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Use of the environmental impact quotient to estimate impacts of pesticide usage in three Peruvian potato production areas

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Abstract

In Peru, potato farmers rely on fungicides to control late blight, the most important disease, and insecticides to control a variety of pests. The study aims to estimate the environmental and human health risk associated with pesticide use through the use of the environmental impact quotient (EIQ) to represent the total hazard posed by all pesticides applied over different potato cultivars.

About half of the fungicide (total formulation) was applied per hectare in Huamachuco (0.8 kg/ha), compared to the other two locations: 2.0 kg/ha in Chaglla and 2.4 kg/ha in La Encañada. Insecticide use in Chaglla was only 0.38 kg/ha while in Huamachuco it was about 0.59 kg/ha and in La Encañada over 2.28 kg/ha. Environmental impact values per hectare were about three to four times higher in La Encañada than in either of the other two locations primarily due to heavy use of highly hazardous insecticides. Lack of correlation of environmental impact with productivity indicated opportunities for improvement.

The high degree of variability in products used among locations as well as the different toxicological properties of the products used makes a purely amount-based comparison of pesticide use less illuminating. The EIQ was helpful in providing information on the potential environmental effect of current application practices. Modifying pesticide application patterns through adequate training on more efficient pesticide use and on integrated pest management strategies would be an effective way to reduce farmer health and environmental impacts in Peru.

Acknowledgements

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INTRODUCTION

Potato is the most important crop in the Peruvian Andes in area planted, and it is produced by approximately 600 thousand farm households in Peru, most of which are located in the highlands. [1] Farms in the Peruvian highlands are characterized by small-scale agriculture [2] and significantly rely on a rain-fed cropping system. The food produced by these farmers is basically for self-consumption, with 15-23% of agricultural production entering the market. [3]

The main potato disease is late blight, which is caused by the oomycete pathogen *Phytophthora infestans* (Mont) de Bary. [4] About 42% of the 268 000 hectares cultivated with potato in Peru are at risk from high or very high levels of late blight incidence [5] and approximately 15% of the Peruvian potato crop is lost annually to late blight, despite the fact that farmers usually spray fungicides for late blight more than six times per cropping season. [6]

Pests are also important problems in the Andes, especially the Andean potato weevil, the potato tuber moth, flea beetles, nematodes and leaf miner flies. [7] However, farmers usually do not understand the life cycle of the insect pest nor their feeding patterns, [8] nor do farmers understand many aspects of pesticide technology (e.g., mode of action, systemic movement in plants, hazard of resistance in the pathogen, etc.). [4] Furthermore, Andean farmers are generally unaware of the human health and environmental hazards associated with pesticides. [4,9,10]

One of the most common fungicides used in Peru for control of late blight is mancozeb, which can cause dermatitis [11] and is considered hazardous among occupational health researchers. [12] Mancozeb belongs to the family of dithiocarbamate fungicides, which is suspected of causing adverse reproductive [13] and mutagenic effects on human cells. [14-16] The insecticide carbofuran, also frequently used in potato production in Peru, is highly hazardous (World Health Organization category Ia) [17] and threatens both human health, due to its high acute toxicity and easy absorption through skin of commonly used liquid formulations, and the environment, due to its high potential for leaching into groundwater. [10]

The International Potato Center and its partners have put a high priority on the development and diffusion of integrated pest management (IPM) technologies that help potato farmers reduce dependence on pesticides. These technologies include a number of IPM practices that help to reduce the damage caused by disease such as growth of potato cultivars with resistance to late blight. Potato farmers in the present study primarily grew the potato cultivars Yungay, Canchan, Liberteña and Amarilis in the study locations (Table 1). Yungay and Canchan are widely grown in Peru, while the other two are restricted to certain regions. Although there is currently no method for quantifying resistance to *P. infestans* in potato cultivars used in developing countries, researchers would generally classify Amarilis as the most resistant, followed in order of descending resistance by Liberteña, Yungay and finally Canchan. [18] Nonetheless, a recent study indicated that Amarilis only has a low level of resistance to *P. infestans*. [19] These cultivars also differ in time needed for maturation and potential yield (Table 1).

Measuring the success of IPM and related technologies requires many tools, not the least of which is a mechanism for measuring the potential benefits of pesticide reduction in terms of reducing environmental and human health hazards. Evaluation of the hazards posed by pesticides to the environment and human health is complex, involving many factors such as: application conditions, slope and altitude of the plot, local soil characteristics, weather patterns, and pesticide properties. In an effort to summarize this complexity more than 100 tools have been developed in different countries for the evaluation of secondary adverse effects of pesticides. [20] A number of those tools were classified using a system ranging from anecdotal accounts to holistic assessments of impact of agriculture. [21] For each tool, examples, units of measure, objectives and limitations were presented. Examples of those scoring systems include the Environmental Hazard Index and the Priority Substances List in Canada; [22] the Ecological Relative Risk indicator in Austria, [23] the European Risk Ranking method (EURAM); and the Chemical Hazard Evaluation for Management Strategies from University of Tennessee, and Purdue Research Foundation's Pollution Prevention Progress Measurement Method in the USA. [20]

One of the more wildly used measures is the Environmental Impact Quotient (EIQ), [24] which is a composite environmental impact assessment system. [21] The EIQ is regarded as relatively easy to use and has been frequently presented in the scientific literature as a useful means to estimate potential environmental hazards associated with agricultural pesticide use. [22, 25-32] Furthermore, the EIQ approach permits the integration into one value of several important environmental and human health impacts that could be reduced through greater use of IPM technologies and practices.

This study had three objectives: The first was to document pesticide use in potato production in the highlands of Peru and explore reasons for variation in use across study areas; the second, was to apply the EIQ approach because of the need for a standardized and practical methodology for environmental and human health impact assessment; and the third, was to develop baseline EIQ data that would permit comparison of the study sites with other potato growing locations and crop experiences and inform ex-post impact assessment of fungicide-reduction technologies, practices or policies.

METHODOLOGY

Three districts from three departments of the Peruvian highlands were selected for the study: La Encañada and Huamachuco in Northern Peru, and Chaglla in Central Peru (Figure 1). These zones were selected because of their importance in Peruvian potato production either at the regional or national level. A total of 307 farmers were surveyed between March and April of 2006 to gather information about potato production during their most recent crop cycle, including detail questions on pesticide use.

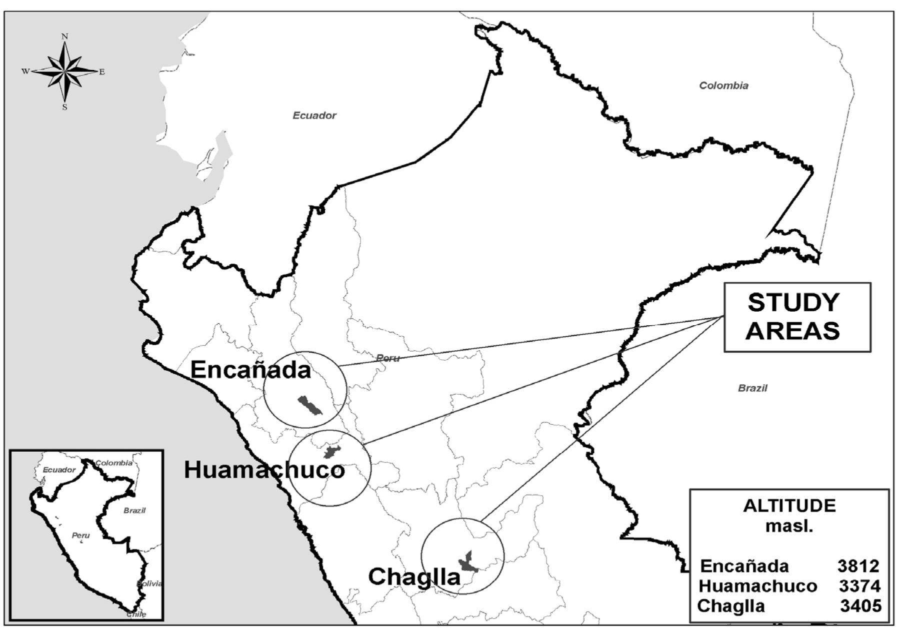

Figure 1.
Location of the surveyed provinces for the study in Peru.

The EIQ is a mathematical and conceptual summary equation of environmental and health impact.[21] The EIQ combines the pesticide hazard posed to farm workers (applicator effect and picker effect), consumer (consumer effect and groundwater effect), and the local environment (aquatic effect and terrestrial effect) into a composite hazard indicator (Equation 1).

Equation 1: Environmental Impact Quotient Formulae.

$$\mathbf{EIQ} = \Big(C\,[(DT \times 5) + (DT \times P)] + (C \times [(S + P) / 2] \times SY) + (L) + (F \times R) + (D \times [(S + P) / 2] \times 3) + (Z \times P \times 3) + (B \times P \times 5) \Big) / 3$$

Where:

C = chronic toxicity

DT = dermal toxicity

P = plant surface residues half-life

S = soil residues half-life

SY = systemicity

L = leaching potential

F = fish toxicity

R = surface loss potential

D = bird toxicity

Z = bee toxicity

B = beneficial arthropod toxicity

Values in the equation are determined by toxicity information from several databases including the Extension Toxicology Network (EXTOXNET), CHEM-NEWS, SELCTV, individual chemical manufacturers' data sheets, and public data sources such as those available from the US Environmental Protection Agency. In terms of the chronicity value ('C') in the human health portion of the EIQ equation, toxicity information comes from databases animal studies assessing the mutagenic, teratogenic, reproductive, and oncogenic effects of these chemicals. Toxicologists judged whether a chemical had either a possible, probable or definite effect; and an ordinal value of 1, 3 and 5 was assigned to these effects respectively. To create a summary value across all available studies for an active ingredient, all assigned values were averaged to give a single value. In terms of dermal toxicity ('DT'), these values were taken directly from the chemical manufacturers. Values 1, 3 and 5 were assigned to each toxicity value for a given active ingredient according to the distribution of toxicity values available. From this collection of ordinal values a single average value was determined to represent the 'DT' value for a given active ingredient. A similar approach was taken for the coefficients in the consumer and environmental portions of the EIQ equation (Kovach J, pers. comm.). EIQ values for over 300 active ingredients are available on a Cornell University website (http://nysipm.cornell.edu/publications/eiq/) as well as several other sources. [28]

EIQ values for fungicides and insecticides were taken from the Updated Table of the EIQ values from the Cornell University web page or when not available there, estimated in one of two ways. First, EIQ values for 7 fungicide active ingredients and 6 insecticide active ingredients found in one or more of the three locations were estimated based on chemical similarity to active ingredients included in the online EIQ list. For example, propineb, which is an EBDC fungicide, was given the average value of the EBDC fungicides present on the published list. In some cases, no similar chemical was found on the published list and the EIQ was estimated based on the World Health Organization (WHO) recommended classification of pesticides by hazard. [17] In this sense, iprovalicarb has a toxicological classification of III, therefore it was assigned an EIQ value corresponding to the average value of insecticide compounds with toxicological classification III present on the published list. A sensitivity analysis was performed in order to assess the impact of using the minimum, average and maximum value of missing EIQ values for selected pesticides and compares the effect on total EI value per cultivar and location.

The Environmental Impact (EI) of each pesticide was calculated by multiplying the EIQ value by the amount of pesticide used (amount of active ingredient in kilograms or liters per particular area based on application rates and percentage of active ingredients) and then summing over the number of applications per season. [28] The EI per hectare was calculated by dividing the total EI values to the number of evaluated hectares by cultivar and location.

RESULTS

Approximately equal numbers of farmers were recruited from the three departments. Average farm size differed substantially, with those from Chaglla having the largest planted areas compared to La Encañada with the smallest planted areas (Table 1).

Table 1. Cultivars, potato production, and farmers sampled across different locations in Peru.

Location	Altitude	Cultivars *	Potato area (ha.)**	Farmers interviewed	Average potato area per farmer (ha.)	Potato area represented by interviewees
La Encañada	3300	Amarilis Liberteña	1849.56	101	0.89	4.9%
Chaglla	3075	Canchan Yungay	1097.94	102	4.96	46.1%
Huamachuco	3200	Amarilis Canchan	3029.82	104	1.55	5.3%

* Amarilis has a growing period of 90-120 days and a productivity under optimal conditions of 30 t/ha.; Liberteña 160-180 days and a production of 35 t/ha.; Yungay 150-180 days and a productivity of 50 t/ha.; and Canchan 120-150 days and a productivity of 40 t/ha.
** Refers to total area in the location and is based on the National Agricultural Census of 1994 (the most recent available).

Twenty-three fungicide active ingredients (Table 2) and fifteen insecticide active ingredients (Table 3) were reported as having been used to control pest and diseases in the most recent potato crop cycle. EIQ values were classified as low (0-20), medium (20.1-40) and high (>40.1), [26] and we found 9 low, 8 medium, and 6 high hazard fungicides. No low hazard insecticides were found, while 7 were medium hazard and 8 high hazard insecticides were found.

Table 2. Active ingredients, environmental impact quotient (EIQ) and doses (l/ha or kg/ha) of fungicides used in three locations in the highlands of Peru.

Active ingredients and measures	EIQ	Chaglla		Huamachuco		La Encañada	
		Canchan	Yungay	Amarilis	Canchan	Liberteña	Amarilis
Dimethomorph (kg)	24	4.0	4.0	0	0	0	0
Cymoxanil + Propineb* (kg)	14.1	3.5	3.2	1.8	2.7	4.3	6.7
Propineb* (kg)	14.6	3.3	3.3	2.1	0	4.3	5.7
Cymoxanil + Mancozeb (kg)	14.1	3.1	3.5	1.5	2.5	0	0
Cymoxanil (kg)	8.7	4.3	4.2	0	0	0	0
Metalaxyl M (kg)	29.4	3.0	3.5	1.3	1.7	3.3	4.4
Zineb (kg)	44	4.4	4.2	1.1	1.3	0	0
Iprovalicarb** + Propineb* (kg)	8.7	2.2	1.8	1.1	1.5	0	7.3
Propamocarb hydrochloride (l)	21.5	5.9	5.7	0	0	0	0
Metiram (kg)	40	2.3	4.5	0	0	0	0
Methyl thiophanate (kg)	22.42	0.5	0.5	0	0	0	0
Mancozeb (kg)	14.6	2.3	2.6	0	0	4.2	6.1
Propamocarb * (l)	21.5	1.1	1.0	0	0	0	0
Iprodione (kg)	11	0.4	0.5	0	0	0	0
Carbendazim (l)	56.17	0.4	0.4	0	0	0	0
Sulfur (kg)	45.5	1.7	1.6	0	0	0	0
Copper oxychloride* (kg)	33.3	0.8	1.2	0	0	0	0
Benomyl (kg)	52.6	0.3	0.2	0	0	0	0
Tebuconazole (l)	40.3	0.3	0.2	0	0	0	0
Fentin Acetate* (kg)	70.1	0.0	0.0	0	0	0	0
Captan + Flutolanil (kg)	25	0	0.2	0	0	0	0
Benalaxyl* + Mancozeb (kg)	16.2	0	0	2.1	3.0	0	0
Metalaxyl + Mancozeb (kg)	16.2	0	0	0.5	0.7	0	0
Average/ha		3.2	3.1	1.4	1.9	3.8	5.3

* EIQ values of pesticides calculated based on values from the same chemical family.

** EIQ values of pesticides calculated based on values from the same toxicological class.

Table 3. Active ingredients and absolute amount (l/ha or kg/ha) of insecticides used in three locations in the highlands of Peru.

Active ingredients and measures	EIQ	Chaglla		Huamachuco		La Encañada	
		Canchan	Yungay	Amarilis	Canchan	Liberteña	Amarilis
Carbofuran (l)	50.67	1.19	1.15	1.74	1.56	5.92	7.87
Cypermethrin (l)	27.3	0.79	0.79	2.12	1.83	---	---
Methamidophos (l)	36.8	0.64	0.97	1.46	1.31	3.70	4.71
Lambdacihalothrin (kg)	43.5	1.06	1.20	---	---	---	---
Oxamyl (kg)	22.9	0.85	0.83	---	---	---	---
Benfuracarb* (kg)	23.3	1.62	0.60	---	---	---	---
Carbosulfan* (l)	23.3	1.21	1.20	1.41	1.22	---	---
Monocrotophos* (l)	90.92	0.61	0.60	---	2.03	---	---
Cyfluthrin (l)	39.6	0.61	0.60	---	---	5.52	6.02
Fipronil (kg)	90.92	0.61	0.60	---	---	---	---
Betacyflutrin* (l)	39.6	---	---	1.41	1.22	3.80	4.42
Parathion etilic (kg)	104.4	---	---	0.94	0.81	2.58	3.76
Chlorpyrifos (kg)	43.5	---	---	2.82	3.65	---	---
Aldrin* (kg)	104.5	---	---	1.41	---	---	---
Fenvalerate (l)	49.6	---	---	1.41	1.22	---	---
Zinc phosphide** (kg)	50.67	---	---	1.41	1.22	---	---
Average/ha		1.00	1.00	1.58	2.28	5.16	6.62

* EIQ values of pesticides calculated based on values from the same chemical family.

** Inorganic rodenticide, therefore not counted for the analysis.

However, not all products were used in similar amounts and some that were used in small amounts were not labeled for the disease for which they were applied (e.g., carbendazim is not adequate for controlling late blight on potato). Overall, a much larger number of products was used in Chaglla than in the other two locations, perhaps related to the greater area under cultivation and greater experimentation with different products.

There was variation among locations for the most frequently used commercial fungicide products. For example, the most common fungicides used in Chaglla were based on dimethomorph, which was not used at all in La Encañada or Huamachuco. Similarly, products containing the phynalamides (benalaxyl and metalaxyl) were used in Huamachuco but not in the other locations (Table 2). For Chaglla and Huamachuco, similar products and doses were used on both cultivars. Overall, only about half as much fungicide (total formulation) was applied per hectare in Huamachuco (0.8 kg/ha), compared to the other two locations: 2.0 kg/ha in Chaglla and 2.4 kg/ha in La Encañada.

The location effect on total amount used was even greater for insecticide use. Insecticide use in Chaglla was only 0.38 kg/ha while in Huamachuco it was about 0.59 kg/ha and in La Encañada over 2.28 kg/ha. The most common insecticides used across all three areas were carbofuran (1.9 kg/ha) and methamidophos (1.2 kg/ha), both highly hazardous to human health. [17]

The pattern of usage was highly variable when both insecticides and fungicides were considered together. In Huamachuco, similar and relatively low intensity of both types of pesticides were applied (Table 4). However, in the other two locations this was not the case. In Chaglla, intensity of insecticide was relatively lower (1 kg/ha), less than one third the amount of fungicide applied. In La Encañada, the pattern was reversed, although to a lesser degree. Here, relatively higher application intensities were observed for insecticides compared to fungicides.

Table 4. Number of sprays per season, amount applied and environmental impact (EI) of pesticides used in potato production in three locations in the highlands of Peru.

		Sprays/field/season		**Total pesticide (L or Kg/ha/season)**		**EI/ha/season**		
Location / cultivar	**Number of Ha.**	**Fungicide**	**Insecticide**	**Fungicide**	**Insecticide**	**Fungicide**	**Insecticide**	**Total**
Chaglla								
Canchan	239	5.31	2.26	3.19	1.00	50.74	16.90	67.64
Yungay	225	5.14	2.30	3.14	1.00	48.76	17.03	65.78
Huamachuco								
Amarilis	73	2.81	2.19	1.37	1.58	18.34	24.71	43.05
Canchan	50	2.82	3.67	1.94	2.28	26.48	34.18	60.65
La Encañada								
Liberteña	43	2.73	3.16	3.84	5.16	59.85	101.55	161.40
Amarilis	21	3.01	3.01	5.33	6.62	80.04	135.59	215.63

EI values per hectare were about three to four times higher in La Encañada than in either of the other two locations primarily due to heavy use of highly hazardous insecticides. Overall EI per hectare ranged from about 43 (Huamachuco, Amarilis) to 216 (La Encañada, Amarilis).

Sensitivity analyses across the range of imputed EIQ values found no change in rankings of EI/ha across cultivars and areas, although expected differences in absolute value were observed with the greatest difference from 184/ha to 244/ha for Amarilis in La Encañada, with an average of 216/ha (Figure 2).

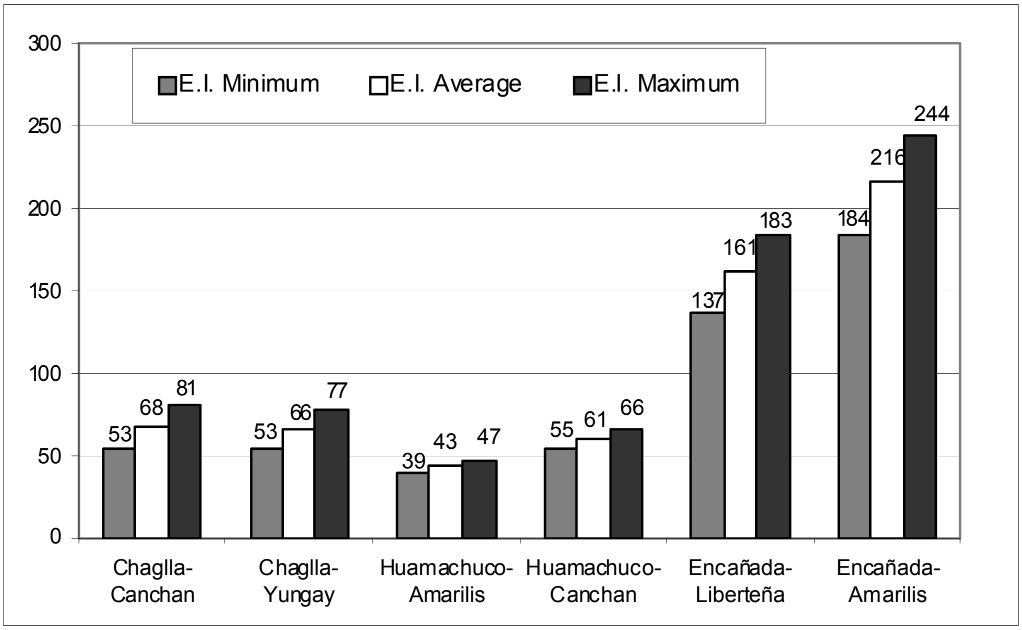

Figure 2. Sensitivity analysis of the EI values per hectare with respect to the minimum, average and maximum values for the categories of the missing EIQ values of pesticides of the main potato cultivars in the three study areas.

EI values were not linked with productivity in the three locations (Figure 3). Chaglla, which had similar total EI/ha to Huamachuco, had about three times the productivity of the latter. On the other hand, Huamachuco had similar productivity to that of La Encañada, but its EI/ha was approximately three times lower.

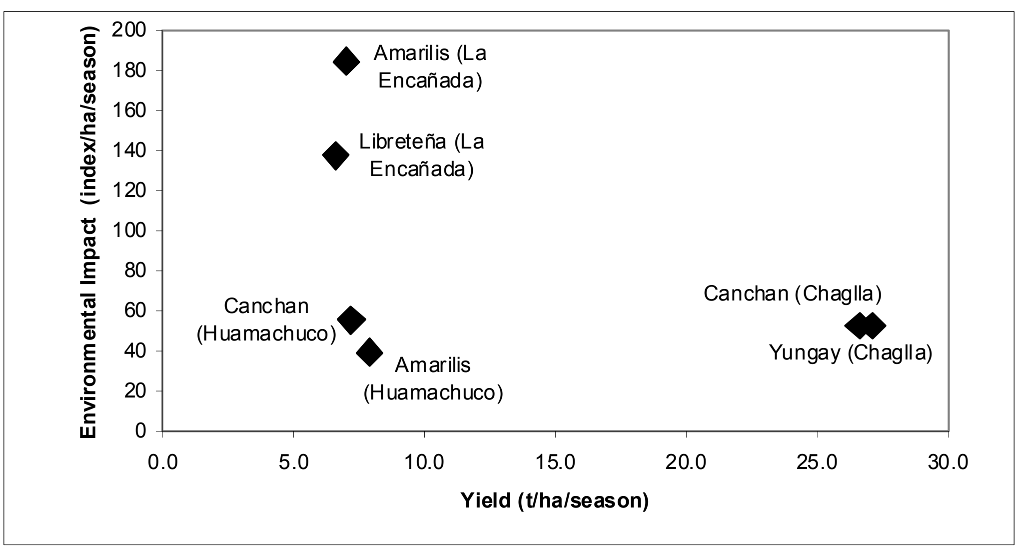

Figure 3. Tradeoff between productivity and environmental impact of pesticides for different potato varieties on three localities of the Peruvian Andes (the localities are shown into brackets).

DISCUSSION AND CONCLUSION

We observed substantial variation in pesticide use across the study areas. Possible reasons that may have led to these differences are differences in pest and disease severity, differences in the number of pesticide options available related to access to agricultural input sales outlets, income available to spend on pesticides, and lack of farmer knowledge regarding IPM alternatives, all of which are characteristic of small-scale farmers in the Peruvian Andes. [33]

We found little evidence to indicate that farmers in this study treated cultivars differently with regard to pesticides. This is not surprising for fungicides considering the relatively similar level of susceptibility to late blight in the cultivars. Furthermore, since little is known about cultivar resistance to the major insect pests, Andean weevil and potato tuber moth, farmers would have no criteria to differentiate insecticide use based on cultivars. Very high levels of resistance to late blight in potato cultivars has been identified in some developing countries, particularly in Africa, [34] an area where exploration of the pesticide reducing options associated with use of such varieties is worthy of exploration.

We found no clear relationship between fungicide use and simple indications of precipitation. According to Figure 4, La Encañada generally has the lowest precipitation per year, [35] but that location also used the most fungicide per ha/season while Huamachuco had the highest precipitation but the lowest fungicide application. Water deficiency early in the season in La Encañada may have caused a higher incidence of *Epitrix* spp., which could explain the high insecticide application in that location.

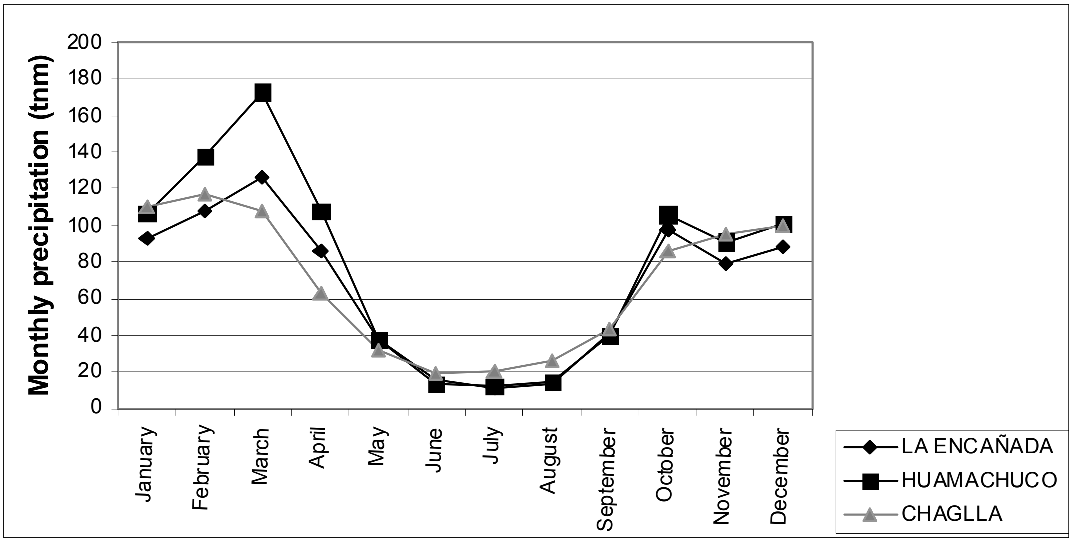

Figure 5.
Monthly distribution of precipitation in the three study areas (average of the last 50 years).
Source: Hijmans *et al.*, 2005.

While La Encañada had the highest use of pesticides it also was characterized by smallest area per farmer (Table 1). The overall greater intensity of use of both fungicides and insecticides on smaller farms may be related to the packaging of available products for sale, and the farmer's desire to use most of the purchased amount in each application (Paredes M, pers. comm.), even when potato area under cultivation might require less active ingredient i.e. there may be a floor effect of amount per application which disregards farm size. The lack of increases in productivity even with higher pesticide use compared to Huamachuco warrants consideration of alternative management practices as do the higher productivity with equivalent pesticide use in Chaglla, though differential soil fertility may play a role in each.

While this paper is the first EIQ-based evaluation on use of potatoes in low and lower-middle income countries, this is the fifth to our knowledge, to use the EI values to estimate likely impacts of pesticide use on any crop in low to lower-middle income countries. Mazlan and Mumford compared the proportion of cabbage farmers among five zones in the highlands of Malaysia, using categories of field use rated EIQ insecticide active ingredients (low, medium, high toxicity). [26] Bardenes-Perez and Sholton used a similar technique on non-field use rated EIQ active ingredients to compare impact in cruciferous vegetables growing areas - two areas of the Kenyan highlands and three areas of the Kullu Valley in India. [27] Morse et al assessed the environmental impact of an agricultural shift to genetically modified cotton production in South Africa. [29] Muhammetoglu and Uslu used field rated EIQ results to select the least detrimental pesticide for an evaluation of different pesticide management scenarios in an intensive agricultural area in Turkey. [36] None of these papers, however, explicitly explore the reasons for variation in EI or EIQ field rated values in their study areas as most of these articles used the EIQ as a supplementary descriptive tool to emphasize the need to have better pesticide practices in specific areas or to show a reduction in potential hazard over time.

In comparing the above studies in terms of the proportion of low (0-20), medium (20.1-40) and high (>40.1) toxicity of active ingredients applied, the present study population uses the highest proportion (in relation to total amount applied) of highly environmental risk insecticides at 63%. In addition, the EI values for insecticides used in La Encañada in the current study far exceeded the field rated EIQ values seen in any of the other studies by at least a factor of two, reflecting both the use of highly hazardous active ingredients and a high application rate. Those insecticide active ingredient EI values reported for Chaglla and Huamachuco were very similar to those reported in the other studies described above. The present study stands out as the first among low to lower-middle income country EIQ studies that examines hazards related to fungicides.
Compared to higher income countries, the EI values per hectare of potato farmers in the highlands of Peru were at the low end of those associated with tomato production in Southern Europe and in the French Island Reunion in Indic Ocean [37]. In some of the locations studied in Europe, EI per hectare (referred to as EIQ in that paper) were over 1000, and in Reunion, over 1500. Tomato producers in Reunion used about 40 kg/ha of pesticides per year over the three-year period of the study.

The primary advantage of using a common metric for comparing pesticide usage across time and space is that it can facilitate cross-area and crop comparisons, and potentially meta-analyses. However, for such comparisons there is an underlying assumption that the metric is appropriate for all locations. The EIQ is composed of three hazard components: farm worker, consumer and environment, but one can easily postulate that these hazards are not the same in all locations. Based on a rapidly increasing body of knowledge, it appears evident that hazard to farm workers (and their families) is higher in the developing world than in the industrialized countries. [12,38] Although the current EIQ values do not take into account method of application or use of personal protective equipment (Kovach J, pers. comm.) and hence some overestimation in applicator exposure may occur in higher income countries, greater bystander exposure might be expected in lower and middle income countries where separation of agricultural operations and home life is less clear. As well, potentially vulnerable fauna may have greater exposure due to unsafe pesticide use practices e.g. washing backpack sprayers in streams, or may themselves be more susceptible to pesticide toxicity due to species differences and variation in environmental conditions.

While it is understood that the EIQ was developed primarily as a tool for agricultural practitioners to rapidly assess the hazards associated with pesticide use, there are several limitations affecting how accurately the hazard is portrayed by the EIQ, particularly for the human health component. Firstly, the use of a limited range of ordinal ratings to assign an active ingredient as a possible, probable or definite risk to human health and the low ordinal values assigned to these ratings dilute the underlying extent of variability in toxicity values that may be present. This ordinal ranking would cause the EIQ values assigned to active ingredients to appear more similar in hazard level than would be reflected in the original data, subsequently attenuating the variation in the hazard present for different crops and geographic areas. Secondly, studies used for dermal toxicity (DT) values are entirely rabbit or rat based models with active ingredients being applied directly to the skin and toxicity subsequently assessed. The EIQ equation indicates multiplying the ordinal DT value by a factor of five in order to take into account the increased risk associated with handling concentrated pesticides. However, given the fact that DT was assessed on exposed mouse skin, this value should more appropriately be divided by a factor to take into account the fact that applicators do wear some protective clothing in some countries and therefore the risk would be less than if the skin was directly exposed to the active ingredient.

To our knowledge this is the first use of EIQ and EI/ha values for evaluation of fungicide use in potato in low and lower-middle income countries. The EI/ha metric provided a synoptic view of pesticide hazards to human health and environment in the three selected locations in the central highlands of Peru. The high degree of variability in products used among locations as well as the different toxicological properties of the products used makes a purely amount-based comparison of pesticide use less illuminating. Based purely on amounts of pesticide used, the larger relative human health and environmental hazard of potato production in La Encañada would not have been fully appreciated. Further, the relatively high EI/hectare values compared to other lower income country reports, warrant both further investigation in other settings where such high use may occur, and estimation of the environmental and human health benefits potentially associated with IPM and other interventions. [38] In particular, the EI value per hectare would be a good tool for exploring changes in fungicide use due to use of more highly late blight resistant potato cultivars in Africa.

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