Toward an integrated understanding of pesticide use intensity in Costa Rican vegetable farming

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Abstract

Understanding the factors that influence the adoption of synthetic pesticides has to date overshadowed explanations of variation in pesticide intensity. I conducted a survey of vegetable farmers in Northern Cartago and the Ujarrás Valley, Costa Rica, in 2003-04 with the goal of explaining differences in pesticide intensity with reference to socioeconomic, political economic, and agroecological characteristics and relationships. Using ordinary least squares regression models, this paper explores the factors that influence pesticide use intensity in potato and squash production. Results indicate that many variables strongly influence pesticide intensity, including variables related to the farmer, farm household, political economic relationships, the biophysical environment, and agroecological relationships. Conclusions discuss the need for an integrated approach to adequately understand pesticide intensity and potential policy interventions including agroecological education and extension, increased enforcement of pesticide residue limits in the national market, and land reform to allow for longer fallow periods.

Keywords: Costa Rica; agriculture; pesticide use; pesticide intensity; cultural and political ecology; econometrics

Introduction

Farmers have widely adopted synthetic pesticides in many industrial and semi-industrial agricultural systems around the world since their introduction in the 1940s. More recently, realizations of acute and long-term human health effects and environmental damage have led to widespread questioning of the modern agricultural paradigm (Carson, [1962] 1994; Wright, 1990). Part of the widespread questioning emphasizes that pesticide use fundamentally results in unequal distribution of benefits and harms. For example, Pimentel et al. (1992) estimate that in the early 1990s, the total costs of pesticide use to US society were $8 billion per year, while farmers spent $4 billion on pesticides and saved $16 billion on their crops (Pimentel *et al.*, 1992, p. 758). The $8 billion in costs include both the $3 billion in costs born by farmers and society—natural enemy destruction and pests' resistance to pesticides—and the $5 billion "paid" by society in environmental and health costs, including acute and chronic health effects, water pollution, bee poisonings, losses of other beneficial or economically useful species, and government costs in controlling pesticide contamination (Pimentel *et al.*, 1992, p. 758). With this uneven distribution and the "externalization" of costs from the production system, political debates and struggles over pesticide use remain important to discussions of the sustainability of agricultural systems.

Given this background, prominent political ecologists have made calls for better understandings of the issues and risks involved in pesticide use and accumulation in the environment (Bryant, 1998; Bryant and Bailey, 1997). A handful of political ecologists have already examined pesticide use in developing countries. Thrupp *et al.* (1995, p. 49) point out that high pesticide use "cannot be seen merely as a 'natural' reaction to high pest incidence." Instead, Thrupp *et al.* (1995, p. 49-50) point to many other factors—largely structural—that influence pesticide use, including stringent market requirements for aesthetic perfection, national polices that create incentives for pesticide use, credit policies that often mandate pesticide use as a loan condition, active sales promotion by agrochemical companies, intermediaries who provide technical assistance to contract farmers and promote and sell agrochemicals, and inflated perceptions of pest risks on the part of farmers. Stonich (1993) also highlights problematic pesticide use in new exports from Latin America, linking their heavy use to the need to generate foreign exchange to repay debt that increased dramatically with the debt crisis of the early 1980s. Grossman's (1992, 1998) work expands upon a largely structuralist interpretation of pesticide use by also highlighting the agency of farmers and the importance of the environmental rootedness of agriculture in pesticide use. He posits that differences in farmers' pesticide use can be explained by their individuality and propensity to experiment.

Mostly separate from this political ecological research on pesticides is a large body of literature in agricultural economics and rural sociology that explores the adoption of agrochemical inputs by farmers. This immense literature most often addresses one question about a binary outcome: what factors influence a farmer's decision to adopt or not adopt a certain technology? The way the research question is posed ignores more interesting but more complex questions that I argue would benefit from a political ecology approach. As Feder *et al.* (1985, pp. 287-8) pointed out more than two decades ago,

> for many types of innovations, the interesting questions may be related to the intensity of use (e.g., how much fertilizer is used per hectare or how much land is planted to HYVs [high-yielding varieties]). Future studies can rectify this problem by properly accounting for a more varied range of responses and by employing statistical techniques suitable for the variables considered.

Even with this explicit call to understand the *intensity of use* of various agro-industrial inputs, there remains little work focused on explaining pesticide use intensity on specific crops at the farm or field level (for the few examples, see Rahman, 2003; Roschewitz *et al.*, 2005). In 2003-04 I conducted fieldwork on intensive vegetable production in Costa Rica, with one of my goals being a context-specific explanation of the variation in pesticide intensity. Using a political ecology approach, I wanted to examine the effects of many kinds of influences — farmer and farm household characteristics, broadly defined political economic relationships, and the biophysical environment and agroecological management — in order to move beyond overly simplistic but common notions that farm scale or market orientation or size of monocultures are the major determinants of pesticide use intensity.

By using data from my fieldwork, this paper attempts to explain the variability in the intensity of pesticide use on two main vegetable crops — potato and squash — in Northern Cartago and the Ujarrás Valley, Costa Rica. To do so, I employ appropriate econometric methods, still a relatively rarity among political ecologists. While econometrics as applied to environmental questions is best developed and most commonly used by agricultural and resource economists, geographers in land change science and cultural and political ecology (Coomes and Barham, 1997; Roy Chowdhury and Turner, 2006; Takasaki *et al.*, 2000), environmental anthropologists (Godoy, 2001), and sociologists (Rudel *et al.*, 2002) are increasingly using econometric and microeconomic analyses to explain human-environment relationships. I use econometric methods here not as a substitute for a qualitative understanding of the relationships involved, but rather as a complement. My other work has examined specific slices through the question of pesticide intensity, notably the effect of regulation from afar in export systems (Galt, 2007) and comparisons of crops produced for export and the domestic market (Galt, in press), by mixing qualitative and quantitative methods.

Econometric models can be appropriate to the study of pesticide intensity for two main reasons. First, while some portray agrochemically dependent agriculture as a monolithic set of technologies that farmers adopt and use in a similar manner, substantial variation exists in the intensity of use of various inputs between industrial agricultural systems (Bayliss-Smith, 1982; Turner and Brush, 1987). Considerable variation in input use also manifests itself between farms in the same location and system (Grossman, 1992). For example, in a descriptive study of 23 chile farmers in Sri Lanka, Burleigh *et al.* (1998, pp. 54-5) report that pesticide use between farmers varied by two orders of magnitude. These high levels of variation in pesticide use intensity between farmers sharing the same crop and place of production have not been adequately explained.

Second, an examination of empirical data and theory from a number of different disciplines that study agriculture — agroecology, anthropology, economics, geography, sociology — reveal that many factors — personal, cultural, social, economic, regulatory, agroecological, and biophysical — influence pesticide use (Grossman, 1992; Murray, 1991; Nicholls and Altieri, 1997; Rahman, 2003; Roschewitz *et al.*, 2005; Thrupp, 1990; van den Bosch, 1980; Vandeman, 1995; Ward and Munton, 1992; Wiebers *et al.*, 2002; Wilson and Tisdell, 2001; Zilberman *et al.*, 1991). I argue that this complexity results from the interplay of various elements in the agricultural system, as theorized below. Ecological interactions of the pest and pathogen populations with the crop and biophysical elements like antagonistic organisms, soil, and weather affect the intensity of pest and pathogen populations (Letourneau, 1997). Farmers' understandings of these observable and unobservable interactions result from both personal knowledge (Bentley, 1989; Johnson, 1972; Richards, 1993) and social interactions with other farmers, agrochemical dealers, extension agents, and off-farm service providers (Wolf, 1998). These imperfect and structurally influenced understandings inform farmers' economic decision-making (Roberts and Swinton, 1996), which itself is based on imperfect knowledge of the effectiveness of spraying, potential returns, and future crop prices. Farmers' spraying decisions do not result merely from economic considerations but must be weighed against their understandings of the health, environmental, and regulatory risks involved in spraying (Galt, 2007; Grossman, 1992; Thrupp *et al.*, 1995). All of these interactions and decisions occur within a broader political economy that normalizes pesticide use as an acceptable form of pest control. This theorization suggests that including appropriate independent variables to explain variation in pesticide use presents a considerable challenge. I argue that adequate models must include socioeconomic, political economic, and agroecological variables.

If the theoretical understand above is correct or at least practically adequate (Sayer, 1992), research from a reductionistic perspective that attempts to explain differences in pesticide intensity without combining socioeconomic, political economic, and agroecological factors will prove inadequate. For example, Roschewitz *et al.* (2005) use agroecological theory to explore pesticide use by correlating it to the proportion of farm dedicated to annual crops and to landscape complexity. Their work did not find the expected results. While they found that the average number of disease species in cereal crops increased with the percentage of arable land on a farm (i.e., larger monocultures have more diseases present), higher fungicide applications did not follow. Nor did pesticide intensity increase with lower landscape complexity or on bigger, more specialized farms as predicted by agroecological theory. While field- and landscape-scale agroecological and biophysical variables certainly affect pest populations and thereby should influence pesticide use, analyzing these variables in the absence of important socioeconomic factors and political economic relationships will mean that the analysis omits important human, social, and economic sources of variation. As noted above, farmers' decision-making process results not just from their personal (and imperfect) understanding of the agroecosystem, but also from cultural, social, political, and economic influences and pressures (Bayliss-Smith, 1982; Blaikie and Brookfield, 1987; Marsden *et al.*, 1996; Thrupp *et al.*, 1995). It follows that statistical and econometric explanations including only agroecological or socioeconomic or political economic variables will miss important sources of variation. Thus, more detailed econometric analyses are needed that combine agroecological, socioeconomic, and political economic variables to attempt an "inveterate weaving" (Zimmerer and Bassett, 2003) that is critical to understanding society-environment relationships generally, and pesticide intensity variation in particular. The analysis below is one attempt to tackle this challenge within the context of two Costa Rican vegetable cropping systems.

This paper's organization is as follows. I first provide a brief background on export and domestic vegetable booms in Latin America. A description of the study site and its cropping systems, extension activities, and farm households follows. I then elaboration on methods by explaining the farmer survey, the concept of field-specific crop pesticide intensity that is the unit of analysis, the econometric models used, and their theoretical justification. Results are presented briefly, followed by a discussion grouped around important socioeconomic, political economic, and agroecological variables. The conclusion cautions against reductionistic explanations of pesticide intensity and discusses policy recommendations.

Background: expanding vegetable production in Latin America

The question of pesticide intensity looms large in horticultural production systems. The pest susceptibility and high value of the vegetable, fruit, and ornamental crops causes them to be more heavily sprayed than agronomic crops like grains and pulses (Dinham, 2003; Fernandez-Cornejo *et al.*, 1998; Galt, in press). For this reason, I chose to focus my research on horticultural, specifically vegetable, systems.

Vegetable production systems for export and national markets are expanding concurrently in developing countries (Weinberger and Lumpkin, 2007). A large literature in political economy and political ecology focuses on one of these expansions, the non-traditional agricultural export (NTAE) boom in Latin America. NTAEs include export crops that were not traditionally grown in an area, or crops of local origin that are newly exported (Barham *et al.*, 1992; Thrupp *et al.*, 1995). For Central America and the Caribbean, the NTAE category includes any fresh fruit or vegetable other than bananas, such as broccoli, cantaloupe, snow peas, squash, and strawberries. Since the 1980s, Latin America has supplied much of the fresh fruits and vegetables (FFVs) available in US supermarkets in winter (Hamilton and Fischer, 2003; Llambi, 1994). The situation across the Atlantic mirrors this, where former African colonies now supply FFVs to their former colonizers in

Europe (Barrett *et al.*, 1999; Freidberg, 2003). Both of these South-to-North commodity chains form part of the shift from classic, often non-perishable export commodities like coffee to "high value foods (HVF)" like fruits, vegetables, poultry, dairy products, and shellfish (Watts and Goodman, 1997, p. 10).

The second and less-emphasized vegetable boom involves the expansion of vegetable production in the global South to feed increasing national—especially urban—consumer demand for highland tropical and temperate vegetables like potato, carrot, cabbage, broccoli, onion, lettuce, etc. (Horst, 1987). Areas of intensive vegetable production typically exist near major urban areas in von Thünen (1826) style, made possible by road connections to tropical mountains with their year-round temperate conditions.

I chose Costa Rica as a country to understand the ramifications of these vegetable expansions because three important characteristics overlap there. Costa Rica ranks as one of the top three Latin American vegetable exporters (Barham *et al.*, 1992), it has a large national vegetable market because of its relatively large middle class (Ramírez Aguilar, 1994; Saborío Mora, 1994), and it faces serious pesticide problems (Hilje *et al.*, 1987). This last characteristic merits explanation. Costa Rica, despite its "green" image, has the highest intensity of agricultural pesticide use in Latin America—the most pesticide intensive world region—and the world (FAO, 2004). This high level of pesticide use suggests the need for an understanding of the reasons behind pesticide intensity variation—i.e., what factors explain high levels of pesticide use? Answers to this question within the context of specific production systems can inform agricultural policy to lower pesticide use and promote the use of alternative pest control methods.

Study site

Physical geography and history of production

With the intent of understanding export and national market production systems, I chose the area in Costa Rica where production for both markets strongly overlaps. The area to the north and east of the city of Cartago, referred to as Northern Cartago and the Ujarrás Valley, is Costa Rica's "vegetable basket" (Figure 1). Truck farmers take advantage of a range of environments and fertile volcanic and alluvial soils to produce a wide variety of tropical and temperate climate vegetables for Costa Rica and, to a lesser extent, export markets including the U.S., Canada, and Europe. All exports involve "conventional" (non-organic) produce since certified organic production does not yet exist in the area. The area produces 95 percent of Costa Rica's potatoes, a majority of the country's many temperate vegetable crops,[1] and millions of dollars worth of fresh vegetable exports.

INSERT FIGURE 1 HERE

Northern Cartago sits on the southern flank of Volcán Irazú, a stratovolcano and the highest peak of the Cordillera Central, reaching 3,432 masl (Barquero H., 1998). Although the climate throughout the study site can support forest because of annual precipitation well above 100 cm, indigenous peoples practiced agriculture for millennia. The Spanish conquistadors, arriving in the 1560s, noted that throughout the Ujarrás Valley the indigenous population planted chayote,[2] corn, beans, plantain, cassava, and pejibaye, a palm with a protein-rich fruit. Cot in Northern Cartago produced mostly corn. Hunting and fishing also provided much food (Bolaños *et al.*, 1993).

Corn, bean, and chayote cultivation continued with the intermarriage of the indigenous people and the Spanish colonists that led to the current mestizo population of the area (Waibel, 1939). Corn and bean intercropping systems — *milpas* — dominated annual crop production until the 20th century. Durable export commodities — coffee and sugar cane — became important by the late 1890s at elevations below 1,600 masl in the Ujarrás Valley and the area around Cartago. By

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[1] The exact percentage cannot be determined, as Costa Rican agricultural census data do not provide much information on most vegetable crops.

[2] Chayote, *Sechium edule*, is Central American cucurbit vine that produces a squash-like fruit with a single seed.

about 1900, most of the towns in the area had been established (Bolaños *et al.*, 1993).

Commercially-oriented vegetable production started with the first planting of potato for the national market in 1910 near San Rafael de Oreamuno (Ramírez Aguilar, 1994, p. 419), which now forms the northeastern edge of the city of Cartago (Figure 1). Between 1915 and 1920, farmers started potato production around Cot, Tierra Blanca, and Potrero Cerrado until it reached San Juan de Chicuá, near the top of the volcano (Ramírez Aguilar 1994: 419). By the 1930s, potato, corn, and bean production dominated the annual cropping landscape of Northern Cartago. Farmers increasingly preferred potatoes, and the canton of Oreamuno in Northern Cartago led in the provision of potato to the central national markets (La Tribuna 1934, p. 15, cited in Arrieta Chavarría, 1984). At the time farmers planted two potato crops a year, generating a profit higher than even coffee production in the top coffee producing areas of Alajuela and Heredia. Other vegetables were also produced in the area in the 1930s, "but this business was not of great importance … because of the low prices quoted in Cartago and San José"[3] (La Tribuna 1934, p. 15, cited in Arrieta Chavarría, 1984).

Roads proved essential for this market integration. Work on the paved highway from San José to Turrialba that runs through Cartago, Paraíso, and Cervantes finished in 1936 (Morrison, 1955, p. 207). The paved road to the north of this highway from Cartago to Capellades running just south of Cot and through Cipreses was completed before 1951, as it appears on Morrison's map based on data from that year. By connecting small farming communities to local markets in Cartago and Paraíso and to the main national markets in San José, these roads allowed for the rapid growth of truck farming that eventually incorporated many other vegetables.

By the 1960s, capitalist social relations permeated much of the Costa Rican countryside (Seligson, 1980). According to the 1963 census, 80.8 percent of Costa Rican farms sold at least

[3] I made all translations from Spanish.

some of their produce (DGEC 1965: 244-5). In Cartago province, the rate was 82.6 percent, with most of the cantons having a higher rate of farms making sales. The 1970s witnessed a further increase in the importance of national market vegetable production in the area, with an almost complete replacement of the *milpa* with vegetables (Castellanos Robayo, 1972; Fuentes Madríz, 1972; Pineda Cabrales, 1973).

Chayote export production boomed in the late 1970s (Bolaños *et al.*, 1993), followed by the production of introduced mini-vegetable NTAEs in the mid-1980s (Breslin, 1996).[4] Export firms in the area target the US and Canadian markets, and the European Union to a much lesser extent. Mini-squash dominates the exports of mini-vegetables, which involves an estimated 74 contracted farm families[5] and two exporters. Presently, roads in the area remain good, and vegetable production continues to dominate the landscape of the Ujarrás Valley and of Northern Cartago, where it also shares prominence with pasture for dairy cattle.

Currently vegetable crops zones exist in "overlapping patchworks" rather than distinct, exclusive crop zones (cf. Zimmerer, 1999). The lower elevations in the Ujarrás Valley support fields of chayote, cassava, chile, cilantro, corn, eggplant, green bean, lettuce, plantain, squash, tacaco, tomatillo, and tomato. The highest elevations support artichoke, carrot, cauliflower, onion, and potato. The middle elevations involve a very diverse mix of many of the warmer-zone crops and the cooler-zone crops mentioned above and those crops that fall in between like beet, broccoli, cabbage, green onion, radicchio, and spinach. Rather than analyzing all of my data on the wide variety of vegetable crops in the area, I focus on two of the most important vegetable crops in the area. These are potato (*Solanum tuberosum*) and squash (*Cucurbita* spp.), both of which face numerous pests and

[4] SEPSA (2004, p. 51) data show that 555 hectares were dedicated to chayote production in 2002 for both the export market and national production.
[5] The manager of the larger of the two exporters reports 46 farmers growing mini-vegetables, while the smaller reports 27 members in the farmer organization associated with it. Also, one large-scale, independent family-run operation grows mini-vegetables.

pathogens in the area. Farmers control these pests and pathogens primarily though synthetic pesticide use, as in most areas of Costa Rica (Hilje *et al.*, 1987).

Potato for national market

Potato is the third most important source of food in Costa Rica after rice and beans (PRECODEPA, 1982). With a total market value of $17 million in 2001, potato ranks as the second most valuable crop of those produced almost exclusively for the national market (SEPSA, 2004, p. 8). Potato occupies 3,300 hectares per year, less than one percent of Costa Rica's arable land, which shows the high level of productivity and inputs. Total potato yield in Costa Rica in 2002 was 86,785 metric tons (SEPSA, 2004, p. 53), so yields are typically 26.2 metric tons/ha/growing cycle. Latin America and the Caribbean's average yield for 2004 was 16 metric tons/ha, while Northern Europe's average was 29.2 metric tons/ha (FAO, 2008). These comparisons speak to the high level of production currently made possible by high agrochemical inputs in Costa Rica.

Potato ranks as the most important crop in Northern Cartago (Figure 2), which produces 95 percent of Costa Rica's potatoes. Some 1,350 farmers in the area grow potato, and its production and processing represents 30 percent of the agricultural and agroindustrial economy of Cartago Province (Ramírez Aguilar, 1994, p. 420).

INSERT FIGURE 2 HERE

Potato production systems typically involve very intensive inputs. According to Horton (1987, p. 48), potato is "a high-input, high-output, high-risk crop. The great responsiveness of yields to inputs—such as high quality [seed] tubers, fertilizers, pesticides, additional labor, and other forms of energy—motivates farmers to use inputs more heavily on potatoes than on other crops." Several potato pathogens make production difficult. Of particular importance is late blight, *Phytophthora infestans*. Abad and Abad (1995) argue that late blight is the most devastating plant disease in history, most infamously as the biophysical root of the Irish potato famine. The severity of late blight attacks makes fungicide use on potatoes very high, especially in areas conducive to the disease. As Horton (1987, p. 41-42) notes:

> To prevent the buildup of lesions that serve as sources of infection, the fungicide must be present on the foliage at the time of inoculation. Farmers often begin spraying early in the growing season before the first attack is expected … . Where blight occurs, and where fungicides are available, farmers usually spray every 3 to 20 days, depending on the probability and severity of the attack.

Northern Cartago appears to have some of the highest late blight pressure in the world. Writing about Northern Cartago, Molina (1961, p. 9) notes that with "strong outbreaks of *P. infestans* … a field can be eliminated in a period of one to four days." Of all nations surveyed by the International Potato Center, Costa Rican potato farmers use the largest number of fungicide applications at 15 per season. Next highest are the Dominican Republic and Cuba at 12, while Costa Rica's Central American neighbors Guatemala and Nicaragua have an average of six and three, respectively (Hijmans *et al.*, 2000, p. 704).

Several other diseases and insects impose important constraints on potato production. Other fungal pathogens include early blight, *Alternaria solani*, and *Rhizoctonia solani*. Farmers control early blight with the same fungicides used for late blight control. *R. solani* resides in the soil and can be spread by tubers (Jackson, 1983) and is controlled with soil sterilants like PCNB. Two important bacterial diseases of the potato in Costa Rica include bacterial wilt, *Pseudomonas solanacearum*, and blackleg, *Erwinia carotovora*. Bacterial wilt exists below 2,200 masl and stays in the soil for many years (Jackson, 1983, p. 104). It can be reduced by rotations, including those with pasture grasses.

Major insect pests include two species of tuber moth (*Scrobipalpopsis solanivora* and *Phthorimaea operculella*), the females of which lay their eggs on exposed tubers. Tuber moth damage results in unmarketable tubers (Jackson, 1983), so farmers regularly use granulated insecticides—including carbofuran, chlorpyrifos, and phorate—in potato production. In 1989, leafminer, *Liriomyza huidobrensis*, became an important secondary pest in the area, greatly reducing potato yields that year, and continuing to cause problems in potato and many other horticultural crops (Comité Técnico de *Liriomyza*, 1990; Rodríguez, 1997). Most insect pests cause greater problems at lower elevations, and leafminer only causes major damage to potato at elevations under 2,400 masl (Rodríguez, 1997, p. 3). As a result of these pests and pathogens and the norm of intensive pesticide use in the area, pesticide use on potato is extremely pesticide intensive, higher than notoriously heavily sprayed bananas and other vegetables (Galt, in press).

Squash for export and the national market

Squash produced for export in Northern Cartago and the Ujarrás Valley belongs to the species *Cucurbita pepo*. Mini-squash — a category that includes mini-patty squash and mini-zucchini — form the backbone of what is known as the mini-vegetable sector in Northern Cartago and the Ujarrás Valley (Figure 3). These mini-vegetables, like the "micro-veg" in the African context, "are not cheap, but they are convenient and fresh, as well as novel and terribly cute. All qualities the discriminating shopper is willing to pay a little extra for" (Freidberg, 2003, p. 27). In addition to exports, the exporting firms have worked hard to strategically create a "high end" national market in restaurants and grocery stores that they supply with mini-vegetables and many other specialty vegetables.

INSERT FIGURE 3 HERE

Despite a number of theses on various aspects of the sector (Hernández Hernández, 2000; Salazar Paz, 2001), adequate data concerning the land area and production and export volumes of squash and mini-vegetables from Costa Rica remain extremely limited. Exporters estimate that 74 farm families now grow mini-vegetables between 1,000 masl and 1,700 masl in Northern Cartago and the Ujarrás Valley. The 26 mini-vegetable farmers in my farmer survey had 51.8 hectares devoted to mini-vegetables at the time of the survey. Assuming these farmers are representative and considering that these represent 35 percent of the reported 74 farmers devoted to their production, and that at least four complete crop cycles of most mini-vegetable can be completed in a year, I estimate that roughly 590 hectares in the area are devoted to mini-vegetables annually. The larger exporter reported about $1 million in sales in 2003, including both the national and export market (Castro, 2004), so the value of mini-vegetables produced in the area approaches $2 million annually.

The export squash farming system differs considerably from that of potato. It is a moderate-input and moderate-output crop that faces a relatively low marketing risk in Northern Cartago because contract farmers have access to a guaranteed market with a stable price. Because of export market requirements for low levels of pesticide residues, many export squash farmers attempt to rationalize and reduce their pesticide use relative to national market farmers (Galt, 2007).

Two other types of squash — ayote and zapallo — provision only the national market. Ayote refers to *Cucurbita moschata*, the most important tropical squash (Bolaños Herrera, 2001). Farmers grow ayote from the Ujarrás Valley at 1,000 masl up to about 1,350 masl. Zapallo refers to *C. maxima*, which belongs to the "winter" squash group. Farmers in Northern Cartago grow it between 1,300 and 2,100 masl. With both species, farmers grow hybrid and *criollo* varieties.[6] Production data on these squash does not exist, as they are excluded from the agricultural census and there is no central purchaser from which to obtain estimates.

National market squash production also involves moderate inputs. In contrast to the mini-squash sold to exporters, farmers typically sell national market squash at farmers' markets or to intermediaries that supply grocery stores and vegetable stands. As with potato and national market vegetables generally, the market price varies greatly, sometimes changing drastically from one day to the next. In contrast to the export market, regulatory bodies do not consistently enforce pesticide residue regulations in the national market, meaning that national market farmers do not face the

[6] As Bolaños et al. (1993) do not mention squash other than chayote from conquistador accounts, I find it difficult to say whether these squash varieties were part of indigenous production prior to Spanish conquest, or whether they have resulted from more recent introductions.

pressures export farmers do to reduce pesticide use.

The plant diseases downy mildew (*Peronospora parasitica*) and squash phytophthora blight (*Phytophthora capsici*) are the most important pathogens affecting squash in Northern Cartago (Agronomist for Exporter A, Interview, December 8, 2003). Downy mildew thrives with high relative humidity (Bernhardt *et al.*, 1988), making the climate of fog and heavy rains in the lower areas of Northern Cartago extremely conducive to its development. *P. capsici* also presents major difficulties for squash farmers since it can destroy an entire crop, especially in areas receiving more than 2.5 cm in a rainfall event (Hausbeck and Lamour, 2004, p. 1299).

Squash in the area faces three main insect pests. Pickleworm (*Diaphania nitidalis*) larvae often feed on the fruit, rendering the squash unsuitable for sale and more vulnerable to pathogens. Cucumber beetles (*Diabrotica* spp.) feed on leaves, and whitefly (*Bemisia tabacii*) can transfer a yield-reducing virus (Hilje, 1997). As with the other crops, squash farmers in the area depend mostly on pesticides to control these pests and pathogens.

Spraying and agricultural extension in the area

The vast majority of farmers in the area rely on calendar spraying of insecticides and fungicides to protect their vegetables from insect pests and pathogens. This reflects a long history of pesticide use in the area, dating back to the 1940s and 1950s (Sáenz Maroto, 1955). More recently, the Ministerio de Agricultural y Ganadería (MAG) has promoted the use of integrated pest management (IPM) in potato production. However, receipt of IPM and other information from extension agents remains low. Of the 148 farmers I surveyed, only two reported frequent visits of MAG extension agents, and these agents do not necessarily promote IPM. Instead, most farmers rely almost entirely upon agrochemical salespeople for production information. Salespeople clearly have a vested interest in increasing sales, and therefore farmers' dependence on agrochemicals (cf. van den Bosch, 1980).

Some farmers, however, show strong interest in sustainable agriculture. Their main source of information for sustainable agriculture is an organic agriculture school near Cuesta La Chinchilla run by the Instituto Nacional de Aprendizaje (INA). While this provides important courses free to the public — including courses on organic fertilizer production, soil and water conservation, vermiculture, plant protection with beneficial bacteria and fungi, making of nurseries and greenhouses, and a general class in organic agriculture — it provides no extension services. Thus, while farmers in the area are aware of organic production generally, few pursue these production techniques. Even those farmers most interested in organic agriculture maintain the use of synthetic pesticides, although often at a reduced level compared to their neighbors. These farmers attribute their continued use of synthetic agrochemicals to the exceptionally strong local pest and pathogen pressures. Thus, all farmers in the survey rely to some extent on synthetic pesticides, and the vast majority relies on them as their only form of pest and pathogen control.

Farm households

Table 1 shows farmer and farm household characteristics derived from the survey of 148 farmers described below. Most farmers in the area have a sixth grade formal education, although some have earned high school and college degrees. Households are generally small, with the median size of two adults and two minors. Most farmers own their house and a pickup truck for marketing perishable produce, suggesting that significant accumulation of capital has been possible with truck farming. Land ownership and profits reveal large disparities in wealth and resources,[7] as the median

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[7] One of the most important colonial legacies in Latin America is very unequal landholdings. Despite the perception that Costa Rica is an exception in Latin America, the 1984 Costa Rican census shows that the inequality of holdings "is as unequal as the majority of Latin American countries" (González B., 1987, p. 97). A similar pattern exists in Northern Cartago. In his geographic analysis of Northern Cartago, Arrieta (1984, p. xi) determined that "less than 5 percent of the farms in Cot-Irazú (fewer than 50 farms) are latifundios or modern businesses and they have 72 percent of the land (some 11,000 hectares) while 850 farms of the 95 percent possess some 3,000 hectares, or 28 percent." Most of the large landholdings are dominated by pasture for dairy

value of these variables are considerably lower than the mean. Most farmers own 2.1 hectares or less and grow on two separate parcels, although they tend to plant more area through rental or sharecropping arrangements. Most farmers produce three different vegetable crops, but some specialize on only one, while others maintain very diverse production systems for farmers' markets.

Methods

Farmer survey and field-specific crop pesticide intensities

Below I use data from 145 standardized surveys[8] I conducted of vegetable farmers in Northern Cartago and the Ujarrás Valley.[9] These surveys included closed- and open-ended questions concerning farmer characteristics, farm households and labor availability, crops (including varieties, harvests, an contracts), farm and field characteristics, finances and resources, pesticide use, information sources and social networks, pesticide handling and knowledge, and organic and alternative production methods. The surveys occurred between April 23, 2003, and January 4, 2004, corresponding to the rainy period known as *invierno* (winter) in the study site. They yielded information necessary to calculate pesticide intensity for 27 different vegetables. Following human subjects protocol, I read each farmer a standard script, which, among other things, emphasized that their responses would be confidential. I then asked for their consent (1) to be a participant in the study and (2) for me to audio record their responses to the open-ended questions.

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production, but these farmers also engage in potato and vegetable production. A few very large, family-run vegetable operations own and farm more than 100 hectares.

[8] Three of the 148 surveys did not result in sufficient information about pesticide use intensities, but did yield other information on the farm household.

[9] Below I use only information from potato and squash farmers, of which 70 and 43 were interviewed, respectively. Including all crops in the analysis, even when controlling for them with dummy variables, would not allow for the signs of the coefficients of independent variable to change, but would instead only shift the intercept. This would hide the possibility that the relationship between a certain variable and pesticide intensity could be positive in one crop production system and negative in another. The additional benefit of analyzing two crop-specific models is that pesticide use decisions and the factors affecting them likely differ between high- and moderate-input crops like potato and squash, meaning that similarities across the models allow for more robust conclusions than one crop alone.

Sampling of national market farmers occurred in part through a "snowball" technique (Patton, 2002), which started with a handful of farmers and proceeded by asking them for contact information of other farmers. Additionally, key informants in six towns introduced me to many potato and squash farmers in their communities and in surrounding towns. I chose these key informants because of their knowledge of agriculture (all are farmers), their strong ties to their communities, and, importantly, their enthusiasm for my study topic. When requesting other farmer contacts, I told both the key informants and surveyed farmers that I wanted to include a range of farmers from small-scale (2 hectares or less) to large-scale (10 hectares or more). An additional sampling technique involved approaching farmers in their fields. I combined these three sampling strategies to help avoid seriously biased samples in terms of farm size or other important characteristics.

To survey export squash farmers, I started with a small number and again used a snowball technique of asking them for the contact information of other export and national market farmers, large- and small-scale. I then used farmer lists I obtained from the area's two mini-squash exporters to determine if I had an adequate sample of the export farmers in the area.

Using the theoretical framework outlined in the introduction, I created the farmer survey with considerations about the independent variables that would affect the dependent variable, pesticide intensity. Thus, I included questions concerning socioeconomic characteristics of the land user and household, political economy, and agroecological relationships (for the survey instrument, see Galt, 2006, p. 496-503). The data from the survey allows for very detailed analysis since each variable relates specifically to the farmer/farm family, crop, or field. The survey took from one to five hours to complete, depending on the complexity of the farmers' pesticide use, the number of fields, and the length of discussion of the open-ended questions. Most surveys lasted less than two hours.

Obtaining complete data to calculate a crop's pesticide intensity in active ingredient per hectare week (ai/ha/week) involved a set of questions, accomplished by the use of a large table in the survey. The first question was "On crop ABC, which insecticides do you use?" I recorded this list, dividing it according to granulated versus sprayed formulations. I then asked about fungicides and herbicides on the crop and recorded these. With this complete list, I asked the following questions about each pesticide used on crop ABC: (1) "How much of pesticide XYZ do you use per *estañón* (50-gallon drum)?," (2) "During what part of the cycle do you use pesticide XYZ?," (3) "How frequently do you use pesticide XYZ?" or if that question did not yield an answer about frequency, "How many times in the cycle do you use pesticide XYZ?," and (4) questions concerning the amount of time between the spray and the harvest. I proceeded in this manner for each crop, as well as for the same crop planted in different locations. The pesticide data are linked to field-specific information gathered during the interview, including location, fallow, etc. Compiling this field-specific data on pesticide dose and frequency on specific crops yielded what I call "field-specific crop pesticide intensity" expressed in kilograms of active ingredient per hectare per week (kg ai/ha/week), which became the dependent variable for the analyses below.

Econometric models

Econometric models of agricultural technology adoption typically use binomial probit or logit regressions because of the dichotomous nature of the dependent variable, i.e., whether a technology is used or not used (e.g., Fernandez-Cornejo and Jans, 1996; Fernandez-Cornejo and McBride, 2002; Gockowski and Ndoumbe, 2004). A few authors have argued for the treatment of adoption as an integer-valued gradient (i.e., count data) and use Poisson count regressions (Ramírez and Shultz, 2000). Ordinary least squares (OLS) regression is not appropriate for these type of adoption studies since it requires the dependent variable to be continuous and assumes a normal distribution, which is not the case for a binary dependent variable or for count data. OLS is, however, an appropriate regression for the task here—explaining weekly field-specific crop pesticide intensity—since this dependent variable is continuous and has a very low percentage of cases that are values of zero. Thus, the regression models used below are OLS regressions.

I regressed the dependent variable — kilograms of active ingredient per hectare per week (kg ai/ha/week) — in Stata using two OLS regression models, one for potato and one for squash. The same crop grown in different areas by the same farmer are treated as separate cases in the regression, e.g., a farmer who grows potato on three different fields has his information attached to those three cases in the analysis, and the field-specific information is different for each. This spatially explicit procedure violates one of the assumptions about the standard treatment of the error term in OLS regressions, that the error terms are not correlated. Robust clustering of the error term in Stata, clustered by farmer number, resolved this.

Table 2 defines and categorizes the variables included and provides summary statistics by model. I specified the model for potato as:

$$\begin{aligned} \text{kg\_ai\_wk}_{potato} = {} & \beta_1 + \beta_2\text{age} + \beta_3\text{age\_sqr} + \beta_4\text{spry\_frm} + \beta_5\text{tmpwk\_ha} + \beta_6\text{minors\_h} + \\ & \beta_7\text{mi\_label} + \beta_8\text{courses} + \beta_9\text{pr\_sprmo} + \beta_{10}\text{credit} + \beta_{11}\text{out\_incm} + \\ & \beta_{12}\text{debt\_scl} + \beta_{13}\text{nt\_prod} + \beta_{14}\text{res\_test} + \beta_{15}\text{p1\_elevn} + \beta_{16}\text{p1\_vegyr} + \\ & \beta_{17}\text{p1\_fallo} + \beta_{18}\text{p1\_numcr} + \beta_{19}\text{c1\_fol\_n} + \beta_{20}\text{c1\_ipm} + \beta_{21}\text{c1\_numos} + e \end{aligned}$$

I specified the model for squash as:

$$\begin{aligned} \text{kg\_ai\_wk}_{squash} = {} & \beta_1 + \beta_2\text{age} + \beta_3\text{age\_sqr} + \beta_4\text{spry\_frm} + \beta_5\text{tmpwk\_ha} + \beta_6\text{minors\_h} + \\ & \beta_7\text{married} + \beta_8\text{courses} + \beta_9\text{pois\_num} + \beta_{10}\text{p1\_owner} + \beta_{11}\text{par\_shrc} + \\ & \beta_{12}\text{pr\_sprmo} + \beta_{13}\text{credit} + \beta_{14}\text{ntaeprod} + \beta_{15}\text{res\_test} + \beta_{16}\text{p1\_elevn} + \\ & \beta_{17}\text{p1\_vegyr} + \beta_{18}\text{c1\_area} + \beta_{19}\text{c1\_ipm} + \beta_{20}\text{c1\_orgfl} + e \end{aligned}$$

The variable prefix "c1" refers to the specific crop, "p1" refers to the field, and variables without either are farmer, farm family, or farm-wide characteristics.

As discussed in the introduction, theory from a number of disciplines shapes these models and they reflect my attempt at a synthetic model explaining pesticide intensity by reference to socioeconomic, political economic, and agroecological variables. I break socioeconomic variables into two general categories, including (1) farmer, farm labor, and household characteristics, and (2) farmers' information sources, education, and experiences with pesticides. The first category includes the availability of human capital at the household level, while the second represents human capital and experiences at the farmer level. Labor availability at the household level poses constraints on farming systems, and pesticides can be thought of as substitutes for some human labor practices, e.g., weeding, collecting insects, etc. and also for management knowledge (Vandeman, 1995). Farmers' personal individuality, experimentation, experiences, and training should also influence their management decisions (Johnson, 1972), including decisions to spray, as these will affect their interpretation of the ecological situation in their fields, as well as market signals.

The second broad category I use is political economic variables.[10] Drawing on political ecology's use of a "broadly defined political economy" (Blaikie and Brookfield, 1987, p. 17), this category includes (1) the household's physical resource base, land tenure, and financial situation, and (2) the household's articulation with markets and regulation. Political ecology asserts that production decisions are strongly influenced by the relative resource wealth of households, although this is often simplified to the idea that the most marginalized land users will be most likely to undermine their productive resources (Blaikie and Brookfield, 1987). Additionally, political ecologists and environmental historians have asserted that the integration of small-scale farm households into the market economy has led to more environmentally disruptive production (Worster, 1979), including higher levels of pesticide use (Thrupp *et al.*, 1995). More recently, this view has been qualified to suggest that export markets have led to some pesticide use rationalization (Galt, in press; Okello, 2005), but both circumstances show that farmers' markets integration affects

[10] As with any classification system, potential overlap exists between the categories and subcategories I make here. For example, a farm family's financial situation could be placed in either the socioeconomic or political economic, but I choose the latter because the specific variables included, such as credit use, are the result of engagement with the broader political economy.

their production decisions and pesticide use.

Agroecological variables encompass the third broad category I employ. Following Gliessman (1998), agroecology involves both farmers' management of soil, water, crops, pests, and pathogens as well as environment-crop interactions. I divide agroecological variables into (1) influences of physical geography, especially those of climate and its impact on pathogens; (2) field management, including crop diversity and fallow periods; and (3) other agricultural inputs that can either take the place of pesticides (e.g., home-made concoctions) or influence the agroecosystem in a way that may affect pest and pathogen population dynamics (e.g., the use of organic fertilizer in place of synthetic).

Multicollinearity

With any regression model, one must avoid the problem of multicollinearity, which arises when two or more of the included independent variables have a strong linear relationship with each other. Important symptoms of multicollinearity — including large changes in coefficients when variables are added and subtracted from the analysis, insignificant statistical results of the overall model or coefficients, and tolerances of less than 0.1 — were checked and are absent from the models. Additionally, I ran bivariate correlations to estimate the extent of multicollinearity. All are less than 0.5, below "rule of thumb" problematic bivariate correlations of 0.6[11] (Hamilton, 2006).

Omitted variables

I initially included many variables with potential influence on pesticide intensity and then ultimately removed them from the regressions because they were not statistically significant, or they correlated highly with other variables. Excluded socioeconomic variables based on these criteria are (1) most variables on farmers' primary source of information, including whether it is from agrochemical salespeople, the nearby organic agriculture school, or a farmer network; (2) knowledge

[11] The variable age_sqr (age squared) is excluded from this discussion, as it is highly correlated with age.

of various health problems caused by pesticides; (3) labor availability, including the number of family members helping with farming and permanent workers. Excluded political economic variables include (1) most indicators of wealth, including education level, whether the farm is an incorporated business, whether the farmer owns land, the amount of land a farmer has planted, the amount of land and parcels owned, the quintile of land ownership into which a farmer falls, house value, and number of livestock owned; (2) production expenses, sales, and profit variables, which, in addition to being insignificant, were excluded because of potential endogeneity with the dependent variable (i.e., expenses are in part a function of pesticide intensity); and (3) some credit and debt variables, including the type of credit, whether a household is credit constrained (wants credit but cannot obtain it), and whether a household has debt other than agricultural credit. Excluded agroecological variables are the use of many organic inputs, including nonsynthetic fertilizers such as compost, vermicompost and its "tea," bocachi, pig manure, chicken manure, and organic repellents, as well as number of years using organic fertilizers and sprays. Testing many of these potentially important variables in the regressions saves the models and analysis from the critical omitted variable problem, which, as explained in the introduction, can plague efforts at explaining pesticide intensity.

Results

Tables 3 and 4 show the results of the OLS regressions. The F-statistic, which tests the overall fit of the model to the data, is 7.73 for potato and 38.43 for squash, both of which have a very high statistical significance of $p<0.00$. The variables included in the potato model explain about 55 percent of the variability in the data set, as the R^2 value is 0.55. The R^2 value is much higher for squash, at 0.89. The rest of the variability is in the residual, represented in the error term, *e*.

The main strength of multiple regression analyses rests in the ability to expose the relationship between the dependent variable and the many independent variables while controlling for the other independent variables in the equation. The sign of the estimated coefficient (the β's in the model above) represents whether the relationship between the dependent variable and independent variable is positive or negative. The statistical significance of the coefficient, measured by the t-statistic, tells the statistical strength of the relationship between the dependent and independent variables. The size of the coefficient is its economic significance (cf. McCloskey and Ziliak, 1996), which in this paper means the magnitude of its influence on pesticide intensity. Below both statistical and economic significance of the estimated coefficients for the variables are discussed in light of theory, qualitative data from fieldwork, and the empirical literature.

Discussion

The OLS regressions reveal a number of significant relationships, many of which are predicted by the literature and my understandings from fieldwork, but some of which are unexpected. I discuss the potato and squash models together since direct comparisons are potentially revealing. In considering these together, one must note the differences in the production systems discussed above. Very briefly, the mean of the independent variable illustrate the differences in input intensity. On average, potato is sprayed with 3.5 kg ai/ha/week, while squash is sprayed with 0.9 kg ai/ha/week (Table 2). This must be kept in mind when interpreting the economic significance of the estimated coefficients of the variables. For example, a positive coefficient of 0.21 for a variable in the squash model suggests a 23 percent increase in pesticide use intensity (from 0.9 to 1.11 kg ai/ha/week), whereas the same size coefficient in the potato model suggests only a six percent increase (from 3.5 kg ai/ha/week to 3.71 kg ai/ha/week). This coefficient size is much more economically significant in squash than potato. The coefficients and their statistical and economic significance are discussed according to major groupings below.

Socioeconomic variables

Farmer, farm labor, and household characteristics

The regressions show that farmer characteristics matter. Age does not matter in potato, but in squash the negative and statistically significant coefficient of age suggests that pesticide intensity decreases initially as farmers gain experience. However, the positive and significant coefficient of age squared suggests possible generational effects, with older generations being more accustomed to more intensive pesticide use. Yet, the small coefficient of age squared suggests that this relationship is fairly unimportant relative to other ones discussed below.

Personally spraying pesticides on their farm, as opposed to having it done entirely by a family member or worker, decreases pesticide intensity in a statistically and economically significant way in both systems. All farmers surveyed know the dangers of pesticide poisoning. This suggests that when they face the risk directly, they moderate or decrease their pesticide use. I did not ask farmers directly whether they think farmers would spray less if they themselves were exposed, but it is highly unlikely that many would directly admit to being willing to spray more intensively if only their workers or family members are exposed. Nor would this relationship have been directly observable. Thus, the model reveals an interesting relationship potentially hidden by using only qualitative methods.

The number of temporary workers hired at the moment when they are most needed (usually harvest) has different signs in the two models. In potato it is negatively related to pesticide intensity, meaning that large-scale farmers that rely on a large number of hired workers spray less intensively. This suggests that farms relying more on family labor spray more heavily. As Van der Veen (1975, cited in Feder et al., 1985) suggests, the finding that small-scale farms sometimes use pesticides more intensively may be a Chayanovian "savings" from the reliance on family labor (Chayanov, 1966). That is, the family invests savings from not having to pay wages in agrochemicals. In squash, this variable has a different meaning. It indicates that a farmer engages in large-scale production of national market vegetables like potato and carrot.[12] This variable's coefficient is fairly large, and it is the most statistically significant of all included in the squash model. Thus, it means that farmers engaged in large-scale national market production spray their squash more intensively than farmers who are not. Export farmers agree that national market farmers spray their produce more heavily, and the model suggest that this has important spillover effects into export production systems.

Household characteristics also have important influences. In both systems, the number of minors in the household reduces pesticide intensity, although only significantly in squash. Additionally, in the squash model, being married significantly lowers pesticide intensity and has the largest coefficient of all the variables included. Together, these models suggest that pesticide use decreases with minors and wives in the household, a result not described in the literature or identified specifically by farmers. However, during the survey and interviews, farmers voiced suspicions that pesticides cause cancer, birth defects, and other health impairment and that the effects are differentiated by age — young children are more vulnerable — and gender, e.g., some farmers said that "women are more susceptible" to the problems caused by pesticides. These beliefs appear to have important effects on pesticide intensity.

Information sources, education, and experiences with pesticides

The survey included a question on farmers' primary sources of information about pesticides. In the potato model, a farmer's use of the label primarily increases pesticide use in a statistically and economically significant manner. In contrast, taking an agricultural class decreases pesticide intensity in a very strong way in potato production. In fact, it is one of the most significant independent variables and has a very large coefficient, equal in size to reliance on the label, but with

[12] In contrast to mini-squash, which requires consecutive harvests every few days, these crops require a large number of workers at harvest because of a single harvest at the end of the growing cycle.

an opposite sign. One could interpret this as meaning that the classes succeed in educating farmers about agriculture and changing behavior, but it should also be considered that the variable of taking an agricultural course also measures a farmer's willingness and initiative to learn new material and to experiment. The opposite sign on the coefficient of the course variable in the squash model is somewhat perplexing. Many export farmers have taken courses to learn agroecological methods to reduce their pesticide use, yet the model controls for their production for export market and their use of agroecological methods. Thus, holding market and other variables constant, those squash farmers who have taken classes tend to have higher levels of pesticide use, or perhaps the courses have encouraged higher pesticide use (although the coefficient is not large and only significant at the 10 percent level).

The number of times a farmer has experienced pesticide poisoning reduces pesticide intensity in the squash model, though not in a significant way. This weakly supports an expectation that farmers who have been poisoned more will decrease their pesticide use, as they take pesticide risks more seriously. The weak relationship may be a result of a mixed signal, in that farmers who spray more heavily are likely to have been poisoned more and do not necessarily change their spraying decisions as a result.

Political economic variables

<u>Resources, land tenure, and finances</u>

When included in the models, no apparent relationship exists between the amount of land a farmer owns and pesticide intensity. The lack of a relationship is not surprising since the empirical literature does not find a straightforward relationship between farm size and pesticide intensity (Feder *et al.*, 1985, p. 272). Pesticides are divisible inputs as opposed to non-divisible inputs like a tractor or tube well. This means that even small farmers can typically afford them, and will use them on high-value crop where it makes economic sense to do so.

On the other hand, one would predict that tenurial arrangements would influence pesticide intensity. In the squash model, owning the parcel reduces pesticide intensity in a statistically and economically significant way. As a substantial literature suggests, landowners more willingly invest in land improvements and do not have to be as extractive as renters (Fraser, 2004). Participation in *a medias* planting in the squash model also reduces pesticide intensity, but not as much as parcel ownership. *A medias* arrangements in the area are diverse, often involving one farmer supplying the land and the other providing the variable inputs, or two farmers pooling resources. These arrangements are common among resource poor farmers, as they help pool labor and capital for production of input-intensive crops. This suggests a relatively weak positive relationship between resources and pesticide intensity in squash production.

Material resources on the farm generally had little effect on pesticide intensity when included in the models, with the exception of motorized backpack sprayer ownership. In the potato model it is significantly reduces pesticide intensity and is economically important. Some farmers noted that they do not use as many *estañones* (50-gallon pesticide mixing drums) per hectare when using a motorized sprayer because the spray is better dispersed. The opposite relationship exists in the squash model—a motorized backpack spraying increases pesticide use. Ownership of a motorized backpack sprayer is also an indicator of wealth, which again suggests that in squash production (but not potato production), higher farmer wealth might slightly increase pesticide intensity.

Farmers' use of formal agricultural credit increases pesticide intensity, although this relationship is very strong for squash but weak for potato. The literature would this, as Costa Rican banks have historically required agrochemical use for credit disbursement (Thrupp, 1990). Use of credit can also be used as a measurement of intermediate wealth levels (farmers with enough wealth for collateral, but without enough resources to independently support their input use), again supporting the positive but weak relationship between wealth and pesticide use in squash.

The relationship between production risk and pesticide use is difficult to discern. Econometric studies find mixed results on the relationship between risk aversion and pesticide use in part because risk taking and risk aversion are difficult characteristics to quantify. One measure of risk is diversity of household income. We would expect farmers whose household depends entirely on income from the farm to be more risk averse in their farming, and to therefore use pesticides more intensively as a form of "insurance." The potato model supports this idea, showing that outside income reduces pesticide intensity in a statistically and economically significant way. Yet this is complicated somewhat by the negative relationship between debt outside of agriculture and pesticide intensity in the potato model. Rather than conceiving of outside debt as leading to heightened production risk, it may instead put constraints on the agricultural inputs that farmers can afford.

Marketing relationships and residue enforcement

Arguments I make elsewhere suggest that contracts with exporters should reduce pesticide use in the area since exporters attempt to control their contract farmers' pesticide use to comply with regulations in industrialized countries (Galt, 2007). The models presented here support this: growing a crop under contract—nt_prod in the potato model and ntaeprod in the squash model—is negatively associated with pesticide intensity. Producing for export significantly reduces pesticide intensity in the squash system, suggesting that pesticide use rationalization has occurred with export production, but not in the national market. The potato model suggests spillover effects: growing nontraditional crops (on which produce buyers police pesticide use to control residue levels) reduces pesticide use. In both models, having experienced pesticide residue testing lowers pesticide intensity in a very statistically and economically significant manner. Importantly, this suggests that a presence of regulatory activities in the area can help reduce pesticide use in both systems.

Agroecological variables

Geographical influences

A separate analysis (Galt, 2006, pp. 335-378) has shown that the climate of the area in which farmers grow potato and mini-squash makes a large difference in pesticide intensities. Fields in the more humid and storm-prone areas of the lower-elevation cloud belt are sprayed significantly more largely because of greater problems with pathogens. Farmers with sufficient resources move their production of these crops to capture environmental advantage outside of the cloud belt. When included in the models, the dummy variable of a parcel's location in the cloud belt was far from significant, however. Instead, farming at higher elevations reduces pesticide intensity and very statistically significant in both models. If one scales the variable by 1000, it is also very economically important, suggesting that moving production higher by 1000 meters will lead to significant pesticide use reduction in both potato and squash. During my fieldwork, I traveled with farmers who lived in the lower elevations to the fields they plant above to ask about geographic differences in pests, pathogens, and pesticide use. These conversions revealed that insect, fungal, and bacterial pests cause fewer problems at higher elevations, a pattern confirmed in the models.

Field management

As agroecological research and theory suggests, temporal field management matters greatly in explaining pesticide intensity. Two of the most significant variables in the models are years of consecutive vegetable production for both potato and squash and fallow period for potato. First, and statistically significant in both models, longer periods of consecutive vegetable production increase pesticide intensity. Although the economic significance appears low, it shows that the decadal time scale matters rather than a time scale based on years, i.e., if the coefficient is multiplied by 10 it becomes close to the economic significance of other variables. Many farmers in the area grow vegetables without rotating non-vegetable crops. As Altieri (2000, p. 78) notes, a lack of diverse rotation makes agroecosystems "dependent on high chemical inputs."

Another aspect of temporal field management, the fallow period, also matters. Longer fallows reduce pesticide intensity in the potato model. As with the previous variable, increasing fallow by a handful of days is not economically important, but doing so by 100 days (i.e., multiplying the coefficient by 100) makes an important difference. The statistical relationship supports the age-old idea that longer fallows reduce pest pressure, translating into real reductions in pesticide use. Farmers noted that longer fallows of many months could "break the cycle of pests," but fallows in the area are typically kept short, with an average of 42.4 days and a median of 19 days. Most farmers focus on maximizing production unless they have a large amount of land and do not have to use it intensively.

While these temporal management variables correspond to agroecological theory, there are two spatial associations contrary to agroecological thought upon first glance: (1) the number of crops planted on a parcel in the potato model increases pesticide use (i.e., more crop diversity in a parcel means higher pesticide use), and (2) increases in the area planted to the crop reduces pesticide intensity, a relationship that is very strong statistically and economically (i.e., larger monocultures are less heavily sprayed). In agroecological research, higher crop diversity in the field, and smaller patches of crops, are associated with more floral and faunal diversity, and has been shown to reduce pest problems in some agroecosystems (Altieri, 2000; McLaughlin and Mineau, 1995; Roschewitz et al., 2005). This agrobiodiversity of panting reduces pest problems most famously in the corn-bean-squash polyculture in Central America (Risch, 1981). I propose that these unexpected relationships in the models have management roots. First, farmers use a spatial intercropping strategy for continuous vegetable production to take the place of sequential cropping with diverse rotations, so pest population buildup can occur because of lack of fallow.[13] Second, I noticed during the surveys that farmers who have a large number of crops planted next to one another on a small plot tend to use similar pesticide regimens across crops, even for those as different in average pesticide intensities as potato (3.5 kg/ha/week) and squash (0.9 kg/ha/week). This simplified management means that each crop in the field is likely to receive a pesticide application when the farmer decides another needs it, thereby making each crop in the field more pesticide intensive than if it was planted in a separate field and managed in a more independent manner.

Other agricultural inputs

Contrary to expectations, use of foliar nutrient[14] sprays reduces pesticide intensity in the potato model, and this reduction is very significant economically and statistically. I suspected foliar nutrients to be ineffective given the high rainfall of the area. Thus, I had predicted that they would serve as an indicator of farmers who had been convinced by agrochemical salespeople to use more agrochemicals and therefore be positively related to pesticide intensity. Instead, the significant negative relationship can be explained in two ways. First, upon investigating their labels I found that some foliar nutrients have the same active ingredients as fungicides (e.g., sulfur and copper compounds) and therefore act as direct fungicide substitutes. Second, it is possible that the foliar nutrients help to strengthen the outer cells of the leaves, thereby slowing the cellular invasion by pest organisms, especially the penetration of fungal hyphae. This cellular mechanism has been shown in rice plants foliarly treated with silicon, which made them more resistant to rice leaf blight (Kim et al., 2002), yet no studies of this type of mechanism are available for various foliar nutrients used in Northern Cartago and the Ujarrás Valley. The strength of the economic relationship suggests that mechanisms might be uncovered with careful research.

[13] This relationship is supported by the negative correlation between the number of crops in a field and fallow for all crops in the entire dataset (Pearson correlation=-0.128, p=0.008).
[14] Foliar nutrients are crop nutrients applied directly to crop foliage by spraying.

The widespread questioning of the value of agricultural industrialization (Altieri, 1995; Richards, 1985; Wright, 1990) has contributed to alternative agricultural methods making inroads in some areas of the world (Pretty, 1995). As discussed above, most farmers in the area know of organic agriculture and a few are adopting some of its methods because of classes they have taken at the INA's local organic agriculture school. Integrated pest management (IPM) as an alternative to calendar spraying has also been promoted in the area. Thus, it is necessary for explanations of pesticide intensity to consider farmers' use of these alternative methods. They can either be direct substitutes—e.g., chile and garlic extract sprayed on plants as an alternative to a synthetic insecticide—or function in a manner that would render pesticide applications less necessary—e.g., soil fertility enhancements that decreases pest and pathogen incidence (Altieri and Nicholls, 2003).

A rather surprising finding is that farmers' reported use of IPM increases pesticide intensity in both models, although it is only statistically significant and economically important in potato. This finding does not contradict the literature, however, since as Fernandez-Cornejo *et al.* (1998, p. 479) note, "the empirical evidence on the effect of IPM on pesticide use is mixed, even for a given crop." Some studies show that IPM training and use decreases pesticide expenditures (Burrows, 1983) and the number of applications of fungicides and insecticides (Fernandez-Cornejo, 1996). Other work shows no significant differences in pesticide use between IPM users and conventional farmers not using IPM (Fernandez-Cornejo and Jans, 1995, 1996; Wetzstein et al., 1985). Still others have shown an increase in pesticide use with the use of pest monitoring (Yee and Ferguson, 1996). Thus, it is not particularly surprising that there is a positive association between IPM and pesticide intensity. It may be that agrochemical interests have co-opted IPM in the area (cf. Benbrook *et al.*, 1996), but I suspect that farmers answered yes to the IPM question if they conduct insect counts but do not consider economic thresholds. This would be only a partial adoption that would not necessarily result in the rationalization of pesticide use. Additionally, fungicides used against the fungal pathogen late blight, *Phytophthora infestans*, dominate overall pesticide use on potato, and IPM has not adequately addressed this pathogen, so will not affect heavy fungicide use.

Most organic inputs— various sprayed substances and fertilizers—had insignificant coefficients when included in the models. While the general thinking in organic agriculture is that a healthy soil leads to pest-resistant plants (Lampkin, 1990) and some agroecological studies show that fertilization with nonsynthetic fertilizers can lower pest problems (Morales and Perfecto, 2000), the empirical evidence is still not conclusive and is sometimes contradictory (Culliney and Pimentel, 1986; Eigenbrode and Pimentel, 1988; Letourneau et al., 1996). That the use of organic fertilizers does not reduce pesticide intensity in Northern Cartago and the Ujarrás Valley is likely because many conventional farmers use manure and compost together with synthetic fertilizers, which may confound the effect it has on buffering crops' and soils' resistance to pests.

Of all the organic inputs that farmers use, only two have a moderate to strong negative relationship with pesticide intensity. The first is the number of different types of organic foliar sprays used, which reduces pesticide use in the potato model, but is not quite significant. The second is the farmer's use of homemade organic foliar nutrients in the squash model, which significant reduces pesticide use. In addition to agroecological effects, I argue that these serve as indicators of a farmer's commitment to organic agriculture since they are not currently easy to procure (Carballo V., 1998). This availability contrasts with the input of manure, which many conventional farmers use to augment their synthetic fertilizers.

Conclusion

Pesticide intensity at the field level is a difficult variable to adequately explain. Perhaps for this reason it has remained mostly unaddressed in the human ecological literature, and is also surprisingly not well explored even in the agricultural economics or agroecological literature. I argue that adequate explanations must integrate socioeconomic, political economic, and agroecological factors that influence pesticide intensity at the field level. This integrative theoretical framework informed both the creation of the farmer survey and the models used above.

The relationships in the OLS models indicate the complex nature of pesticide intensity, showing that it is strongly influenced by a variety of variables related to the socioeconomic characteristics of the farmer and farm household, political economic relationships in which the farm household finds itself embedded, and agroecological relationships including both management and the biophysical environment. Farmer's personal characteristics—age, agricultural courses taken, and use of information sources—are important. Household and labor variables matter, especially whether the farmer is married, the number of minors in the household, whether the farmer personally sprays pesticides, and the intensity of temporary labor use. Political economy is clearly important through tenure arrangements, households' financial situation, credit use, contracts and markets, and pesticide residue enforcement. Many biophysical and agroecological variables—parcel elevation, years of consecutive vegetable production, fallow periods, number and spatial extent of crops, foliar nutrients and some organic foliar nutrient sprays, and IPM—also influence on pesticide intensity.

These complex relationships underscore the necessity of a holistic view in understanding place-based human-environment relationships in agriculture as promoted by cultural and political ecology (Netting, 1993; Zimmerer, 2007). For an adequate understanding of pesticide intensity at the field level, knowledge about socioeconomic, political economic, and agroecological relationships must be included. Both the potato and squash model clearly show that variables in each of these broad categories strongly influence pesticide intensity. In emphasizing the joint importance of socioeconomic, political economic, and agroecological relationships, this paper serves to refute reductionistic conceptions of pesticide intensity that attribute differences solely to market differences (export versus local/national), farm scale (small versus large), a farm household's economic situation (investment poor versus wealthy), or agroecological management (monoculture versus polyculture). These and other important influences intersect and jointly influence pesticide intensity, so much so that explanations cannot be adequately constructed without the inclusion of each. Cultural, human, and political ecology offer important academic spaces for these integrative approaches, and future work can highlight the extent to which the relationships highlighted in this paper apply in other settings.

The analysis above also can speak to policy and future research needs in Costa Rica and other areas of intensive vegetable production in developing countries. Ideally, agricultural policy outcomes would decrease pesticide use while maintaining or increasing farm profitability, and perhaps yields (although this does not necessarily address equity issues). Intervention can focus on changing individual behavior at the farm and farmer level, or can be broader societal changes.

My analysis suggests that promoting organic agriculture and agroecological methods can indeed help to decrease pesticide use in the area. Organic foliar nutrient sprays, including the "teas" from worm compost and mixtures made from garlic and chile, reduce pesticide intensity. Additionally, the models suggest that foliar nutrients might substitute for some pesticides. This relationship should be further studied with the goal of replacing the most problematic pesticides with safer foliar nutrient sprays, many of which can be locally produced. In contrast, IPM programs do not appear to have reduced pesticide use in potato production. I suspect this has more to do with selective adoption of insect counts without calculating economic thresholds, but it highlights the difficulty of diffusing all components of IPM as a coherent technological package that relies on considerable expertise.

Education programs to promote better management at the field scale, especially longer crop rotations with non-vegetable crops and fallow periods, should be implemented and should include market development for non-vegetable crops. Consecutive vegetable production in the area is currently only possible with intensive use of synthetic pesticides and fertilizers. To remain profitable in an increasingly liberalized vegetable market that might be mandated by Costa Rica's recent entry into the Central American Free Trade Agreement (CAFTA), Costa Rican farmers will need to learn vegetable production using fewer synthetic inputs as their prices continue upward with the price of petroleum. Further economic work could be conducted on fallow periods by addressing the question of how long a period makes economic sense in light of the reductions in pesticide use accomplished. However, many farmers do not have the luxury of longer fallow periods since they own small areas of land, or can only rent land, meaning that in both situations they must continually cultivate it to make ends meet. The relationship of land tenure to pesticide use also brings up the idea of land reform, which has occurred to a limited extent in the area and nationwide (Edelman, 1989; Seligson, 1978). While land reform must be based on other considerations, especially social equity, the analysis suggests potential environmental and health benefits since land ownership — and the related, longer fallow periods this allows — clearly reduce pesticide intensity. In other word, giving small-scale farmers access to a larger amount of land can help them increase fallow periods and reduce pesticide use, but should be accompanied with agroecological extension and co-learning.

Since attending agricultural classes is strongly associated with a large decrease in pesticide use in potato and potato is extremely pesticide intensive and the most important crop in the area, I suggest that incentives be given to farmers to attend agricultural courses at the organic agriculture school run by the Instituto Nacional de Aprendizaje (INA) at La Chinchilla in Northern Cartago. Additionally, given the very high levels of pesticide use in general in Costa Rica, MAG should develop a national program of agroecological extension and facilitate farmer-to-farmer learning to promote conservation in agricultural landscapes as an important complement the country's successes in protected area conservation.

One policy change at the societal level should be greater enforcement of pesticide residue limits on national market vegetables. My analysis suggests that experiencing pesticide residue testing and having a contract that enforces minimal residues significantly reduce pesticide use. While I have shown elsewhere that export farmers in the study site decrease or rationalize their pesticide use because of regulatory risk (Galt, 2007), enforcement of the national market pesticide residue limits should be increased to lower the pesticide residue burden for the Costa Rican population, and to push pesticide rationalization. Enforcement at both the farm and retail level should be explored, with explicit attention given to how enforcement at the retail level might affect market access of smaller producers (cf. Dolan and Humphrey, 2000).

In sum, agroecological education and extension, land reform with local backing, and enforcement of pesticide residue limits for nationally sold produce could substantially reduce pesticide use in vegetable production in Costa Rica, making the sector more competitive and lessening the high pesticide burden faced by Costa Rican consumers and especially rural people — children, adults, farm workers, and farmers — in the production areas.

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Tables

Table 1: Farmer and farm household characteristics

	median	mean	st dev	n
Farmer Characteristics				
Age	40	42.1	11.1	148
Years of formal schooling	6	6.5	2.9	148
Years in farming	23.5	23.7	12.3	148
Member of a farmer group	—	36%	0.5	148
Household & Labor Characteristics				
Number of minors in household	2	2.14	1.6	148
Number of adults in household	2	3.12	1.5	148
Number of permanent workers	1	4.2	13.6	148
Greatest number of temporary workers at one time	3	5.0	9.2	148
Land Ownership & Land Use Characteristics				
Hectares of land owned	2.1	8.4	27.8	147
Current number of hectares planted	2.8	7.0	22.6	148
Number of parcels planted	2	2.1	1.7	148
Number of crops planted	3	3.9	2.3	148
Produces NTAEs	—	26%	0.4	148
Farm Equipment				
Owns a pickup truck or car	—	75%	0.4	148
Owns a tractor	—	16%	0.4	148
Economic Characteristics				
Home ownership	—	89%	0.3	143
Value of house(s) owned[a]	$15,050	$20,926	$21,762	133
Received credit in the past 12 months	—	52%	0.5	148
Total reported agricultural profits in 2002[b]	$2,779	$8,540	$40,778	123

[a] Using the 2003 exchange rate of 398.66 colones/US$.

[b] Using the 2002 exchange rate of 359.82 colones/US$.

Source: Author's farmer survey 2003-04.

Table 2: Explanation of variables in OLS regressions

Variable name	Variable explanation (unit)	Potato (n=93, farmers=70) mean	Potato st dev	Squash (n=65, farmers=43) mean	Squash st dev
c1_ai_wk	field-specific crop pesticide intensity, per week (kg of ai/ha/week)	3.50	1.86	0.90	0.62
Socioeconomic variables: farmer, farm labor, and household characteristics					
age	age (years)	41.20	10.50	40.57	11.57
age_sqr	age squared	1808.60	969.90	1777.87	1000.29
spry_frm	farmer sprays pesticides on farm (dummy)	0.74	0.44	0.62	0.49
tmpwk_ha	temporary workers employed per hectare at peak times (number)	2.09	4.13	1.68	2.46
minors_h	minors in household (number)	2.30	1.61	1.96	1.27
married	farmer is married (dummy)	—[a]	—	0.82	0.38
Socioeconomic variables: information sources, education, and experiences with pesticides					
mi_label	primary information source is the pesticide label (dummy)	0.08	0.27	—	—
courses	farmer has taken agricultural classes (dummy)	0.30	0.46	0.66	0.48
pois_num	farmer has been poisoned by pesticides (number of times)	—	—	0.31	0.57
Political economic variables: resource base, land tenure, and finances					
p1_owner	parcel is owned by farmer (dummy)	—	—	0.46	0.50
par_shrc	farmer participates in *a medias* arrangements[b] (dummy)	—	—	0.64	0.48
pr_sprmo	property owned includes a motorized backpack sprayer (dummy)	0.59	0.49	0.35	0.48
credit	farmer received formal agricultural credit in last 12 months (dummy)	0.65	0.48	0.64	0.48
out_incm	farm family has income from outside of agriculture (dummy)	0.36	0.48	—	—
debt_scl	level of debt outside of agricultural credit (number, scaled)[c]	1.20	2.64	—	—
Political economic variables: marketing relationships and residue enforcement					
nt_prod	produces nontraditional crops for national or export market (dummy)	0.15	0.45	—	—
ntaeprod	produces export crops (dummy)	—	—	0.60	0.49
res_test	farmer has had produce tested for pesticide residues (dummy)	0.28	0.45	0.62	0.49
Agroecological variables: geographical influences					
p1_elevn	elevation of parcel (meters)	2159.60	447.85	1504.12	277.91
Agroecological variables: field management					
p1_vegyr	length of consecutive vegetable production on parcel (years)	18.76	17.30	18.57	16.52
p1_fallo	fallow between vegetable crops (days)	62.57	93.43	—	—
p1_numcr	crops planted on parcel (number)	2.36	1.66	—	—
c1_area	area in crop (hectares)	—	—	0.60	0.72
Agroecological variables: other agricultural inputs					
c1_fol_n	foliar nutrients are used on the crop (dummy)	0.94	0.24	—	—
c1_ipm	IPM used on crop (dummy)	0.08	0.27	0.08	0.27
c1_numos	different types of homemade organic sprays used (number)	0.40	0.65	—	—
c1_orgfl	homemade organic foliar nutrients are used on crop (dummy)	—	—	0.22	0.41
_cons	constant				

[a] Data collected but not included in model due to lack of significance.

[b] Locally, *a medias* refers to many arrangements, including sharecropping, family members who plant together but maintain separate households, and two farmers (typically friends) who farm together and share input costs.

[c] Scaled by 1,000,000. 1,000,000 Costa Rican colones (CR¢) = US$2,500 in 2004.

Table 3: OLS regression for weekly pesticide intensity in potato, Northern Cartago

	Number of observations	93
	F(18, 69)	7.73
	Prob > F	0.0000
Number of clusters (by farmer): 70	R-squared	0.5516
	Root MSE	1.4007

c1_ai_wk	Coefficient[a]		Standard Error	t	P>|t|	95% Confidence Interval Lower	Upper
age	0.0619		0.1001	0.62	0.54	-0.1378	0.2617
age_sqr	-0.0007		0.0010	-0.67	0.50	-0.0027	0.0014
spry_frm	-0.8994	***	0.3540	-2.54	0.01	-1.6056	-0.1932
tmpwk_ha	-0.0557	**	0.0243	-2.29	0.03	-0.1042	-0.0072
minors_h	-0.1684	*	0.0948	-1.78	0.08	-0.3576	0.0208
mi_label	1.4859	*	0.7964	1.87	0.07	-0.1028	3.0746
courses	-1.4228	***	0.3580	-3.97	0.00	-2.1370	-0.7085
pr_sprmo	-0.6341	*	0.3543	-1.79	0.08	-1.3410	0.0728
credit	0.2465		0.3852	0.64	0.52	-0.5220	1.0150
out_incm	-0.8591	**	0.3584	-2.4	0.02	-1.5741	-0.1440
debt_scl	-0.0874	*	0.0468	-1.87	0.07	-0.1807	0.0060
nt_prod	-0.2647		0.2480	-1.07	0.29	-0.7594	0.2300
res_test	-0.8411	**	0.3765	-2.23	0.03	-1.5922	-0.0901
p1_elevn	-0.0011	**	0.0004	-2.45	0.02	-0.0019	-0.0002
p1_vegyr	0.0200	*	0.0118	1.69	0.10	-0.0035	0.0435
p1_fallo	-0.0050		0.0031	-1.63	0.11	-0.0111	0.0011
p1_numcr	0.2431	*	0.1358	1.79	0.08	-0.0278	0.5139
c1_fol_n	-1.3155	***	0.5123	-2.57	0.01	-2.3374	-0.2936
c1_ipm	1.6472	*	0.8882	1.85	0.07	-0.1246	3.4191
c1_numos	-0.5015		0.3506	-1.43	0.16	-1.2010	0.1980
_cons	7.5230		2.4799	3.03	0.00	2.5758	12.4703

[a] Coefficients significant at the 10% level are designed with *, at the 5% level with **, and at the 1% with ***.

Table 4: OLS regression for weekly pesticide intensity in squash, Northern Cartago and the Ujarrás Valley

Number of observations	65
F(19, 42)	38.43
Prob > F	0.0000
R-squared	0.8952
Root MSE	0.2500

Number of clusters (by farmer): 43

c1_ai_wk	Coefficient[1]		Standard Error	t	P>|t|	95% Confidence Interval Lower	Upper
age	-0.1461	***	0.0396	-3.69	0.00	-0.2260	-0.0661
age_sqr	0.0015	***	0.0004	3.37	0.00	0.0006	0.0024
spry_frm	-0.2105	***	0.0663	-3.17	0.00	-0.3444	-0.0766
tmpwk_ha	0.1735	***	0.0253	6.86	0.00	0.1225	0.2245
minors_h	-0.0842		0.0623	-1.35	0.18	-0.2099	0.0415
married	-0.6291	***	0.1736	-3.62	0.00	-0.9796	-0.2787
courses	0.1324	*	0.0711	1.86	0.07	-0.0112	0.2759
pois_num	-0.0665		0.0768	-0.87	0.39	-0.2214	0.0884
p1_owner	-0.3314	***	0.0771	-4.30	0.00	-0.4869	-0.1759
par_shrc	-0.1660		0.1008	-1.65	0.11	-0.3694	0.0374
pr_sprmo	0.4665	***	0.0840	5.55	0.00	0.2969	0.6361
credit	0.2133	***	0.0635	3.36	0.00	0.0852	0.3414
ntaeprod	-0.3915	***	0.0814	-4.81	0.00	-0.5557	-0.2272
res_test	-0.2201	***	0.0729	-3.02	0.00	-0.3672	-0.0729
p1_elevn	-0.0006	***	0.0001	-3.94	0.00	-0.0009	-0.0003
p1_vegyr	0.0166	***	0.0028	5.95	0.00	0.0110	0.0222
c1_area	-0.2162	***	0.0399	-5.42	0.00	-0.2966	-0.1358
c1_ipm	0.1369		0.1175	1.16	0.25	-0.1003	0.3741
c1_orgfl	-0.3055	***	0.0824	-3.71	0.00	-0.4719	-0.1391
_cons	5.8399	***	0.9118	6.40	0.00	3.9998	7.6801

[1] Coefficients significant at the 10% level are designed with *, at the 5% level with **, and at the 1% with ***.

Figure captions

Figure 1: Northern Cartago and the Ujarrás Valley, Costa Rica.

Figure 2: Small potato field among other vegetable crops near Cot, Northern Cartago, Costa Rica

Figure 3: A package of mini-vegetables produced in Northern Cartago and the Ujarrás Valley, Costa Rica.

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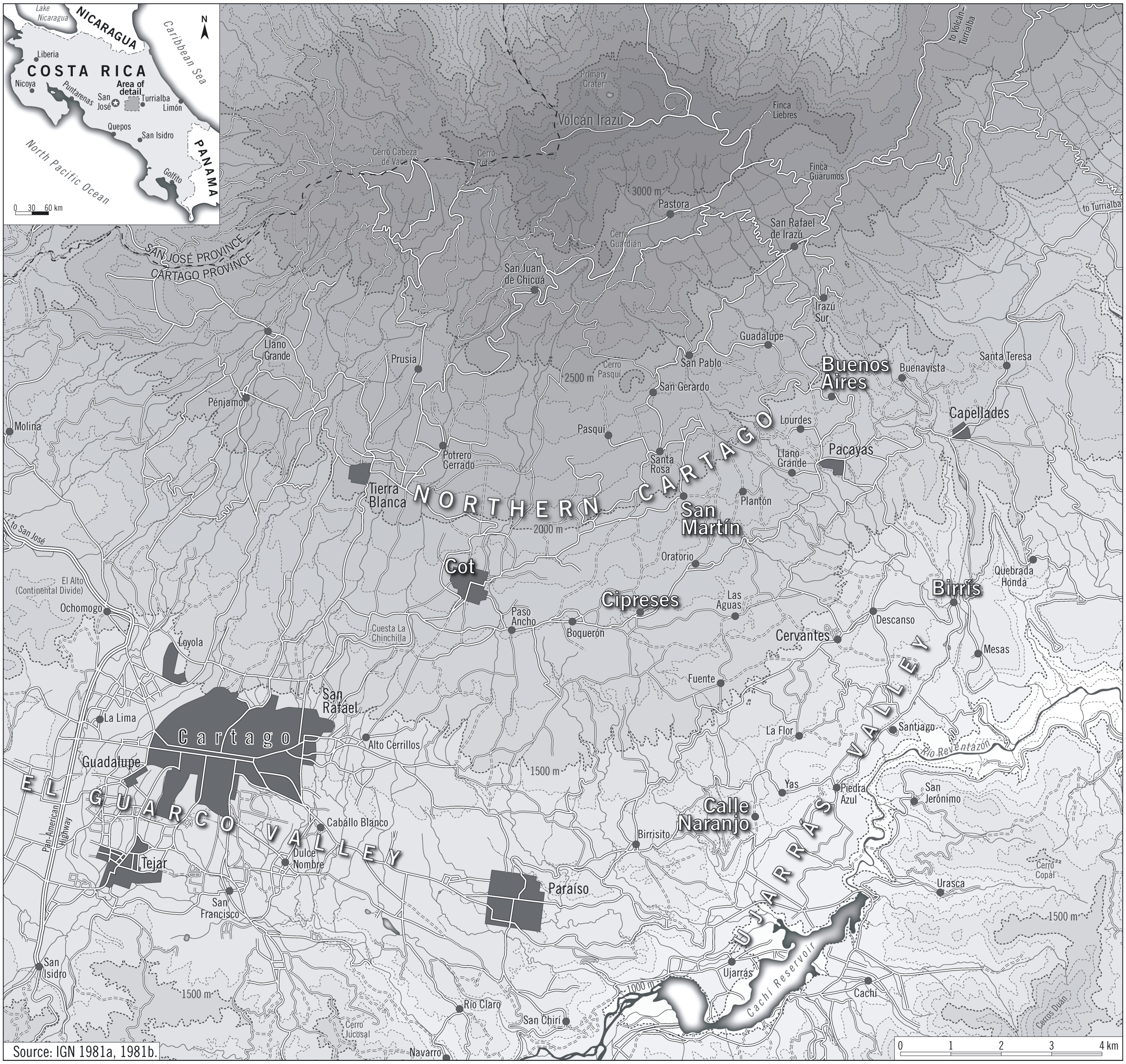

Source: IGN 1981a, 1981b.


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