Perceptions of Potato Practices and their Impacts by Farmers in Guatemala using Fuzzy Cognitive Mapping

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Abstract:

This study aims to assist in adopting production practices that lead to better soil health, low plant parasitic nematodes (PPN) population density, increased potato yield for farmers in Western Guatemala using fuzzy cognitive mapping (FCM). A cognitive map was developed representing farmers' current perceptions of the production practices and their impacts. In comparison with agricultural professionals' cognitive map provided knowledge gaps which will allow agricultural professionals to customize and design more effective technology transfer activities for greater adoption. Primary data were collected in Paquix, Huehuetenango from farmers and at the University of San Carlos in Guatemala from agricultural professionals. Both cognitive maps aligned in general with contrasting perceptions on the impact of certified seeds and compost practices on plant parasitic population density. Training and demonstration plots were perceived as influential to adoption by farmers. Farmers seemed ambiguous on the impact on yield but knowledgeable on the impact on soil health and plant parasitic population density. Most farmers said they receive their information from their local cooperatives and had actively participated in demonstration plots. Understanding the knowledge gaps and knowing where and how farmers got their information, agricultural professionals can effectively design workshops for effective dissemination and thus higher adoption rates.

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Introduction

Potatoes are an important crop of smallholder farmers in the highlands of Western Guatemala (Ministerio de Economía, 2015; MAGA, 2015). Potato is grown for home consumption with excess surplus sold on the market. The average potato yield in the Western Highlands has steadily decreased over the last 20 years to around 17 ton/hectare due to intensive cultivation (Velásquez and Orozco, 1983, MAGA, 2015). The production practices of Guatemalan small farmers intensive cultivation lead to degraded soil health (Lal, 2015; http://www.nrcs.usda.gov/wps/portal/nrcs/ main/soils/health/), such as poor soil fertility and increased pests and diseases, including plant-parasitic nematodes (PPN). PPN are prevalent in nutritionally and biologically degraded soils which leads to poor yield and are at the root of the challenges of poverty alleviation, malnutrition, and food insecurity in the Western Highlands of Guatemala.

Potato cyst nematodes, *Globodera* sp., are the most common and damaging PPN in the Western Highlands of Guatemala (Sanchez-Perez, unpublished data). As soil-borne root pests, PPN are difficult to diagnose and to manage in potato and other fields. In order to increase yield for the smallholder farmers in the Western Highlands of Guatemala, attention needs to be given to management practices that suppress PPN, pests and disease and improve soil health.

For smallholder farms, strategies that improve soil health (http://www.nrcs.usda.gov/wps/portal/nrcs/ main/soils/health/) and lower population densities of PPN within a framework of sustainable intensification and best practices is most desirable (Lal, 2015). Several management tactics meet these criteria including the use of seed potato certified to be disease free (Jones *et al*., 2017), application of biological control organisms (Contina *et al*., 2017), the addition of composted manure (Renčo *et al*., 2016), and crop rotation (Trudgill *et al*., 2014). However, there are major socio-cultural and science gaps to be overcome before the smallholder farmers embrace and adopt these practices.

Introduction of research-based technologies and field-tested practices without regards to understanding farmers' perceptions of the innovative farming practices or technologies often leads to failure to adopt. Evidence has shown that new practices introduced by extension, NGOs, or other research institutions are often abandoned for traditional practices after development projects have been completed. Therefore, a major challenge with the traditional development approach of field demonstration alone does not work. There is a need to understand what drives a farming community's behaviors and decision-making processes, contrasted with the adoption of innovative practices that have been shown to increase and sustain productivity. Researchers and those promoting 'best practices' without fully understanding the environmental and socio-cultural factors that influence smallholder farmer behaviors and decision-making processes unknowingly exacerbate the limited adoption issue (Isaac *et al*., 2009).

By developing knowledge of smallholder farm-community perceptions and motivations, values shared among researchers, extension and farmers can be realized. Studies have shown factors influencing local adoption are highly contextual and may vary by location (Knowler & Bradshaw, 2007). Furthermore, evidence shows that a community's agricultural belief system reflects local ecological and cultural conditions, which serve to shape the decision-making process on the farm. Thus, it is crucial to approach the introduction of any new agricultural technology by collecting and distilling community values early in order to understand the community decision-making process in regard to adopting new practices and technologies. This study proposed that in order to promote the adoption of new agricultural practices for the economic betterment of smallholder potato farmers in Western Guatemala, one must identify the community understanding of the impact of soil health and PPN management to potato yield. Specifically, the development of mental models' representations for smallholder farm communities would allow the appropriate framing of change within the existing farming practices. This information, when contrasted with technical expert or professional mental models on their knowledge of best management practices based on field experiments and literature, can be analyzed to determine how introduced technologies can be best presented, adapted and contribute to higher adoption rates of beneficial agricultural practices.

The long-term goal of this study is to develop best outcome practices that lead to a steady state of soil health, low PPN population density, increased and sustainable potato yield, increased farm incomes, and improved food and nutritional security scalable across horticultural cropping systems and social-cultural groups. This paper describes the construction, analysis and forecasts of the mental models of smallholder potato farmers and agricultural professionals using a fuzzy cognitive mapping survey. We anticipate that a better understanding of the farmers' current understanding of the impact of PPN and soil health on potato yield will allow professionals to customize and design more effective technology transfer activities such as training workshops for greater rates of adoption.

Our hypotheses are that inputs of biocontrol, certified seeds, compost and nematicides will be perceived by agricultural professionals and farmers to increase potato yield. These same inputs will be perceived to suppress PPN population density. A negative relationship between soil health and PPN population density will be perceived by professionals and farms. Biocontrol and compost will also be perceived to improve soil health and soil health will have a positive relationship to potato yield. Fertilization will be understood to have no effect on PPN and an adverse effect on soil health. We hypothesized that adoption is perceived to be driven by training. Finally, we hypothesized that agricultural professionals' and farmers' mental models will be aligned.

Method

Fuzzy cognitive mapping (FCM) was selected to assess and compare the mental models of different groups of potato stakeholders in the Western Highlands of Guatemala. FCMs provide "semi-quantitative, detailed representations of individual or group knowledge structures" (Gray *et al.*, 2014). FCM allows for modelling dynamic systems with feedback loops. Results and multi-stakeholder assessment of FCMs contribute useful information for decision-making, problem-solving, negotiation, and policy-making. FCMs have been applied in diverse areas such as environmental management (Özesmi & Özesmi, 2003), agriculture (Halbrendt *et al.*, 2014), socio-ecological systems (Gray *et al.*, 2015), medicine (Papageorgiou *et al.*, 2006), and immigration (Ramos, 2015).

Axelrod (1976) used cognitive maps to represent stakeholders' understanding of scientific knowledge. The framework was further expanded by Kosko (1986) who incorporated the concepts of diffusion and mathematical neural networks to create a fuzzy method to improve the understanding of the dynamics of complex systems. FCMs consist of variables (or components) and connections that represent causal relationships between the variables. The variables and connections are characterized by a directional relationship (positive or negative) and weights on a diffuse set of real numbers [-1, 1]. The connections are represented by arrows from one variable (transmitting node) to another (receiving node). For agriculture, structured questionnaires were used to collect the data as professionals work with stakeholders so primary data can be obtained. With the weights calculated from the data collected, variables are organized in a matrix of adjacency for analysis of network structures and dynamics, as well as aggregation into community models and comparison across stakeholder models. Additionally, once calculated, FCM models can be utilized to simulated 'what if' intervention scenarios to discover the most effective strategies for the desired outcomes (Papageorgiou, 2011). FCM output provides graphical representations of selected or 'important variables' their positive or negative influence and directional causal relationships.

Study Site

The study was conducted in Huehuetenango located in the Western Highlands of Guatemala (Fig. 1). Huehuetenango, the second most populated department (or state in the US terms) of Guatemala, has 1.26 million people (7.8% of the country's population), over 73% of the population living under the poverty level (MAGA, 2015), and 70.4% of the population in the department depends on agriculture for their livelihood. Except for the urban area, Huehuetenango has low levels of economic development, food and nutritional security concerns, high illiteracy rate (above 35%), and above 80% of the population is indigenous.

Smallholder farmers in Huehuetenango are responsible for over 75% of the national potato production in Guatemala (Ministerio de Economía, 2015). The GT06 area on the map (Fig. 1) produced 400,558 metric tonnes of potatoes in 2013, with 70,897 producers and an average farm size of 0.22 ha/producer (Ministerio de Economía, 2015).

Although Huehuetenango is the main producer of potatoes in Guatemala, average yield (17 TM/ha) is low compared to other countries: United States (44 TM/ha), Canada (32 TM/ha), and Argentina (29 TM/ha) (MAGA, 2015). Potato yields have been adversely affected by potato cyst nematodes (*Globodera* sp.), the Guatemalan potato moth (*Tecia solanivora*), and potato late blight (*Phytophthora infestans*) (MAGA, 2015).

Study Sample

Perceptions of agricultural professionals and farmers were collected using a questionnaire. The agricultural professions were participants from the Faculty of Agronomy, University of San Carlos (USAC) in Guatemala City. They have knowledge of agronomy, plant diseases, and rural development. The potato farmer participants came from a marketing cooperative in the district of Huehuetenango.

All of the USAC participants were randomly chosen. We used several methods to attract the respondents. Announcements were posted on the USAC campus; through word of mouth; and those who were interested in attending a workshop on FCM. The USAC study sample consisted of 17 individuals with average age of 40 years, of which 12 were male and 5 were female (Table 1). Their level of education ranged from high school diploma to doctorate with bachelor degree as the median level of education. All participants reported being familiar with PPN, though the level of familiarity varied with only 35% having participated in scientific research projects on nematodes. All surveys were conducted on the USAC campus.

All of the potato farmers were members of the Cooperativa Agrícola Paquixeña Cuchumateca, in Paquix hamlet, municipality of Chiantla in the department of Huehuetenango. Cooperativa Paquixeña has 350 potato farmers as members. Due to the hamlet remoteness, lack of trust of outsiders, and language barriers, farmers were invited to a public informational session on potato production, PPN, and soil health and later stayed behind to be surveyed. We interviewed 20 farmers of which 30% were women and 72% of the farmers reported being the head of their household with average farm size of 11 cuerdas (0.5 ha). Twenty percent of the participant reported being illiterate. The most recent National Agricultural Census data for Huehuetenango reported that 8.5% of the rural producers were women (versus 6.2% nationally), 71% were 35 years of age or older (similar to national average), and 42% were illiterate (compared to 36% nationally) (MAGA, 2004). Our sample have more women and less illiterate which help with responding to a more complex questionnaire.

Survey Instrument

The data were collected using a structured questionnaire consisting of three parts. The first part gathered socio-demographic data of the respondent. The second part of the questionnaire consisted of the structured mental model questions. The third part of the questionnaire enquired about additional relevant information on agricultural practices. To design the FCM instrument, face-to-face interviews were conducted with agricultural experts from the University of Hawaii and Michigan State University (co-PIs' affiliations) to identify the most important causal relationships of inputs to soil health to PPN to economic outcomes. Each individual expert was asked about the variables, their relationships, the directions with their respective signs and weights to create individual cognitive maps using the software Mental Modeler (Gray *et al*., 2013). To initiate the questioning, a common template containing four critical variables (PPN, soil health, adoption of potato agricultural practices and potato yield) was presented to these experts. The data from nine interviews were combined to create a cognitive map of the experts (Özesmi & Özesmi, 2004). From this expert cognitive map, thirteen variables, including the four key initial variables, were identified and included in the survey instrument. Two additional variables, household consumption and demonstration plots, were added to the farmers questionnaire to reflect the Guatemalan household consumption needs and the practice of extension staff.

For the cognitive map session of the questionnaire, each variable was paired with another variable and respondents were asked a series of questions. First, respondents were asked whether a relationship existed between the two variables. If the answer was 'Yes', the respondent was asked whether the relationship was positive or negative. The respondent was then asked to categorize the magnitude of the influence or relationship as low, medium or high. A 'No' response to the first question lead directly to the respondent being asked about the next pair of variables.

The individual cognitive map data were collected between July 26 and August 2, 2017. The data from the USAC professionals were collected through self-administered questionnaires, whereas data from the smallholder farmers were obtained through in-person interviews due to language and literacy concerns. Interviews were conducted in Spanish by recruited and trained local enumerators. A USAC student also assisted with the in-person interviews.

The individual responses were transposed into adjacency matrices, and aggregated by their group affiliation (one for agricultural professionals and one for the cooperative farmers) (Özesmi & Özesmi, 2004). The perceptions of direction and magnitude of the relationships were used as collective cognitive maps to simulate policy or 'what if' scenarios. Using a sigmoid activation function (Nápoles *et al.*, 2016), five different 'what-if' scenarios were run to calculate the relative perception of the impact for five agricultural practices or scenarios. Each scenario is represented by a variable in the model that is a recommended practice. For each scenario, one agricultural practice was activated via a forced increase of the selected variable in the model, allowing the comparison of the perceived effects of a change in PPN, potato yield, and soil health. Five scenarios were conducted to evaluate how the impacts were distributed among the model variables. In the graphs, the results of the simulation show relative change of certain variables in the model. The results of the community-level cognitive maps and the scenario simulations contribute to a better understanding of the gaps in knowledge and provide essential information to design more effective technology transfer activities to boost the rate of adoption for managing PPN and soil health to increase potato yield and improve food security in the region.

Results and Discussion

We will first discuss the mental models of farmers and agricultural professionals from USAC and their perceptions on relationships among the variables, i.e. causation and magnitude of the relationships. We will next compare the differences between the cognitive maps and highlight differences in perceptions. Finally, using the mental models created, the results of the simulation exercise with plausible 'what if' scenarios will be reported to provide knowledge of differences in impacts and outcomes. Before discussing the results, some definitions are warranted. The transmitting nodes/variables are those that will affect changes and receiving nodes/variables are those being affected. To describe the model structure and relationships, first we will discuss the nodes that are being impacted i.e. receiving nodes or variables.

The results of the agricultural professionals and farmers cognitive maps differed slightly, as is expected between stakeholders with differing areas of expertise, experience, and context (Figs. 2 and 3). Three key study variables have the most interactions with the other model variables. These key variables are PPN, soil health, and adoption of potato growing practices. For the receiving variable or being affected PPN variable, the agricultural professionals from USAC believed that practices of biocontrol, certified seeds, use of compost and nematicides will decrease the PPN whereas the use of uncomposted chicken litter and fertilizer will increase the PPN. In the case of the farmers, they perceived that the use of biocontrol and nematicides will lower PPN whereas the use of certified seeds, compost, chicken litter and fertilizer will increase PPN. To summarize the impact on PPN, two variables standout as different between the two groups - use of certified seeds and compost. The agricultural professionals perceived those two variables to decrease PPN population density and farmers perceived the same variables to increase PPN (Table 2). The negative perceptions by farmers can be attributed to the lack of knowledge of what certified seeds can do. For compost, farmers' negative perceptions could be from their experience or a lack of scientific knowledge being made available to them in ways that they can understand and contextualize. In an earlier focus group survey, these farmers had expressed a belief that PPN contaminated the compost.

As a receiving node, adoption of potato production practice was positively affected by farm income and training according to the farmers' and USAC professionals' perceptions. However agricultural professionals perceived a lower degree of influence of training on adoption (Table 3). This could be attributed to experts being disappointed in the slowness of adoption even with the obvious benefits of the technologies. Other factors that weaken the relationship for the experts could come into play such as be a lack of resources for adoption or some of the technologies have not spread to remote rural areas. Additionally, farmers perceived technology transfer (demonstration plots) to affect positively to adoption of farm practices. Eighty percent of farmers from Paquix have participated in demonstration plots.

For soil health as a receiving node, all farm potato production practices (such as biocontrol, use of chicken litter, compost, fertilizer, and pesticides) for both cognitive maps were found to similarly impact soil health. Fertilizer is perceived to be negatively impacting soil health consistent with scientific evidence related to deleterious effect on nitrogenous compounds on the environment (Chen *et al*., 2016; Habteweld *et al*., 2017). Inorganic fertilization enriches the soil but fails to provide stabilizing structure to the biological community. Use of chicken litter and nematicides were also perceived by both groups to negatively impact soil health. There are however, statistically significant differences in the degree of influence of certified seeds, and nematicides on soil health between the two cognitive maps. Farmer groups perceive the use of certified seeds as having a higher positive impact on soil health and nematicides as having a lower negative impact on soil health compared to agricultural professionals (Table 3).

The same three key variables that act as transmitting variables to the other model variables can be summarized as follows. Both agricultural professional and farmer groups agree as to the negative impact of PPN on potato yield and soil health. Also in sync is that both groups perceive soil health to have a positive impact on potato yield. In regard to adoption of agricultural practices, it is unanimous that more training and more income affect higher adoption of all agricultural practices. For both maps, the variables with the highest centrality scores were 'adoption of potato growing practices' followed by 'soil health,' and 'potato yield'. The centrality scores indicate the contribution of a variable within a cognitive map and are calculated by the addition of all the values assigned to connections receiving (in-degree) or transmitting (out-degree) a variable (Özesmi & Özesmi, 2004; Gray *et al*., 2014).

The 'what if' scenarios were chosen based on the plausibility of adoption of potato production practices given sufficient resources and government support. Scenarios play a critical role in the interpretation of cognitive mapping because they illustrate the strength of the influence of a variable over the entire cognitive map (Nápoles *et al*., 2016). The five 'what if' scenarios were use of biocontrol, certified seeds, compost, nematicides, and fertilizer. Our hypotheses are that biocontrol, certified seed, compost, and nematicides can be used to suppress PPN; biocontrol and compost improve soil health. Fertilization improves yield with no effect on PPN but with an adverse effect on soil health. Except for biocontrol, over 50% farmers self-reported the usage of the other four agricultural practices (Table 4).

The first scenario simulated an increased use of biocontrol (Fig. 4). The perceived impacts showed the same direction of influence between the farmers and agricultural professionals reflecting overall higher positive influences on yield and soil health and negative influences on PPN. However, the agricultural professionals showed higher values in terms of agreement and strength of those relationships. This result is consistent with the expectation of USAC professionals being more knowledgeable in the usage and benefits of biocontrols than farmers, which also explains adoption of this practice by less than 50% of farmers in Paquix (Table 4).

For the scenario increasing the use of certified seeds (Fig. 5), the anticipated influences on soil health are stronger for the farmers compared to the agricultural professionals. Most farmers in Paquix reported the use of certified seeds, and the simulation also indicated as anticipated benefits, the reduction of PPN and increase in yield. For USAC professionals, the use of certified seeds produced mixed results with a negative impact on PPN and a positive impact on soil health. The comparison with the other scenarios suggest that USAC professionals consider that other practices (e.g. biocontrol, compost) have greater influence on improving soil health and reducing PPN.

Under the scenario increasing the use of compost (Fig. 6), the simulation suggests that both groups expect positive benefits on potato yield and soil health. Experts additionally believe that compost decreases PPN. The difference in perception of compost could be due to lack of clear understanding of the true value of compost since the use of uncomposted chicken litter was the predominant practice until recently (MAGA, 2015). It is also possible that some farmers still do not fully know how to manage compost preparation and usage. Farmers had a clear understanding of the improvement compost brings to soil health a boon for experts wishing to increase the use of compost as a sustainable input into the cropping system.

Although the simulation indicates that both groups perceive that an increase in nematicides reduces PPN, negative impacts on soil health and potato yield were expected by the agricultural professionals (Fig. 7). As expected, the agricultural professionals demonstrated a better understanding of the range impacts of nematicides not only on PPN but also to beneficial nematodes, with consequent reduction to soil health. Farmers do understand the value in nematicide application in reducing PPN, but do not recognize any impacts on soil health or potato yield. Farmers may be short term thinkers whereas experts understand that long term application of pesticides is generally harmful to soil health.

In the last simulation, the application of fertilizer generally was perceived by both groups to increase PPN and negatively affect soil health (Fig. 8). Both groups did recognize the negative effects on soil health with the continual input of inorganic fertilizers. When asked about the impact of fertilizer, eight agricultural professionals perceived no influence on soil health, six reported a negative impact and three reported a positive impact between these variables. These differences reveal a lack of consensus in the perceptions within the agricultural professionals. The perception of the overall negative effects on soil health could be due to the synthetic nature of the fertilizers and the possible leaching of the nutrients into streams. It may also reflect knowledge of the effect of high concentrations of fertilizers, nitrogen in particular, on soil microorganism. Despite the individual differences, the perceptions of both groups are aligned.

Summary and Conclusions

This study initially hypothesized that agricultural professionals' and farmers' mental models will be aligned and we found this to generally be the case. Through the cognitive mapping approach, we can make recommendations to enhance adoption rates of potato farmers in Western Guatemala based on understanding what they perceived as to the impacts of the various production practices. From a scientific standpoint, all of the potato production practices should synchronously increase yield, improve soil health, and reduced PPN populations except for the overuse of fertilizer. Furthermore, these practices should readily be adopted if knowledge is disseminated effectively.

However, from the cognitive maps not all of the potato production practices impacts were perceived by farmers to produce high yields or intended environmental benefits. Shown from the farmer's cognitive maps, if we expect adoption for the purpose of increasing soil health for farmers with degraded soils and low yields then training the farmers on the use biocontrol, certified seeds, and compost would yield the best results. If the goal is to reduce PPN populations in highly infested fields, we can expect adoption to be quicker with biocontrol method and effective training. If the goal is to increase potato yield, however, at this time the farmer's perceptions are that most of the potato production practices have minimal impact. Therefore, more workshops and informational meetings are needed. This study dices to the heart of understanding how farmers perceived the impacts or lack thereof on the scientifically proven technologies. Another important aspect is the delivery mode of the technology transfer information by knowing how and where they receive information about new agricultural practices. When asked about the source of information on new agricultural practices, 95% of the farmers mentioned that they learned about new agricultural practices through the local cooperative and 80% participated in demonstration plots. We should use this information for delivery location and conduct more demonstration plots. Furthermore, through the survey results, we found agricultural professionals gave themselves low rating as to the effectiveness of technology transfer activities. This suggests that the agricultural professionals seem to be critical of their training pedagogy and felt the need to strengthen their extension efforts. This study's analysis will contribute to their job effectiveness. In sum, to have sustained potato yield requires understanding the relationship beyond inputs and yield. Our challenge is to find the most effective manner to disseminate and transfer new growing practices to local smallholder potato farmers for enhanced adoption. This study contributes information to that effort for Guatemalan potato farmers.

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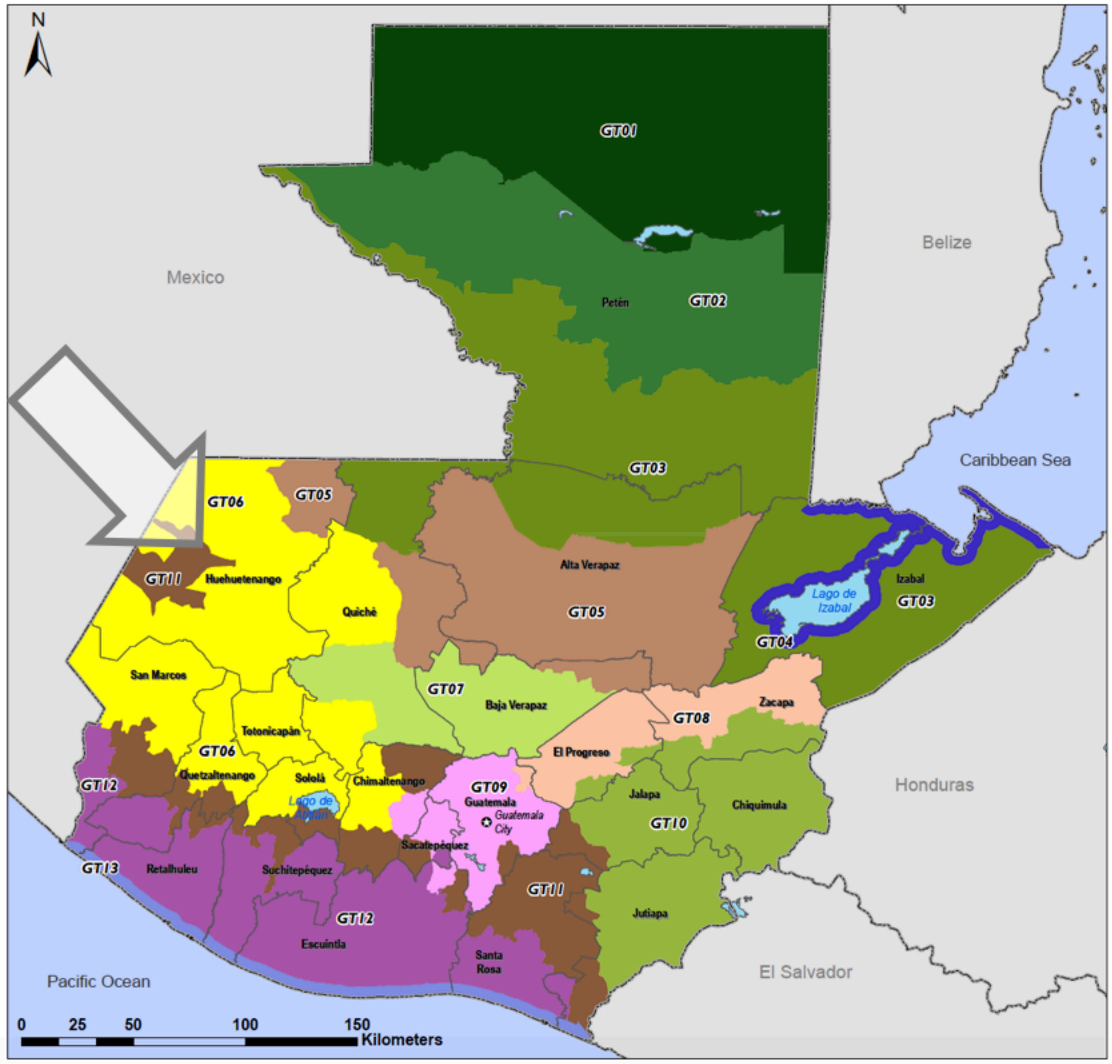

Figure 1. Area of study - Department of Huehuetenango in Guatemala (FEWS NET/USAID, 2017).

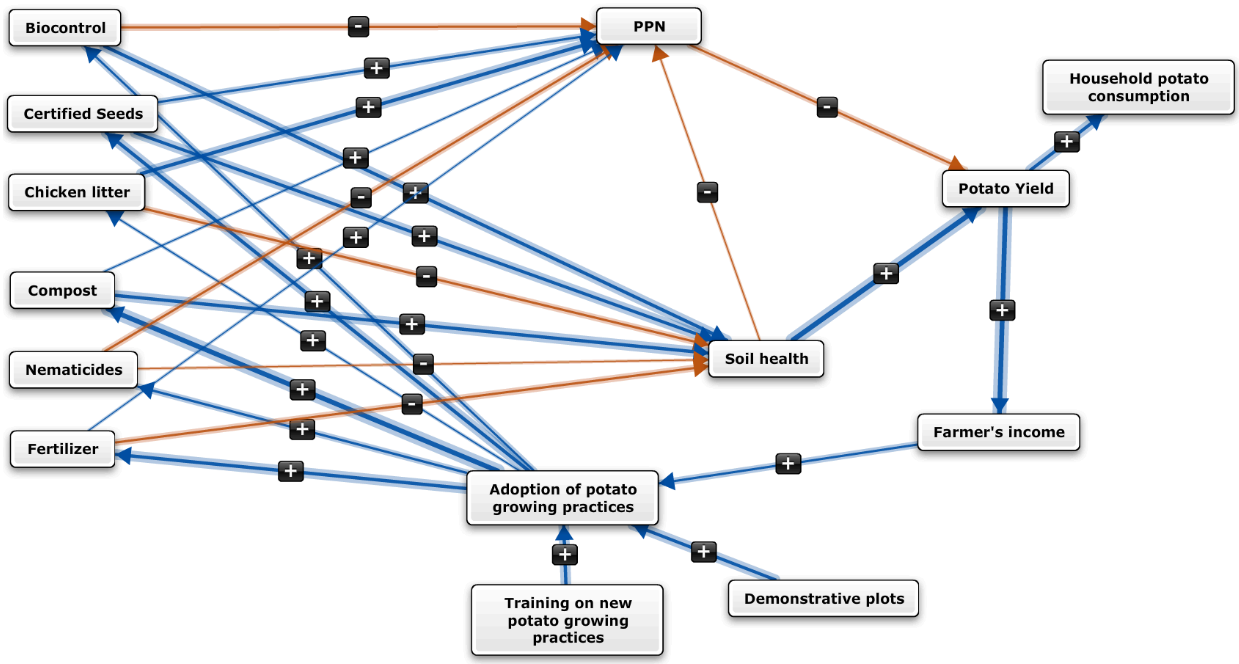

Figure 2 - Cognitive maps for smallholder potato farmers from Paquix, Huehuetenango, Guatemala Blue arrows represent perceived positive (+) causal relationships between two variables and red arrows, perceived negative causal relationships (-). Thickness of the arrows shows the strength of the relationship

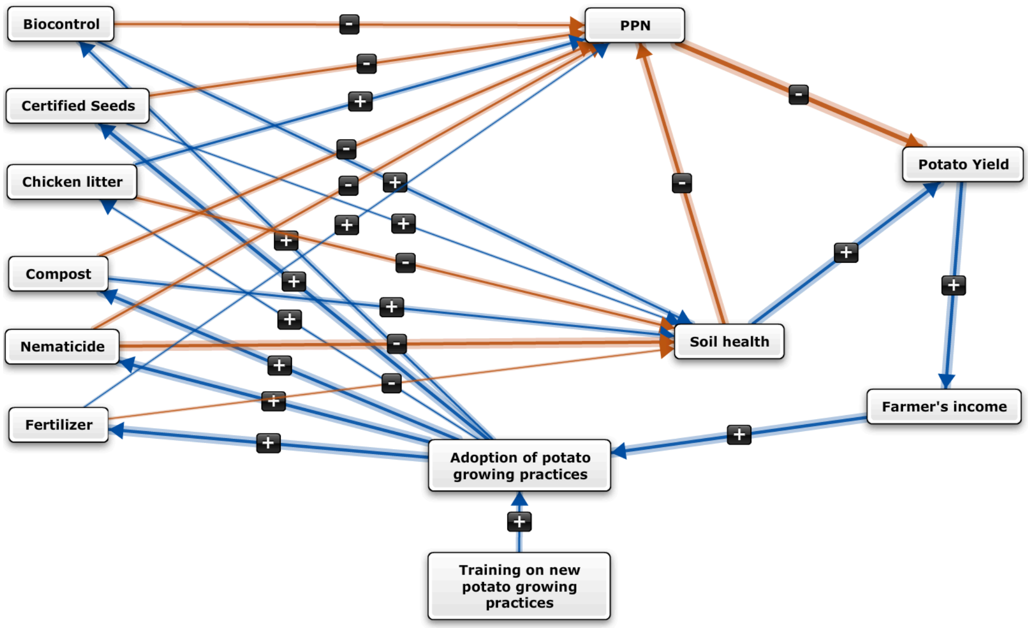

Figure 3 - Cognitive maps for agricultural professionals from University of San Carlos (USAC) in Guatemala City. Blue arrows represent perceived positive (+) causal relationships between two variables and red arrows, perceived negative causal relationships (-).
Thickness of the arrows shows the strength of the relationship.

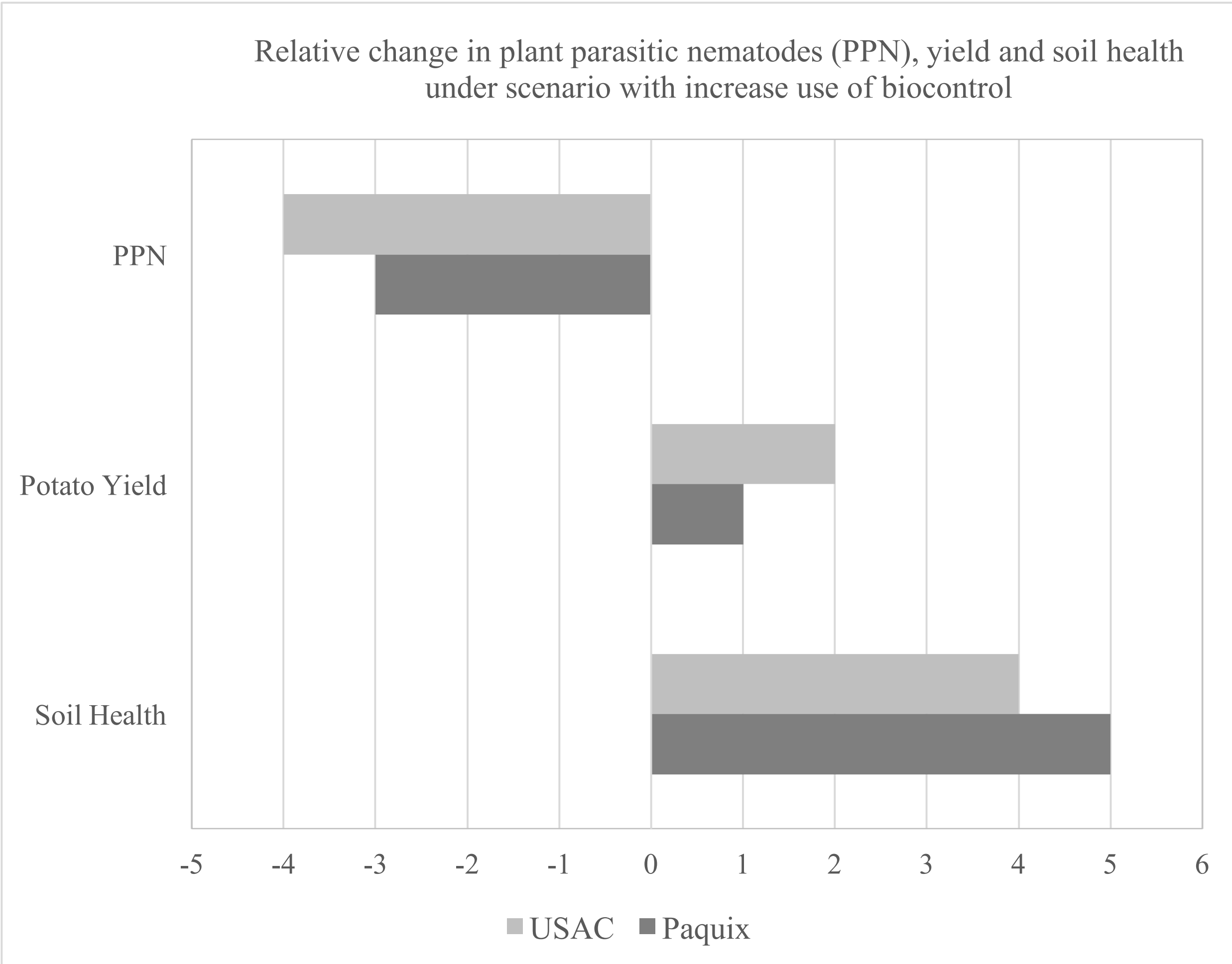

Figure 4 - Scenario of increased use of biocontrol. USAC are agricultural professionals and Paquix are smallholder potato farmers. These values represent perceived relative changes from a steady state condition and only indicates influences compared to other variables within the mental model.

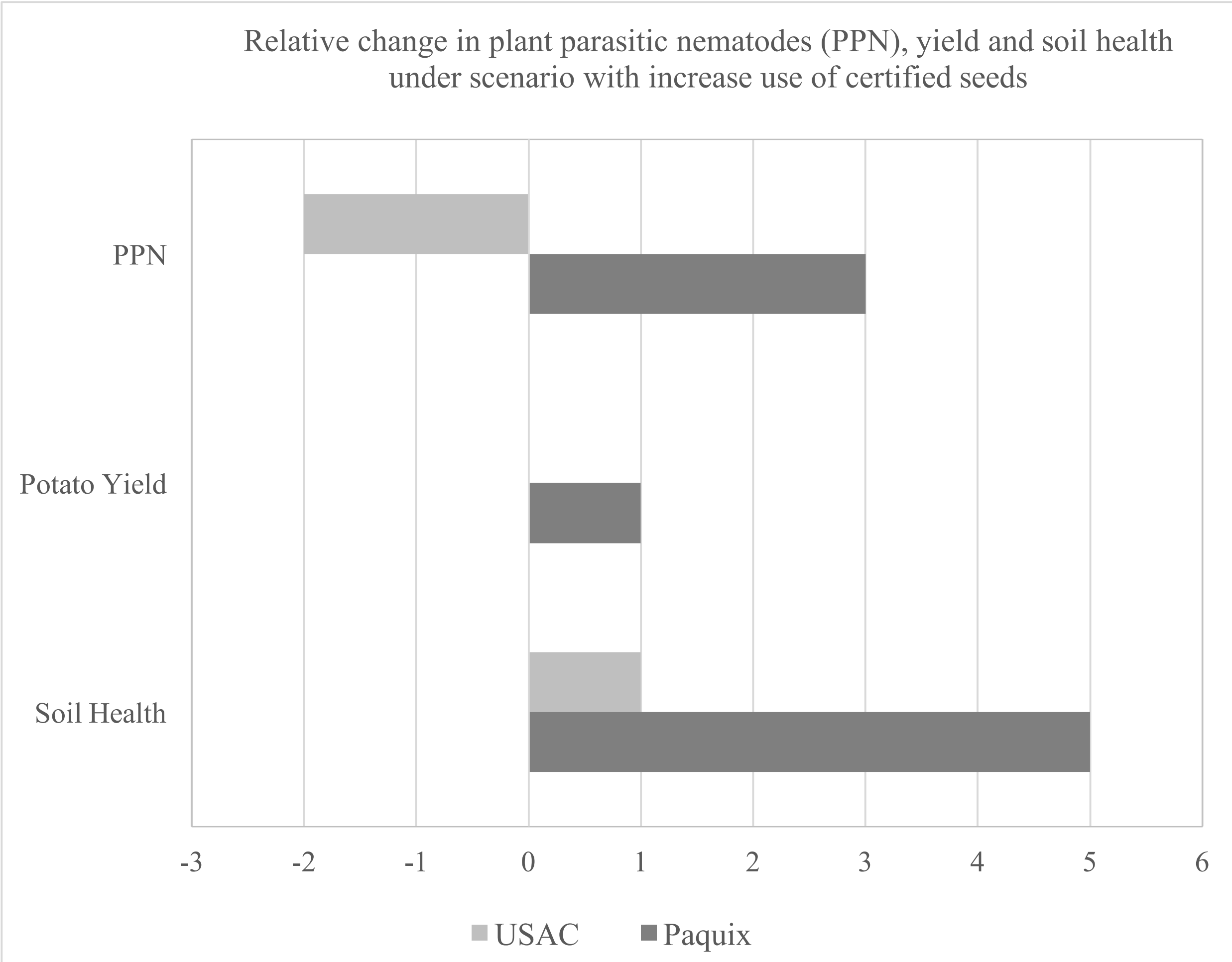

Figure 5 - Scenario of increased use of certified seeds. USAC are agricultural professionals and Paquix are smallholder potato farmers. These values represent perceived relative changes from a steady state condition and only indicates influences compared to other variables within the mental model.

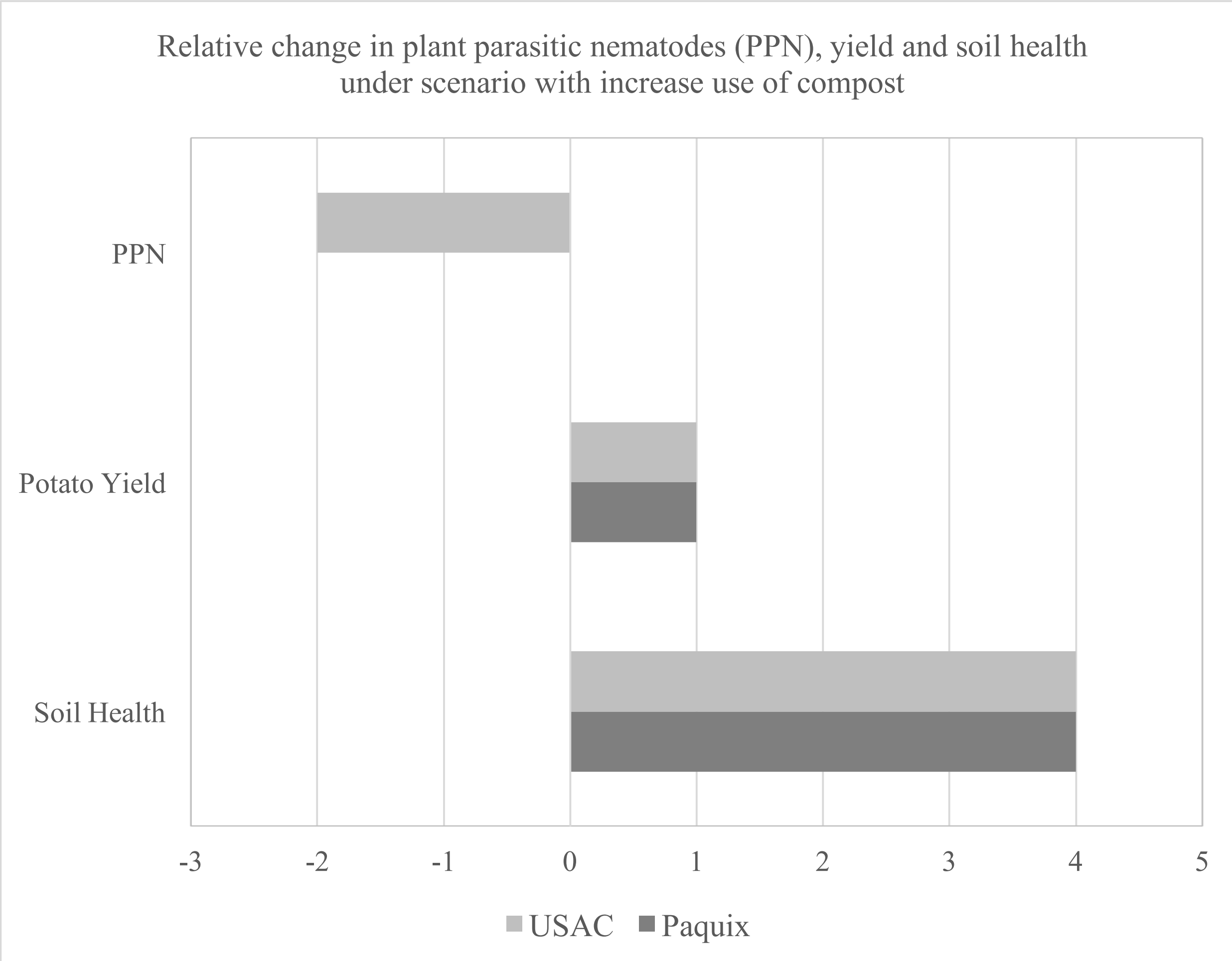

Figure 6 - Scenario of increased use of compost. USAC are agricultural professionals and Paquix are smallholder potato farmers. These values represent perceived relative changes from a steady state condition and only indicates influences compared to other variables within the mental model.

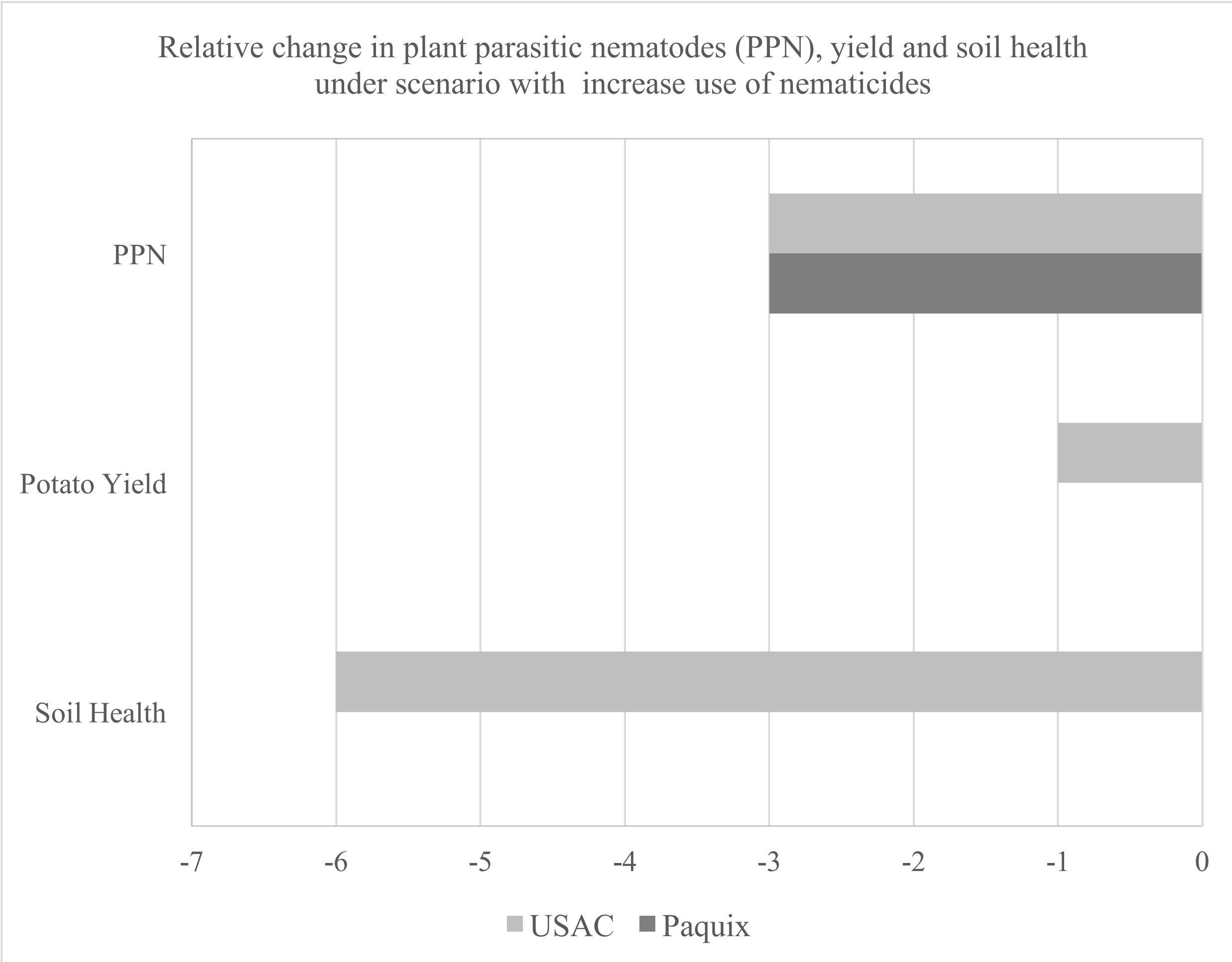

Figure 7 - Scenario of increased use of nematicide. USAC are agricultural professionals and Paquix are smallholder potato farmers. These values represent perceived relative changes from a steady state condition and only indicates influences compared to other variables within the mental model.

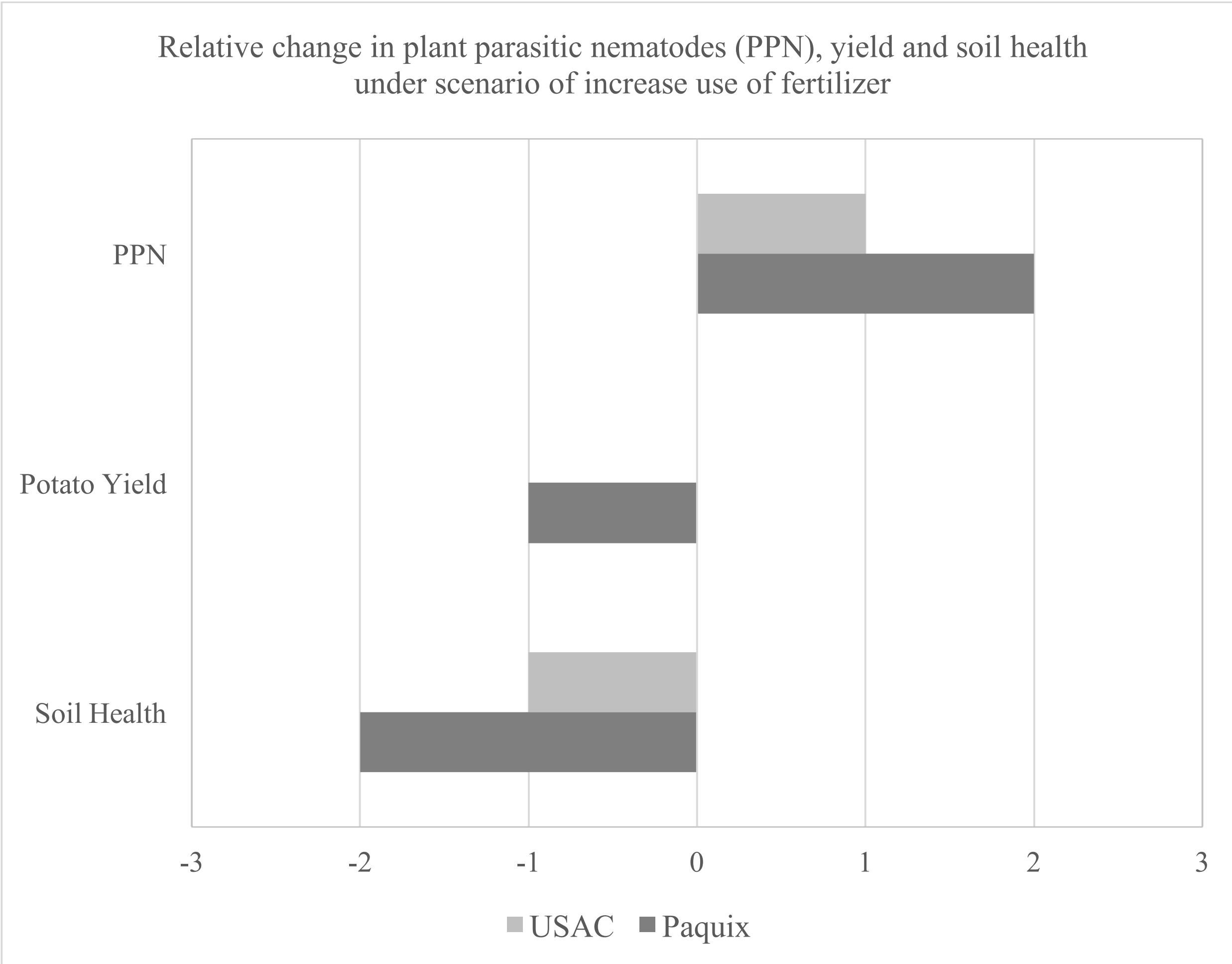

Figure 8 - Scenario of increased use of fertilizer. USAC are agricultural professionals and Paquix are smallholder potato farmers. These values represent perceived relative changes from a steady state condition and only indicates influences compared to other variables within the mental model.

Table 1 – Demographic characteristics of study participants from University of San Carlos (USAC) and Paquix, Huehuetenango, Guatemala.

Group	**Description**	**Total participants**	**Gender**		**Farm size (ha)**	**Median Education Level**
			Male (%)	**Female (%)**		
USAC	Agricultural Professionals	17	70	30	N/A	Bachelor degree
Paquix	Farmers	20	70	30	0.5	Elementary

Table 2 – Key directional differences between farmers and agricultural professionals cognitive maps in relations to PPN

Transmitting variable	Receiving variable	Agricultural Professionals	Farmers
Certified seeds	PPN	-	+
Compost	PPN	-	+

Table 3 –Weights and directions of key pairs of fuzzy cognitive map variables between farmers and agricultural professionals.
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Transmitting variable	Receiving variable	Average degree of influence (weight)	
		Agricultural Professionals	Farmers
Training	Adoption of potato growing practices	+ 0.39 *	+ 0.80 *
Soil health	PPN	- 0.69 *	- 0.13 *
Biocontrol	Soil Health	+ 0.35 **	+ 0.62 **
Certified Seeds	Soil Health	+ 0.06 *	+ 0.77 *
Nematicide	Soil Health	- 0.63 *	- 0.03 *

Note: ANOVA tests indicated statistically significant differences at $^{**}p<0.10$ and $^{*}p<0.01$.

Table 4 – Potato production practices used by farmers in Huehuetanango, Guatemala (2017)

Production practices	Number of farmers	%
Certified seeds	17	85%
Nematicides	14	70%
Biocontrol	9	45%
Compost	16	80%
Fertilizer	20	100%