CULTURAL APPROACHES TO ABATE NITRATE CONTAMINATION OF GROUNDWATER:
THE ECONOMICS OF COFFEE PRODUCTION ALTERNATIVES IN COSTA RICA

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ABSTRACT

This paper provides an examination of the relative costs of reducing the nitrate pollution of groundwater as viewed from the perspective of individual coffee producers in the Central Valley of Costa Rica. The analysis provides a standardized framework within which to compare a number of alternative cultivation techniques and practices, where each has the potential to reduce the escape of nitrogen from fertilizer to groundwater. Stochastic partial budgeting allows the simulation of outcomes when key variables such as prices, yields and uses of supplemental nitrogen fertilizer are allowed to vary over their historical ranges. The resulting cost estimates are also interpreted as from the perspective of national environmental policy. From the producer's perspective, traditional cultivation approaches for coffee using bananas or oranges as a companion crop represent the best investments (respectively) as a move away from intensive monoculture production.

INTRODUCTION

In past years Costa Rica has experienced an increase in the production of coffee, and has done so with a conversion from traditional cropping practices to intensive monoculture. Cultivation practices for coffee now rely heavily on the use chemical fertilizers and pesticides, whereas a number of traditional practices, such as the intermixing of crops, have declined. More recently, average coffee yields have declined, raising new concerns about cultivation practices, including rates of supplemental fertilization. Coffee production is an important agricultural activity in Costa Rica, and changes in production practices can affect a large, heavily populated area of the country.

Significantly, Costa Rica has been experiencing an increase in the levels of nitrates found in groundwater. Nitrates pose a risk to human health when they are consumed in drinking water, and the World Health Organization recommends that water not be consumed if nitrates exceed a specified threshold concentration. There may be numerous anthropogenic sources of nitrogen in groundwater. However, in the case of Costa Rica, the rates and methods of nitrogen fertilizer use in coffee production are seen as an important contributor to the groundwater nitrate problem and to its solution.

The analysis presented here incorporates cultural, cost-of-production and yield data for typical small-scale plantations, as published by the national coffee research agency, CICAFÉ. These data are then augmented and adapted to provide a stochastic analysis of a number of alternative cultural practices, where these alternative practices are associated with lower rates of loss of nitrogen to groundwater. The ultimate purpose of the analysis is to guide national environmental policy choices. The fact that these cost tradeoffs are viewed, in the first instance, from the perspective of individual producers, allows for a characterization of the levels of private incentives (or penalties) that might be required to adopt any specific solution. Moreover, where producers are risk-averse, the analysis also characterizes the variability of these costs or returns.

From the producer’s perspective, the results developed here recommend traditional cultivation approaches for coffee, grown under nitrogen-fixing shade trees with bananas or oranges as a companion crop. Organically certified production of coffee, under shade with bananas, is a third recommended alternative. Each of these alternatives appears to offer a lower expected level of leaching of nitrates to groundwater than conventional production and is a candidate “best management practice.”

The principal contribution of this paper is to provide a standardized comparison of alternative approaches, and to provide an analytical framework for subsequent analysis, especially as more data about rates of nitrogen uses and leaching become available. The identification and analysis of on-farm cultural practices that can contribute to the solution of an important and looming environmental problem is an important contribution of this paper, and one which likely will have application for other crops and regions.

The next section of the paper presents a brief description of the alternative cultural practices that are to be compared along with information about their impacts on groundwater nitrates. Subsequent sections present the economic methodology and data, followed by sections presenting results and conclusions.

ALTERNATIVE CULTURAL PRACTICES

There are three principal production systems or modes of growing coffee on small-scale plantations in Costa Rica; systems described here as conventional, traditional and organic. Conventional coffee production follows a system of intensive monoculture, is reliant on chemical fertilizers and pesticides, and has become the 'status quo' approach in recent years. Conventional production is the natural benchmark against which to compare other alternatives. Traditional coffee production has historically used a system of intercropping coffee with shade trees and other cash crops, often employing leguminous (nitrogen-fixing) species to reduce producers' reliance on supplemental nitrogen fertilizers. Despite the history and tradition of this method of coffee production, it too is innovative, offering new choices and combinations of secondary crops to suit changing market and production conditions. Organic production also follows the traditional approach of intercropping coffee, shade and cash crop species, yet disallows the use of chemical fertilizers and pesticides. Recommended supplemental nitrogen may be added from sources such as composted manure or plant wastes. A multiyear investment in organic certification may earn the producer an output price premium (relative to conventional production) that could offset the higher costs (of labor especially) or lower yields associated with this organic production approach. For greater clarity, these production systems will be denoted Mode A (conventional coffee production), Mode B (traditional coffee production) and Mode C (organic coffee production) in the discussion below.

Within these three modes of production, there are potentially infinite variations on the cultural or production practices that might be employed on individual coffee plantations in Costa Rica. The expected financial profitability to producers will vary across alternatives due to differences in yields, output prices, and input usages, for example. Importantly, each of these approaches to coffee cultivation might have differing recommended levels and types of supplemental nitrogen fertilization, differing abilities to use up or to hold that nitrogen in the crop or in the soil, and differing resulting levels of nitrogen or nitrates that are leached through to the water table and groundwater.

In many countries and for many crops, so-called best management practices have been established and promoted to agricultural producers by governments and by industry groups. These best management practices, in essence, consist of one or more practical approaches to cultivating a given crop. These cultural approaches become recommended on the basis of some combination of their profitability to individual producers and their (beneficial or less harmful) effect on the physical environment, such as their potential effect on soil and groundwater quality. (See, for example, Ontario, 1993.) These best management practices, when available, are often presented as part of, or alongside, a set of recommendations (farm production plans) including data on cultivation methods, specific rates of input usage, and multiyear budgets for given crop production enterprises. Regrettably, no such best management plans yet exist for coffee cultivation in Costa Rica.[1] All the same, provided that the number and type of reasonable coffee production alternatives can be narrowed down and described in specific terms, then it may be possible to compare alternative coffee production alternatives "as if" they were candidates to become Costa Rica's best management practices.

Seven production plans or programs are presented in the analysis that follows—the predominant 'status quo' (Mode A) plus six alternatives (four in Mode B and two in Mode C). Four of these alternatives—two in each of Modes A and B—describe the choice between oranges and bananas as the secondary cash crop, since either fruit crop can be produced alongside coffee plants under either the organic or traditional production system. Bananas and oranges are important cash crops in their own right in Costa Rica and there are varieties of each that are well suited to Costa Rican growing conditions. Bananas have historically been an important shade providing cash crop in the coffee plantations of Costa Rica, whereas the use of oranges on coffee plantations is more common in other coffee-producing countries such as Brazil and Kenya.

In the four production plans where bananas or oranges are to be grown with coffee, two leguminous shade trees are also incorporated, the Inga (*Inga jincuil*) and the Poro (*Erythrina poeppigiana*). This use of these varieties has been important historically, not only for their ability to fix and supplement available soil nitrogen. Both types of shade trees (along with the fruit trees) protect coffee plants from the direct sunlight, from heavy rains and from strong winds, in essence modifying the microclimate in which the coffee is grown (Muschler, 1999). Indeed, a social action movement is promoting the advantages to North American coffee consumers of insisting on shade-grown coffee (Motavalli, 2000).

The other two alternative production plans (both in Mode B) introduce beans as a complementary cash crop to cultivate with coffee. The intercropping of beans and coffee is popular in Nicaragua, for example, and beans are a staple food in the Costa Rican diet. Importantly, beans are also able to fix and supplement soil nitrogen. Beans can be grown to best advantage only in those parts of the coffee plantation where coffee plants have been pruned in a given year. When coffee producers follow a multiyear cycle of pruning (and replanting) the rows of coffee plants, this can contribute to the productive life of the coffee plants and can stabilize the sustainable annual harvest of coffee from a plantation of given size. All the same, pruning a row of coffee plants eliminates the yield in a given year, reduces the coffee yield transitorily in successive years, and reduces the volume of coffee plant foliage drastically. This provides an opening for one or more annual crops of beans, which are generally produced following one of two cultural approaches.

Tapedo bean production is a low-intensity method of cultivating beans, without weeding, without supplemental fertilizers, and with few other production inputs. When not done in conjunction with coffee, *tapedo* bean production is popularly undertaken as a form of broadcast field bean cultivation on lands of poorer quality that might otherwise lie fallow. *Espeque* bean production is a higher-intensity method of cultivating beans, in that the plants are cultivated in rows, staked, and fertilized as necessary. Each bean production alternative will be assessed separately given the potential for differences with respect to labor usage, other input costs and with respect to nitrogen leaching. The two bean production alternatives are analyzed as an adjunct to traditional (Mode B) coffee production, in each case *without* the use of supplemental, nitrogen-fixing shade trees such as the Inga and Poro.

Among the six alternatives to conventional coffee production, the following general observations can be made about their relative effects on the groundwater nitrate problem. Some Mode B production alternatives may recommend less supplemental nitrogen fertilizer per hectare than Mode A, either because of the use of shade trees or because of the use of nitrogen-fixing crops. Even where the total amounts of supplemental nitrogen fertilizer in Mode B are the same or higher than Mode A, there may be greater plant uptake of nitrogen in Mode B due to the alternate mix of crops or there may be a higher rate of soil denitrification (depletion of nitrogen other than to groundwater) due to shading. These effects may also be present in Mode C, where the (organic) forms of supplemental nitrogen fertilizer are different than Modes A and B, and where there is an emphasis on building up soil organic matter and the capacity of the soil to hold nutrients. This effect can keep a given annual load of nitrogen available for plant use longer (before it passes through the root zone to groundwater, for example), thereby increasing the technical efficiency of supplemental nitrogen fertilization.

Having specified a number of coffee cultivation alternatives, where each has the potential to reduce the escape of nitrogen from fertilizer to groundwater, it would be useful to be able to compare their many similarities and differences within a standardized framework.

METHODOLOGY AND DATA

There is a rich research literature in economics that describes and implements a number of analytical approaches relevant to the abatement of nitrate contamination of groundwater from agricultural activities, yet none of these papers' findings can be applied directly to the situation of coffee producers in Costa Rica. For example, Ribaudo *et al.* (1999) survey the use of policy instruments to reduce agricultural non-point source pollution. Morgan *et al.* (2000) propose an interactive bidding process, perhaps mediated by the Internet, through which producers could interact to acquire permits to discharge nitrates into groundwater. Shankar *et al.* (2000) conduct a simulation of the effects of alternative farm management and cultural practices on nitrate contamination of groundwater at the watershed (not farm) level for agricultural producers in Illinois. Lien and Hardaker (2001) explicitly bring information about the variability of crop returns and producers' attitudes towards risk into a farm-level analysis of agricultural policy reform in Norway. In the Costa Rican context, Segura (1993) examines some environmental impacts of coffee cultivation and processing in Costa Rica and El Salvador and recommends the incorporation of orange trees into coffee plantations on environmental grounds. Segura's analysis does not incorporate financial analysis of such recommendations at the farm level. The methodology employed in this paper is informed by, and builds upon these earlier works.

Coffee cultivation in Cost Rica is an economic activity with the potential to impose significant costs (and benefits) on the physical environment and upon other sectors of the national economy. If one were seeking to use economic analysis to guide or to reform national public policy, especially agricultural, environmental or health policy, then one would want to understand how each of the available cultural alternatives for coffee would be viewed from the national (i.e., social) perspective. One would want to make a comparison that takes into account not only the costs and returns as viewed by coffee producers, but all other costs and benefits as viewed from a social perspective.[2]

Suppose one were to find that some specific cultural approach is socially preferable on an ongoing basis. From a policy reform perspective, it would be important to ensure that this were also true when the transition or conversion costs from the present situation to the new production system were included. Moreover, if this analysis were based on an expected value, or average-year basis, then one would want to know how the relative attractiveness of such proposals would be affected by the variability producers experience due to production and market conditions. In this case, such a broad and encompassing view of available options is not yet readily available, in part due to limitations of data and other research resources.

The approach taken in the analysis that follows is to focus on the effect of these alternative cultural practices on the financial returns received by producers. Note that the very existence of a groundwater pollution problem is evidence that, in coffee production, social and private valuations may differ, since groundwater pollution is a significant negative externality. However, social and private values deriving from alternative coffee production practices may also differ for a number of other reasons that will not be explored or estimated in what follows. These reasons may include: the presence of other cultivation-related (positive or negative) externalities (e.g., differences in nutrient or pesticide use other than nitrates), the presence of non-market effects (e.g., differences in risks to population health and changes in the value of environmental amenities), other failures of existing market prices to reflect social opportunity costs (e.g., due to taxes, subsidies and barriers to international trade) and so on.

In future, there may be opportunity for subsequent analysis that is broader, more complete, and able to incorporate more of these social values. If that analysis recommends cultural approaches for coffee that are preferred from all of society's perspective, then there will still be a need, at that point, to identify policy instruments that can induce private coffee producers to conform to such practices. The present analysis of cost tradeoffs from the perspective of individual producers will allow for a characterization of the levels of private incentives (or penalties) that might be required to induce producers to adopt any specific alternative. Moreover, the present analysis provides an analytical framework for estimating the inflows and outflows of nitrogen, where these flows depend largely on the rates of application of supplemental nitrogen fertilizer.

The present approach employs stochastic partial budgeting to simulate financial outcomes when key variables such as output prices, yields and uses of supplemental nitrogen fertilizer are allowed to vary. By definition, a partial budget does not represent a comprehensive measure of the firm's (accounting or economic) profit under each alternative; instead it provides a comparative assessment of those revenue and cost items that will change from one alternative to another. An annual value, referred to here as the firm's "contribution margin" represents the residual between a coffee producer's crop revenues and a number of expenses associated with the coffee and cash crop production enterprises. For the most part, the included expenses are "cash" expenses, and exclude the opportunity cost of owned factors of production such as land, management services, risk taking and so on. By exception to that general definition, "contribution margin" is defined here "net of" depreciation expenses related to structures and equipment and net of some labour expense that might, in practice, be provided, in kind, by the plantation operator. That is, the required labour inputs differ across production alternatives, and all labour inputs are treated as cash expenses. Only a portion of them would be operator-provided in any event.

Working from Mode A as the benchmark or status quo, the analysis projects the annual financial outcomes (measured as contribution margin) over all future years (in perpetuity), reflecting the situation of a representative coffee producer at the start of the year 1999.[3] For Mode A, the annual contribution margin is, by design, unchanged in each future year, as measured in constant currency units.[4] By assumption, the producer stabilizes the sustainable net income. This would be achieved by pruning and replanting a portion of the coffee plantation each and every year, and by using the estimated depreciation expense to maintain intact the capital structures and equipment.

For the six production alternatives in Modes B and C, a series of representative enterprise budgets describes the typical producer's future, following an hypothetical decision made at the start of 1999 to switch from Mode A to each specific alternative. In some cases, the year 1999 includes certain conversion expenses, following which the contribution margin is stabilized at a new level for all years from 2000 onwards. In other cases, the transition process and costs are more significant. For example, with oranges as a companion crop it takes nine years (1999 through 2007 inclusive) for the newly established production model to reach constant (steady state) levels of yields and financial returns. The infinite future series of annual contribution margin values is made comparable across all seven production budgets by calculating the present value of each series, using a real discount rate relevant to producers' financial decisions.[5]

Simulation analysis is used to characterize the effects of variability on the outcomes that the representative producer might face. As in Monte Carlo analysis, each multiyear production plan is evaluated as if undertaken hundreds of times, each time making a different randomized draw in each year for those key, stochastic input variables identified in the analysis.[6] There were limited available data with which to characterize the probability density functions for key variables such as crop yields, output prices, and levels of nitrogen available in the root zone for plant uptake—or with which to characterize the correlations among these. Specifically, there was no basis for one to show or to assume, as input data to the comparisons, for example, that yields might be significantly more variable under monoculture, or that coffee prices might be significantly less variable if the product was organically certified. Even so, the introduction of some variability across these key variables is translated, via the simulations, into corresponding variability in annual contribution margins and in their net present values.

Where (risk-averse) producers and policy makers may in future wish to employ (or modify) similar analysis (within this framework) to investigate their own production choices, the ability to estimate entire distributions of expected returns may have special value. Even if these agents were riskneutral, the incorporation of such variability into the comparative analysis will change the point estimates resulting from each cultivation approach. That is, the mean or expected value of the density function describing net present value, for example, will, in general, be a different numerical (scalar) value than that which would have been calculated by using only the expected (point) values for yields and prices.

Data, drawn from a number of cost of production studies, have been supplemented and standardized in order to reflect the experience of a ten hectare coffee plantation in the Central Valley of Costa Rica looking forward from 1999. For example, standard input and output prices including wage rates are used across the analyses even though the cultivation approaches are assumed to change. By assumption, organically certified coffee expects to earn a 20% price premium, but not until 2004, since it may take a number of years to access the alternate organic market. Table 1 recaps the main features of each of the seven production alternatives and indicates the principal sources of production recommendations and cost data brought into this comparative analysis. Details are reported in De Marco (2001).

Table 1: Alternative coffee cultivation approaches to be analyzed

Coffee Production Alternative	Crops Grown	Principal Cultural Practices	Principal Sources of Production and Cost Data
Mode A (Conventional)	Coffee	Intensive monoculture, no shade, chemical fertilizers and pesticides	Rojas-Cubero (1999)
			Rojas-Cubero (1999) *<u>and</u>:*
Mode B (Traditional)	Coffee and bananas with leguminous shade trees	Mixed crops with shade	Alvarado-Linares and Chaves-Coto (1998)
	Coffee and oranges with leguminous shade trees	Mixed crops with shade	Baraona-Cockrell and Sancho-Barrantes (1998)
	Coffee and *tapedo* bean	No shade, beans grown with few inputs in pruned coffee rows only	Monge-Villalobos (1994)
	Coffee and *espeque* bean	No shade, beans grown with more inputs in pruned coffee rows only	Monge-Villalobos (1994)
Mode C (Organic)			Rojas-Cubero (1999), Montenegro (1999) *<u>and</u>:*
	Coffee and bananas with leguminous shade trees	Shade grown, no chemical fertilizers, organic price premium	Alvarado-Linares and Chaves-Coto (1998)
	Coffee and oranges with leguminous shade trees	Shade grown, no chemical fertilizers, organic price premium	Baraona-Cockrell and Sancho-Barrantes (1998)

Ideally, for each of the coffee production alternatives, one would like to describe and to quantify all of the sources and uses of soil nitrogen on the plantation. This would include nitrogen existing in all of nitrogen's various chemical forms, converted and expressed as kilograms of (elemental) nitrogen per hectare per year, for example. Typically, the sources of nitrogen would include supplemental nitrogen from fertilizers; nitrogen fixation by legumes; decomposition of litter and vegetative matter from crops, weeds and shade trees, and deposition from runoff, erosion and rainwater. Uses or losses of nitrogen would include uptake by crops, weeds and shade trees (including plant biomass removed as marketable crops or after pruning or replanting); denitrification (loss to the atmosphere), and losses due to surface runoff and erosion. As a result of one-time changes between the cultural approaches described here, there might be a year-over-year increase in the capacity of the soils to hold nitrogen (likely resulting in an increase in the resulting efficiency with which a given supply of nitrogen is taken up by the crops). Thus, during the transition period, an increase in the nutrient holding capacity of the soil would also act as a "use" of soil nitrogen.[7] In any given year, it would be possible to define a residual supply of nitrogen, which is the amount by which nitrogen available from all sources exceeds nitrogen disappearance from all uses. This amount of "residual" or "excess" nitrogen (sources minus uses) would be expected to percolate or leach into the water table, eventually to appear as a concentration of nitrates in groundwater.[8]

There are not sufficient data currently available on all of these nitrogen flows to construct nitrogen budgets that are complete, consistent and reliable for any of the production alternatives. The largest data gaps are associated with rates of nitrogen fixation and soil denitrification, and with adjustments to soil nutrient holding capacity and to uptake of nitrogen by plants in response to changes in soil organic matter and crop shading. Although it is possible to estimate and to report differences in nitrogen loading from supplemental fertilization (chemical and organic) these values would present an incomplete picture upon which to recommend a specific production alternative, since that alternative might be less desirable if denitrification and nitrogen fixation were accurately quantified.

Absent these nitrogen budgets, the approach undertaken here is to classify each of the seven production alternatives into one of four (ordinally ranked) categories. This classification is intended to reflect each alternative's expected level of leaching of nitrogen to groundwater in a steady state year, based on such factors as the specific crop production recommendations and fertilization program described in the multiyear budgets. The "High" category is reserved for the status quo, Mode A, where this terminology is simply meant to acknowledge that current practices are seen to be a significant contributor to the groundwater nitrate problem. Some improvement is expected in the two Mode B alternatives featuring beans as a companion crop. The absence of shading and the comparable levels of supplemental nitrogen fertilizers are expected to result in modest, perhaps not significant, improvement in groundwater quality, relative to Mode A. These two production alternatives have been classified as “Medium to High” potential for harm to groundwater.

The two production alternatives in Mode B with leguminous shade trees (i.e., oranges or bananas as shade producing companion crops) are seen as “Low to Medium” where this rating reflects lower amounts of supplemental nitrogen fertilization and a potentially higher rate of denitrification. The fourth category “Low” is reserved for the two organic production approaches (i.e., organic coffee with organic oranges or bananas as shade producing companion crops). The rate of supplemental nitrogen fertilization is significant, but is from organic sources and is used as part of a broader program to build up the soil nutrient holding capacity in a shaded plantation.

It is an acknowledged limitation of this analysis that there is not yet clear and sufficient quantitative data support (from outside the realm of economics) for assigning the seven cultural approaches to these four specific and ordered categories of potential harm to groundwater. An alternative would be to collapse the four categories into one category (“Other”). Foreshadowing the results that follow, provided the six production alternatives in this “Other” category were no more harmful to the groundwater than the status quo, then the qualitative conclusions of the analysis would not be affected. Of course, the more favourable are these approaches to reducing groundwater pollution than the status quo, the stronger would be the force of the recommendations that follow.

RESULTS AND CONCLUSIONS

For the representative producer, three of the production alternatives represent a more profitable alternative than the status quo and three represent a less profitable alternative. From the producer’s perspective, traditional (Mode B) cultivation approaches for coffee with bananas or oranges as a companion crop represent the best investments (respectively) as a move away from conventional (Mode A) production. The next best alternative is organic cultivation (Mode C) of coffee with bananas. Importantly, each of these alternatives appears to offer a lower expected level of leaching of nitrates to groundwater, and is a candidate “best management practice.”

These results are based on a comparison of Net Present Value amounts, calculated as in 1999, over the (perpetual) annual flows of contribution margins, all starting from an hypothetical decision and action taken at the start of 1999. Table 2 shows the change in Net Present Value associated with a move from Mode A to each of six alternative production approaches. As it turns out, the *levels* of the NPV for four of the seven production alternatives, including Mode A, are estimated to be negative, although this finding alone is not necessarily relevant for a producer’s short-term or long-term resource allocation decisions.[9]

As part of the simulation analysis undertaken, the detailed effects of production and price variability can be examined through the use of probability distributions that are constructed for all of the main input and output variables to the financial analysis. For example, given data and assumptions about the range of coffee yields and prices, one can observe the statistical probability that contribution margin or net present value per hectare would exceed any specified threshold value (including zero, for example). Although space limitations prevent a detailed description of such probability distributions here, Table 2 reports the standard deviation for the Net Present Value estimates associated with simulations of each of the seven production alternatives. Table 2 also reports, by way of illustration, the associated probability of achieving a positive Net Present Value amount.

Turning finally to the challenges of reforming national environmental policy to assist in reducing the nitrate contamination of groundwater, these results suggest that producers may already face a private incentive to move in that direction, such as in reverting to the traditional, and historically popular approaches of growing coffee under shade with a companion crop. If these results are borne out, acknowledging that they are based on data and assumptions that may benefit from further verification, it may be the case that various regulatory, marketing or informational barriers are stopping producers from making these cropping changes independently. For example, the levels of risk associated with alternative practices that are otherwise privately profitable may be too high, and there may be no effective means for producers to insure themselves. One policy approach might involve the removal or elimination of some of these types of impediments.

As other data and research results become available, the joint determination of optimal cropping and fertilization practices for coffee production—that is, the nomination of best management practices—will rely upon a much clearer understanding of the evolving cultural alternatives as viewed from the social, not financial, perspective. In some case, it might turn out that the socially preferred practices are not privately profitable; especially once transition costs and risk factors are included. The data and analytical framework presented here can help to quantify the private incentives that would see such practices become adopted voluntarily, acknowledging that there is a diverse set of policy instruments by which such incentives could be delivered.

Table 2: Financial returns and nitrate leaching under alternative cultivation approaches

Coffee Production Alternative	**Classification: Expected level of nitrates leaching to groundwater**	**Expected Value of Annual Contribution Margin (in steady state after any conversion/transition from Mode A)** (colones (1999¢) per hectare per year with $US 1.00=300¢)	**Expected Level of Net Present Value of Annual Contribution Margin** (colones (1999) per hectare) with 9.1% annual discount rate	**Standard Deviation (F) of Net Present Value and Probability that NPV is positive (from cumulative distribution function)**	**Difference in Expected Net Present Value of Annual Contribution Margin relative to Mode A** (colones (1999) per hectare)
Mode A (Conventional)	High	–67,500	–741,400	F: 2,505,196 *prob: 0.34*	0
Mode B (Traditional)					
Coffee and bananas	Low to Medium	1,449,400	15,742,900	F: 3,186,452 *prob: 1.0*	16,484,300
Coffee and oranges	Low to Medium	1,532,500	10,591,000	F: 2,963,438 *prob: 1.0*	11,332,400
Coffee and *tapedo* bean	Medium to High	–73,300	–799,400	F: 2,482,905 *prob: 0.35*	–58,000
Coffee and *espeque* bean	Medium to High	–96,100	–1,061,800	F: 2,499,237 *prob: 0.30*	–320,400
Mode C (Organic)					
Coffee and bananas	Low	225,500	935,400	F: 1,798,945 *prob: 0.67*	1,676,800
Coffee and oranges	Low	601,500	–1,195,600	F: 1,822,455 *prob: 0.25*	–454,200

REFERENCES

Alvarado-Linares, Edwin E. and Rodrigo E. Chaves-Coto. 1998. *Evaluación económica y de desarrollo de una plantación en transición de producción de banano tradicional a banano orgánico bajo condiciones del trópico húmedo de Costa Rica.* Trabajo de graduación presentado como requisito parcial para optar al titulo de Ingeniero Agrónomo con el grado de Licenciado a EARTH. Guácimo, Costa Rica: EARTH.

Baraona-Cockrell, Marcia and Ellen Sancho-Barrantes. 1998. *Cítricos fruticultura especial, Fruticultura II.* San José, Costa Rica: Editorial Universidad Estatal a Distancia.

De Marco, Teresa. 2001. *The economics of best management practices for fertilizer application and groundwater quality in the coffee plantations of Costa Rica.* Unpublished Master of Economics research project report. Calgary: University of Calgary, Department of Economics.

Lien, Gudbrand and J. Brian Hardaker. 2001. Whole-farm planning under certainty: Impacts of subsidy scheme and utility function on portfolio choice in Norwegian agriculture. *European Review of Agricultural Economics* 28(1): 17-36.

Monge-Villalobos, Luis A. 1994. *Cultivo del frijol: Los cultivos básicos de Costa Rica.* San José, Costa Rica: Editorial Universidad Estatal a Distancia.

Montenegro, Luis Fernando. 1999. *Manual de caficultura orgánica.* Guatemala City, Guatemala: Asociación Nacional del Café de Guatemala.

Morgan, Cynthia, Jay Coggins and Vernon Eidman. 2000. Tradable permits for controlling nitrates in groundwater at a farm level: A conceptual model. *Journal of Agricultural and Applied Economics* 32(2): 249-258.

Motavalli, Jim. 2000. Grounds for concern: The case for buying shade grown coffee, *Newsletter* 31(4). New York: Environmental Defense.

Muschler, Reinhold G. 1999. *Arboles en cafetales: Materiales de enseñanza*. Colección módulos de enseñanza agroforestal, modulo no. 5. Turrialba, Costa Rica: Centro Agronómico Tropical de Investigación y Enseñanza, Proyecto Agroforestal CATIE / GTZ.

Ontario. Ministry of Agriculture and Food. 1993. *Best management practices: Horticultural crops*. Toronto: Ontario Ministry of Agriculture and Food.

Palisade Corporation. 1999. *Guide to using @RISK: Risk analysis and simulation add-in for Microsoft Excel or Lotus 1-2-3.* New York: Palisade Corporation.

Pardo-Tassies, Jorge. 1996. *El cultivo del banano.* Serie cultivo mayores no. 7. San José, Costa Rica: Editorial Universidad Estatal a Distancia.

Ribaudo, Marc, Richard Horan and Mark Smith. 1999. *Economics of water quality protection from nonpoint sources: Theory and practice.* Agricultural economic report number 782. Washington, DC: U.S. Department of Agriculture, Economic Research Service, Resource Division.

Rojas-Cubero, Gilberto. 1999. *Modelo de costos de producción de café*, San José, Costa Rica: Instituto del Café de Costa Rica, Unidad Regionales, Centro de Investigaciones en Café (CICAFÉ).

Segura, Olman. 1993. *Environmental impact of coffee production and processing in El Salvador and Costa Rica.* Prepared for the United Nations Conference on Trade and Development. Maestría en Política Economía para Centroamérica y el Caribe. Heredia, Costa Rica: Universidad Nacional de Costa Rica.

Shankar, B., E.A. DeVuyst, D.C. White, J.B. Braden and R.H. Hornbaker. 2000. Nitrate abatement practices, farm profits, and lake water quality: A central Illinois case study. *Journal of Soil and Water Conservation* 55(3): 296-303.

NOTES

[1] There are a number of cost of production estimates available that describe rates of input usage and expected costs for crops including coffee, bananas, oranges and beans in Costa Rica and neighboring countries. See, for example, Monge-Villalobos (1994), Pardo-Tassies (1996), Alvarado-Linares and Chaves-Coto (1998), Baraona-Cockrell and Sancho-Barrantes (1998), Montenegro (1999) and Rojas-Cubero (1999).

[2] Ideally, one would want to learn about the *marginal* valuations of these costs and benefits; that is, how the costs and benefits change as one considers small variations away from the seven specific discrete production plans described here, so that the (socially) optimal amount of each input and resource could be jointly determined.

[3] Even where all producers have finite life spans, the creation of financial profiles that are infinite is expected to reflect any relative increase or decrease in the going-concern value of the plantation, such as to a retiring producer who sells or bequests the plantation in future.

[4] Constant currency units are (1999) Costa Rican *colones*, where 1$US = 300 *colones* (¢).

[5] A typical loan interest rate for coffee producers in 1999 was 24 percent per year, measured in nominal terms under an annual average inflation rate of 13.6%. Thus, the corresponding estimate of an inflation-free loan interest rate would be slightly above 9% annually. This value is used to estimate the net present value of choosing a given production alternative. Since the principal taxes levied on coffee producers are a sales tax on crops and a payroll tax on labour, there is no ability to deduct loan interest payments for tax purposes, and thus no basis to employ a distinct, after-tax discount rate.

[6] The seven production budgets, including data on nitrogen sources and uses, are represented as spreadsheets using Microsoft Excel (version 97). Simulations are conducted with @RISK software (version 3.5.2) operating as an add-in to the Excel spreadsheets, using a stratified (Latin Hypercube) sampling algorithm. See Palisade Corporation (1999).

[7] However, once the nutrient-holding capacity of the soil has stabilized, there would (on average) be zero use of nitrogen for this purpose in a given year.

[8] The process by which excess nitrogen in the crops' root zone could migrate to groundwater is controlled by a number of factors, such as climate, landform and pedogenesis, and is likely to be location specific. Thus, locational zoning of agricultural activities in relation to the location of drinking water aquifers may be an important policy option not otherwise addressed in this analysis.

[9] One cannot draw conclusions about private or economic profitability from the measure of contribution margin used here, since, by design, it potentially omits some cost (e.g., opportunity cost

of some in-kind inputs) and return elements (e.g., increases in the capital value of land and structures associated with improved coffee production or increases in revenue due to expected relative output price increases in future).

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