficulties in measuring behavior contribute to the relatively low descriptive value (R^2) of the regression model tested here. Yet, for empirical studies such as this one, a low R^2 is not unusual. A reason for this is that the TPB does not account for technical and psychological factors such as farm characteristics and a grower's ambitions and strategic management decisions. Cluster analysis highlighted the discriminant importance of technical factors such as production scale and production environment. Thus, these results should be interpreted as potential trends, and are worth further investigating in order to better understand differences in growers' risk management.

With few exceptions, rankings of variables of attitude and subjective norm according to their magnitude were quite similar among the three production sectors, suggesting that these results are rather generic (i.e., applicable to any horticultural production sector). This is not the case for pbc, the variables of which differed considerably in importance between the three sectors. In contrast to the TPB, we did not find a significant contribution of pbc to the explanation of behavior. The positive correlation of pbc with behavior as well as attitude suggests that pbc nevertheless affected behavior indirectly, via attitude. There is increasing evidence that pbc, as interpreted in classical TPB, is not a one-dimensional measure but a combination of two components (3,29). The first one, self-efficacy, refers to people's confidence that they would be able to perform the behavior in question if they wanted to. The second one, controllability, refers to the extent to which people believe that performance of the behavior is up to them. Self-efficacy is believed to be a better predictor of behavioral intentions than controllability. In our questionnaire, the four propositions determining pbc can be split into two propositions concerning self-efficacy and two referring to controllability. Performing the analyses with the two components separately included showed that only self-efficacy was correlated with behavior and had a much higher coefficient than the aggregated pbc measure, although still not significant. Thus, feeling capable or incapable of applying risk management measures is more likely to affect a grower's intention to take measures than feeling out of control of doing so.

Tulip bulb growers had, on average, the highest risk perception. Among other reasons, this is attributable to the fact that tulip bulb growers often have multiple fields and lots. Their overall production thereby faces an increased likelihood of one or more

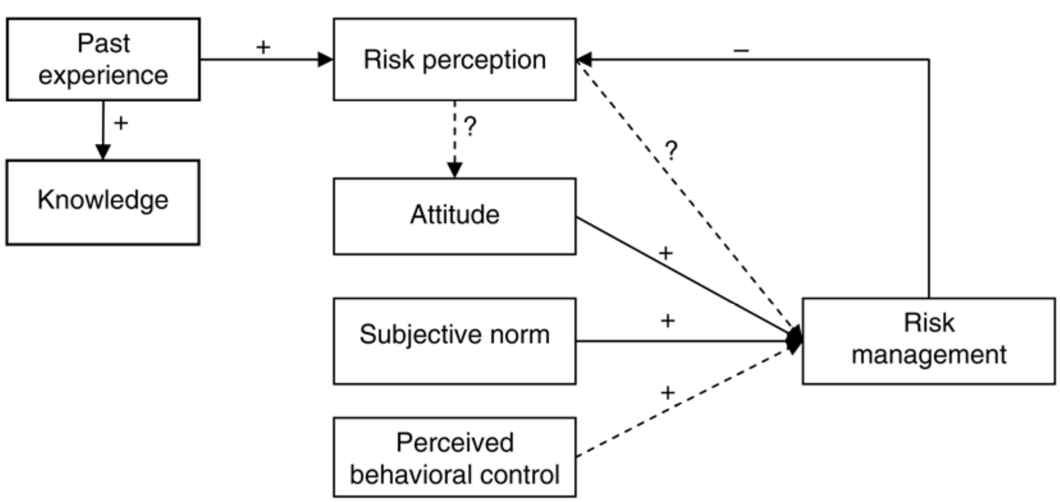

Fig. 3. Analytical framework for invasive pathogen risk perception and management, as supported by statistical analysis of the survey data.

infections per year. Moreover, tulip bulbs comprise propagation material and, as such, are subject to stringent plant health regulations. Likewise, in the strawberry production sector, growers who (among other practices) produced planting material had a higher risk perception than growers who only produced strawberries. Overall, the observed scores for risk perception were rather low. A reason for this is that quantification of risk was biased toward likelihood, which growers frequently estimated at zero. Thus, the product of likelihood and consequences was often independent of the score for consequences. Adjusting the scales of the two variables determining risk did not affect the relations in the analytical framework, suggesting that the observed bias had no effect on our conclusions.

The empirical data suggested a negative effect of risk perception on risk management, which is in contrast to our expectations. However, according to Weinstein and Nicolich (47), the results should be interpreted differently. They show that the causal effect of risk perception can only be measured shortly after a change in any factor that may induce changes in risk behavior, such as the emergence of a new risk. This changes people's risk perception, to which they may adapt their behavior. After they have taken appropriate management measures, they adapt their risk perception accordingly. As more time has elapsed since the change in circumstances, people become less likely to adapt their behavior, and factors preventing people from taking management measures become relatively more important. Because we have measured risk perception in a steady state of the system, the observed negative relation probably represents the negative feedback loop from behavior to risk perception. Thus, growers who have taken appropriate risk management measures appear to feel more protected than growers with a poorer risk management.

Growers' knowledge of invasive pathogens was found to be correlated to past experience but not to grower's risk perception. This may be related to the way we measured knowledge. Macgill and Siu (30) propose that risk perception depends on two types of knowledge: physical and social. The first type refers to the properties and qualities of the risk (i.e., objective invasive pathogen risk as communicated by experts). The second type concerns its significance for one's own life, and relates to whether or not the risk is acceptable. In this respect, the observed positive correlation between previous experience and knowledge makes sense. The analysis also revealed that growers were rather unfamiliar with invasive pathogens that had not caused considerable problems in their production sector thus far. These results suggest that social knowledge is dominant in growers' risk perception. Therefore, in communicating risks, emphasis should be put on visualizing risk; for instance, by presenting practical experiences and showing potential consequences at the farm level rather than presenting theoretical facts and figures.

In this study, invasive pathogen risk management was approached from a sociopsychological perspective. The need for integration of technical and social—including behavioral—science in research on pest risk management was recently drawn to attention in a symposium on the adoption of Decision Support Systems (19). As a first step forward, McRoberts et al. (34) developed a conceptual framework to integrate farmers' risk perception in the design and evaluation of decision tools, based on psychometric analyses. The authors concluded that a more interdisciplinary approach in the development of decision tools can increase their adoption rate among growers. Here, we developed a different framework with multiple determinants of behavior, and applied it to a related type of problem within the domain of plant disease management. Results underscored the need for a sociotechnical approach in improving farm-level risk management, which accounts for differences between production sectors and farm-specific possibilities and limitations. Both studies demonstrate the potential value of accounting for human perceptions and behavior in plant disease management. Frameworks such as the two discussed here can be very helpful in understanding why growers do not behave as expected on the basis of purely rational grounds. Moreover, as shown by the empirical application in this article, they provide insight into the bottlenecks of adoption of enhanced farm-level pathogen risk management, and enable the identification of possibilities for behavioral intervention. Hence, the research agenda, communication, and knowledge transfer can be fine-tuned to the needs and preferences of growers. This will favor closer public–private cooperation, resulting in more effective invasive pathogen risk management.

ACKNOWLEDGMENTS

The research was funded by the Dutch Ministry of Economic Affairs, Agriculture, and Innovation. We thank J. Vriend, P. Knippels, and B. Evenhuis for sharing their expert knowledge about the tomato, tulip bulb, and strawberry production sector, respectively; and Y. Dijkxhoorn and J. Geelen for their technical support during the survey.

LITERATURE CITED

1. Ajzen, I. 1991. The theory of planned behavior. Organ. Behav. Hum. Dec. 50:179-211.
2. Ajzen, I. 2002. Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. J. Appl. Soc. Psychol. 32:665-683.
3. Armitage, C. J., and Conner, M. 2000. Social cognition models and health behaviour: A structured review. Psychol. Health 15:173-189.
4. Baker, R., Cannon, R., Bartlett, P., and Barker, I. 2005. Novel strategies for assessing and managing the risks posed by invasive alien species to global crop production and biodiversity. Ann. Appl. Biol. 146:177-191.
5. Barnett, J., and Breakwell, G. M. 2001. Risk perception and experience: Hazard personality profiles and individual differences. Risk Anal. 21:171-177.
6. Bish, A., Ramirez, A., Burgess, C., and Hunter, M. 2005. Understanding why women delay in seeking help for breast cancer symptoms. J. Psychosom. Res. 58:321-326.
7. Breukers, A., van der Werf, W., Kleijnen, J. P. C., Mourits, M., and Oude Lansink, A. 2007. Cost-effective control of a quarantine disease: A quantitative exploration using "design of experiments" methodology and bio-economic modeling. Phytopathology 97:945-957.
8. Carifio, J., and Perla, R. J. 2007. Ten common misunderstandings, misconceptions, persistent myths and urban legends about Likert scales and Likert response formats and their antidotes. J. Soc. Sci. 3:106-116.
9. Carrasco, L. R., Mumford, J. D., MacLeod, A., Knight, J. D., and Baker, R. H. A. 2010. Comprehensive bioeconomic modelling of multiple harmful non-indigenous species. Ecol. Econ. 69:1303-1312.
10. Dehnen-Schmutz, K., Holdenrieder, O., Jeger, M. J., and Pautasso, M. 2010. Structural change in the international horticultural industry: Some implications for plant health. Sci. Hortic. Amsterdam 125:1-15.
11. Epanchin-Niell, R. S., and Hastings, A. 2010. Controlling established invaders: Integrating economics and spread dynamics to determine optimal management. Ecol. Lett. 13:528-541.
12. European Commission. 2000. Council Directive 2000/29/EC on protective measures against the introduction into the community of organisms harmful to plants or plant products and against their spread within the community. Off. J. Eur. Union L 169:1-112.
13. FAO. 1997. International Plant Protection Convention (New Revised Text). Food and Agriculture Organisation of the United Nations, Rome.
14. FAO. 2006. ISPM No. 11: Pest Risk Analysis for Quarantine Pests Including Analysis of Environmental Risks and Living Modified Organisms. Food and Agriculture Organisation of the United Nations, Rome.
15. Feola, G., and Binder, C. R. 2010. Identifying and investigating pesticide application types to promote a more sustainable pesticide use. The case of smallholders in Boyaca, Colombia. Crop Prot. 29:612-622.
16. Francis, J. J., Eccles, M. P., Johnston, M., Walker, A., Grimshaw, J., Foy, R., Kaner, E. F. S., Smith, L., and Bonetti, D. 2004. Constructing questionnaires based on the theory of planned behaviour—a manual for health services researchers. Centre for Health Services Research, Newcastle upon Tyne, UK.
17. Frewer, L. J., Shepherd, R., and Sparks, P. 1994. The interrelationship between perceived knowledge, control and risk associated with a range of food-related hazards targeted at the individual, other people and society. J. Food Saf. 14:19-40.

18. Gambley, C. F., Miles, A. K., Ramsden, M., Doogan, V., Thomas, J. E., Parmenter, K., and Whittle, P. J. L. 2009. The distribution and spread of citrus canker in Emerald, Australia. Australas. Plant Pathol. 38:547-557.
19. Gent, D. H., De Wolf, E., and Pethybridge, S. J. 2011. Perceptions of risk, risk aversion, and barriers to adoption of decision support systems and IPM: An introduction. Phytopathology 101:640-643.
20. Gilligan, C. A., and van den Bosch, F. 2008. Epidemiological models for invasion and persistence of pathogens. Annu. Rev. Phytopathol. 46:385-418.
21. Goss, E. M., Larsen, M., Vercauteren, A., Werres, S., Heungens, K., and Grunwald, N. J. 2011. *Phytophthora ramorum* in Canada: Evidence for migration within North America and from Europe. Phytopathology 101:166-171.
22. Graham, J. H., Gottwald, T. R., Cubero, J., and Achor, D. S. 2004. *Xanthomonas axonopodis* pv. *citri*: Factors affecting successful eradication of citrus canker. Mol. Plant Pathol. 5:1-15.
23. Guillaumie, L., Godin, G., and Vezina-Im, L. A. 2010. Psychosocial determinants of fruit and vegetable intake in adult population: A systematic review. Int. J. Behav. Nutr. Phys. Act. 7:12. Online publication. doi:10.1186/1479-5868-7-12
24. Heong, K. L., and Escalada, M. M. 1999. Quantifying rice farmers' pest management decisions: Beliefs and subjective norms in stem borer control. Crop Prot. 18:315-322.
25. Ibuka, Y., Chapman, G. B., Meyers, L. A., Li, M., and Galvani, A. P. 2010. The dynamics of risk perceptions and precautionary behavior in response to 2009 (H1N1) pandemic influenza. BMC Infect. Dis. 10:296. Online publication. doi:10.1186/1471-2334-10-296
26. Janz, N. K., and Becker, M. H. 1984. The health belief model—a decade later. Health Educ. Q. 11:1-47.
27. Jones, D. R. 2009. Towards a more reasoned assessment of the threat to wheat crops from *Tilletia indica*, the cause of Karnal bunt disease. Eur. J. Plant Pathol. 123:247-259.
28. Kahneman, D., and Tversky, A. 1979. Prospect theory: An analysis of decision under risk. Econometrica 47:263-292.
29. Kraft, P., Rise, J., Sutton, S., and Roysamb, E. 2005. Perceived difficulty in the theory of planned behaviour: Perceived behavioural control or affective attitude? Br. J. Soc. Psychol. 44:479-496.
30. Macgill, S. M., and Siu, Y. L. 2005. A new paradigm for risk analysis. Futures 37:1105-1131.
31. Margosian, M. L., Garrett, K. A., Hutchinson, J. M. S., and With, K. A. 2009. Connectivity of the American agricultural landscape: Assessing the national risk of crop pest and disease spread. Bioscience 59:141-151.
32. Matthews, G. A. 2008. Attitudes and behaviours regarding use of crop protection products—a survey of more than 8500 smallholders in 26 countries. Crop Prot. 27:834-846.
33. Mauro, I. J., and McLachlan, S. M. 2008. Farmer knowledge and risk analysis: Postrelease evaluation of herbicide-tolerant canola in western Canada. Risk Anal. 28:463-476.
34. McRoberts, N., Hall, C., Madden, L. V., and Hughes, G. 2011. Perceptions of disease risk: From social construction of subjective judgements to rational decision making. Phytopathology 101:654-665.
35. Miller, N., Estoup, A., Toepfer, S., Bourguet, D., Lapchin, L., Derridj, S., Kim, K. S., Reynaud, P., Furlan, L., and Guillemaud, T. 2005. Multiple transatlantic introductions of the western corn rootworm. Science 310:992-992.
36. National Research Council. 2002. Predicting Invasions of Nonindigenous Plants and Plant Pests. National Academy Press, Washington, DC.
37. Parnell, S., Gottwald, T. R., van den Bosch, F., and Gilligan, C. A. 2009. Optimal strategies for the eradication of Asiatic citrus canker in heterogeneous host landscapes. Phytopathology 99:1370-1376.
38. Richard, R., Vanderpligt, J., and De Vries, N. 1995. Anticipated affective reactions and prevention of AIDS. Br. J. Soc. Psychol. 34:9-21.
39. Scott-Parker, B., Watson, B., and King, M. J. 2009. Understanding the psychosocial factors influencing the risky behaviour of young drivers. Transport. Res. F Traffic Psychol. Behav. 12:470-482.
40. Soliman, T., Mourits, M. C. M., Oude Lansink, A., and Van der Werf, W. 2010. Economic impact assessment in pest risk analysis. Crop Prot. 29:517-524.
41. Sorge, U., Kelton, D., Lissemore, K., Godkin, A., Hendrick, S., and Wells, S. 2010. Attitudes of Canadian dairy farmers toward a voluntary Johne's disease control program. J. Dairy Sci. 93:1491-1499.
42. Tucker, M., and Napier, T. L. 2001. Determinants of perceived agricultural chemical risk in three watersheds in the Midwestern United States. J. Rural Stud. 17:219-233.
43. Tversky, A., and Kahneman, D. 1974. Judgment under uncertainty: Heuristics and biases. Science 185:1124-1131.
44. Venette, R. C., Kriticos, D. J., Magarey, R. D., Koch, F. H., Baker, R. H. A., Worner, S. P., Raboteaux, N. N. G., McKenney, D. W., Dobesberger, E. J., Yemshanov, D., De Barro, P. J., Hutchison, W. D., Fowler, G., Kalaris, T. M., and Pedlar, J. 2010. Pest risk maps for invasive alien species: A roadmap for improvement. Bioscience 60:349-362.
45. Vignola, R., Koellner, T., Scholz, R. W., and McDaniels, T. L. 2010. Decision-making by farmers regarding ecosystem services: Factors affecting soil conservation efforts in Costa Rica. Land Use Policy 27:1132-1142.
46. Waage, J. K., and Mumford, J. D. 2008. Agricultural biosecurity. Philos. Trans. R. Soc. London B 363:863-876.
47. Weinstein, N. D., and Nicolich, M. 1993. Correct and incorrect interpretations of correlations between risk perceptions and risk behaviors. Health Psychol. 12:235-245.