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IS CROP ROTATION FEASIBLE?

A LINEAR PROGRAMMING MODEL OF SCALLION FARMS
IN THE CENTRAL HIGHLANDS OF ECUADOR

by

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FOREWARD

Mildred Warner is currently a Master's student in the Department of Agricultural Economics at Cornell University. The research described in this paper is an outgrowth of a paper prepared for Dr. Bernard F. Stanton's course in linear programming. It is with his encouragement that the work was revised to provide the basis for a departmental staff paper.

The research is based on the situation the author found among small farmers in her work as an agricultural extension agent with the U.S. Peace Corps in Ecuador from 1979 to 1981. The author would like to express her gratitude to the local farmers for their enthusiasm, support and interest in experimenting with new ideas, technologies and crops on their farms. The author would also like to thank her colleagues in the Ministerio de Agricultura y Ganaderia, the Instituto de Investigaciones Agropecuarios and the Peace Corps for their cooperation in the research and extension projects.

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Naturally, any remaining errors are the sole responsibility of the author.

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ABSTRACT

A polyperiod linear programming model is used to determine the effect of crop rotation on family income, capital flow and optimum crop mix of small scallion farmers in the central highlands of Ecuador.

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IS CROP ROTATION FEASIBLE?

A LINEAR PROGRAMMING MODEL OF SCALLION FARMS IN THE CENTRAL HIGHLANDS OF ECUADOR

Introduction

Scallion production is a profitable activity for small farmers in the central Andean region of Ecuador. With the heavy clay soils and moderate rainfall of the upper Píllaro zone in the province of Tungurahua, scallion production has become so popular that this zone accounts for a significant proportion of the scallion production for the entire country. This crop is popular among farmers of the region for four reasons: its high price, short production cycle, perennial nature and resistance to drought. As population pressures on the land in this region have reduced the average farm size to roughly four solares (about two acres), scallion production has enabled families to maintain an acceptable standard of living without migrating to the cities or seeking substantial off-farm work.

Unfortunately, scallions are not the panacea farmers had hoped they would be. By the time the author arrived in Tungurahua as an agricultural extension agent with the Peace Corps in 1979, scallion production in this area was in crisis. Due to the perennial nature of its production and the extremely high costs of initial planting, many farmers had left the same field in scallions for ten or even twenty years. Needless to say, production levels were dropping as soil-borne disease (especially Sclerotium cepivorum or allium white rot for which there is no effective chemical control) and insect populations increased to the point where, in some of the worst fields, the onions actually rotted in the soil.

A regular crop rotation appeared to be the only economically and ecologically sound method of improving soil sanitation and, hence, onion production. However, there were many barriers to this technique. Such a rotation requires large inputs of labor and capital and results in lower family income due to substitution of crops of lower value or longer production cycles. Resistance to the idea of a crop rotation was high and necessitated a search for new crops or improved seeds and production methods for traditional crops, which could increase returns and shorten the production cycle (which at 10,000 ft. altitude is often quite long). This had to be done without requiring too many additional demands on labor and capital.

The linear programming model described in this paper was built to test whether a rotation including scallions could be feasible, given the small farmers' limited resources of land, labor and capital.1/ The model attempts to determine

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1/ Linear programming is a mathematical programming technique which determines an optimal allocation of limited resources (such as land, labor and capital) among the various productive activities (crops) to yield the highest net returns over variable costs.

the optimum production mix of scallions, corn, potatoes, peas and barley, and the optimum time for rotating the scallion fields based on a four year rotation plan. To reflect the problem small farmers have in maintaining a steady cash flow to meet planting and family consumption expenditures, a polyperiod structure is chosen. This structure also enables the model to compare the profitability of various crops based on input requirements, returns and length of growing season.

Assumptions About Cropping Activities

The results of any linear programming problem are a product of the assumptions on which the model is built. For simplicity, the cropping alternatives included in this model are limited to scallions, potatoes, corn, peas and barley.

The crop rotation plan incorporated in this model is a simple one requiring that no field remain in scallions for more than four years at a time. Even though the fruiting bodies, or sclerotia, of the Sclerotium cepivorum fungus can overlive in the soil without a host for eight or more years, a four year rotation plan is chosen for this analysis since, realistically, no farmer can be expected to tolerate the income loss of keeping his fields out of scallions for eight consecutive years.2/

Reluctance to rotate scallions is aggravated further by the high costs of initial planting. When a new field is planted in scallions, the soil is prepared by hand with a pick and a hoe to a depth of 80cm (similar to the French double-dig method). This is a very time consuming and arduous task. Transplant stock is usually bought from onions harvested for sale in the market. Few farmers bother with seedbeds. Thus labor inputs and the capital requirements to purchase transplants are very high (Table 1).

Since no traditional crop can compete with scallions in profitability, only improved seeds and production methods are included as options for the alternate crops: peas, potatoes, barley and corn. Production levels are based on farmer interviews and on-farm trials using new methods such as recommended fertilizer use and seed selection. Fertilizer, seed and insecticide inputs for potatoes as well as the associated production levels are based upon on-farm trials in the study area and reflect the production practices of the more progressive farmers (Warner). For peas and corn it is assumed that improved seed is used. This shortens the growing cycle by about one month: to four to five months for sweet peas, six to seven months for sweet corn and eight to nine months for dry corn. Fertilizer inputs for these crops are based on experiment station (Instituto Nacional de Investigaciones Agropecuarias, INIAP) recommendations for typical soils in the area which tend to be low in nitrogen and phosphorous and high in potassium due to their volcanic origin (Garcia and Warner; Warner). A rust resistant variety of barley seed is used with fertilization levels approximating those used on experimental wheat trials in the area.

2/ Little research has been done on the incidence and control of the fungus S. cepivorum in Tungurahua, Ecuador. The time required for a crop rotation to be effective in reducing the population of S. cepivorum varies with climate, other crops grown in the scallion fields, existence of natural parasites and the level of infestation in a particular field (Lorbeer). This study is based on the assumption that a four year rotation of the scallion fields in Tungurahua would be beneficial.

Table 1. PRODUCTION INPUTS AND COSTS FOR PLANTING CROPS, 1980

	Potatoes	Barley	Corn	Peas	New Scallions (for rotation)
	(per 2000 square meters)				
Physical Inputs					
Ox team, days	4	3	4	4	0
Labor, days					
Plowing	4	3	4	4	40
Planting[a/]	6	4	6	6	17
Weed and Spray	7	0	6	6	0
Seed, lbs.	400	25	15	30	5 mulas[b/]
Fertilizer, lbs.					
18-46-0	250	0	120	0	0
0-0-46	30	0	20	0	0
10-30-10	0	100	0	100	0
Urea	0	0	0	60	0
Pesticide					
Applications	2	0	0	0	0
Furadan, lbs.	6	0	0	0	0
Costs			sucres		
Ox team rental @ 150/day	600	450	600	600	0
Seed[c/]	1000	200	200	500	5000
Fertilizer[d/]	1760	550	860	850	0
Pesticides[e/]	380	0	0	0	0
Total Planting Costs	3740	1200	1660	1950	5000

a/ Includes one day for procuring seed.
b/ A mula is composed of 240 bunches of about 10 scallions each.
c/ Seed costs are inflated to include the transactions cost of securing them.
d/ Average local 1980 fertilizer prices used are: 18-46-0, 650 sucres/cwt.; 0-0-46, 400 sucres/cwt.; 10-30-10, 550 sucres/cwt.; urea, 450 sucres/cwt.
e/ Furadan 5% is valued at 30 sucres/lb. and an average price for a spray application of fungicide, insecticide and spreader sticker is 100 sucres.

Production costs for the planting activities are composed of fertilizer, seed and ox team rental costs (Table 1). Labor costs are not included because labor will be hired only when there is not enough family labor available. When hired, the costs are deducted directly from the objective function.[3/] Throughout the model, prices predominant in 1980 are used.

For crops which are in the middle stages of production, only pesticide and fertilizer application expenses are included as production costs for the period (Table 2). Returns based on average production levels and seasonal prices minus spraying, marketing and transportation expenses are reflected in the contribution margins[4/] for harvesting activities (Table 3).

Table 2. PRODUCTION INPUTS AND COSTS FOR CONTINUING CROPS, 1980

	Potatoes	Barley	Corn	New Scallions (for rotation)
	(per 2000 square meters)			
Physical Inputs				
Weed and spray labor, days	10	2	8	14
Pesticides, applications	3	0	0	2
Fertilizer, lbs., urea	30	30	75	0
Costs	sucres			
Pesticide costs	300	0	0	200
Fertilizer costs	150	150	340	0
Total Costs for Continued Crops	450	150	340	200

Production levels for scallions, potatoes and sweet corn are based on estimates provided by farmers in a course on crop budgeting, March 1981. Dry corn and barley production levels, represent the low side of production ranges estimated by the experiment station (INIAP) for improved seed plantings. Sweet pea production estimates come from an experienced vegetable farmer in a nearby town.

Seasonal price variations, i.e., higher prices in the dry season, are incorporated into the contribution margin of each harvest activity. These prices represent the average wet and dry season prices for each crop in the local Píllaro and Ambato wholesale markets (Galarza). The full monthly fluctuations in price are not used since the model seeks to represent the average situation and because harvest of all of these crops can be delayed or advanced a week to capture a better price.

3/ The objective function represents the costs and returns of all activities in the model and in this model seeks to maximize net income.

4/ In linear programming, contribution margins represent the contribution (positive or negative) of the productive activity to the net return of the total enterprise.

Table 3. PRODUCTION INPUTS, COSTS AND RETURNS FOR HARVESTING CROPS, 1980

	Potatoes	Barley	Dry Corn	Sweet Corn	Sweet Peas	Scallions	New Scallions (for rotation)
				per 2000 square meters			
Physcial Inputs							
Labor, days							
Weed & spray	1	0	0	0	8	9	9
Harvest & sell	12	13[a/]	17[b/]	9[c/]	8	12	13
Pesticide, applications	1	0	0	0	0	1	1
Time to harvest,[d/] months	5-6	6-7	8-9	6-7	4-5	2.5	6-7
Average production	100 cwt.	14 cwt.	14 cwt.	50.6 sacks + forage	20 sacks	7 mulas[e/]	8 mulas[e/]
				sucres			
Costs							
Marketing & transportation costs	200	140	150	250	150	100	100
Pesticide costs	100	0	0	0	0	100	100
Returns							
Wet season price	150/cwt.	350/cwt.	800/cwt.	250/sack + 300 for forage	400/sack	1000/mula	1000/mula
Wet season net return	14700	4760	11050	13206	7850	6800	7800
Dry season price	250/cwt.	350/cwt.	800/cwt.	350/sack + 400 for forage	500/sack	1500/mula	1500/mula
Dry season net return	24700	4760	11050	17860	9850	13300	14800

a/ Includes treshing and winnowing. b/ Includes shelling.
c/ Includes cutting and selling green stalks for forage.
d/ All crops which mature in the dry season are assumed to have a slightly longer production cycle and higher labor requirements.
e/ In the 4.5 month dry season 1.3 scallion harvests are assumed with total production at 9 mulas for scallions and 10 mulas for new scallions.

Assumptions About Family Resources

Labor input requirements for land preparation, planting, weeding, harvesting and selling are estimated on the basis of the author's experience and observations after working in the area for two years. Since formal farm records were not obtained, estimates of labor inputs attempt to measure maximum requirements, so that, if anything, they will be overestimated, making family labor resources appear more scarce than they may be in reality.

Because many farm activities are not included in the model, only six days of family labor are made available in any given week. The prototype for the model is a family of five with two adults and three young children. Since two days a week are lost to marketing for family consumption needs, and part of each day is lost to cooking, cleaning, washing clothes and caring for animals, only six worker-day equivalents of family (adult or child) labor per week are made available for agricultural purposes.

The local daily wage predominant in 1980, fifty sucres, is selected for selling one's own labor within the area, but a cost of seventy sucres is required for hiring labor since in addition to the wage it is customary to provide workers with breakfast, lunch and an afternoon snack. The option to both sell and hire labor is made available since families with this small a landholding will often sell their own labor when their farm work is slack.

Although no limits are placed on the supply of labor available for hire in any period, sales of family labor are limited to a maximum of nine days per month in the dry season. Although off-farm employment opportunities do exist in the dry season, they are not as plentiful as in the wet season when agricultural activities require higher labor inputs. Family labor sales in the wet season are not restricted in the model.

Land is the most scarce resource. The land unit is the solar, which is 2000 square meters or one fifth of a hectare. The prototype for the model is a family with only four solares of land, about two acres. This may be smaller than the average family landholding in the area but is chosen because for a farm of this size the idea of a scallion rotation is all the more unattractive. Because land pressures in the area are great, no option is included for renting land. Indeed, with large dairy haciendas and communal pasture lands bounding the area, no additional land for renting is available.

To approximate the status quo, half the family land, two solares, is assumed to be planted in scallions already. Because the local diet consists largely of potatoes and corn, tradition dictates that everyone produce at least some of his consumption needs. Thus, additional constraints for food needs are added requiring the farmer to plant at least one solar of potatoes and half a solar of corn in the course of the year.

Although all crops are treated as if planted in monoculture it should be understood that some intercropping of peas, pole beans, broad beans (haba), lupine (chocho), squash (zambo) and pumpkin does occur in the corn fields. Since these crops are not sold, they are included in the objective function only implicitly in the cost of meeting family consumption demand. Since most small Andean farmers are risk averse, the model requires that except for onions, no more than one solar can be planted to any one crop in any period. Customs based on traditional rainfall patterns also dictate that corn be planted only in the second and third periods (May to September).

Structure of the Model

The model is a polyperiod program which divides the year into four parts. The rainy season, January 15 through the end of August, is divided into three ten week periods (the time required to harvest scallions). The dry season is treated as a single twenty-two week period during which no planting can take place.

The model is constructed in the following manner. Cropping activities are divided into two to three components depending on the length of the production cycle. For example, barley planted in period one (PBAR1) is continued in period two (COBAR1) and harvested in period three (HBAR1) with the following set of consistency constraints:

	Period 1		Period 2		Period 3
	PBAR1		COBAR1		HBAR1
Barl	1	=	1		
Barll			1	=	1

For each period, land planted plus that left fallow must sum to four solares. Labor input for each crop plus own labor sold must equal the total amount of family labor available in the period plus any labor hired. With six man-day equivalents of family labor available per week, there are sixty days of labor available in periods one, two and three; and 132 days of family labor available in period four, the dry season.

Capital constraints are handled as follows. Harvest earnings may be spent on consumption demand (Demandh) or put into capital inventory to finance expenses in the following period. Planting expenses, labor costs, consumption demand (Demandp), and savings in the present period may be financed out of savings and capital inventory (returns minus all period costs) from the previous period or labor earnings in the present period. In this way, harvest earnings which normally occur toward the end of the period are not used to finance planting or consumption expenses which occur at the beginning of the period. To provide more flexibility, up to half the family's consumption demand can be financed out of harvest earnings with the rest drawn from previous savings and capital inventories.

To reflect farmer use of the local credit cooperative, savings at eight percent interest (compounded each period) are made available for any excess operating capital after planting and consumption expeses are met. Savings may only be deposited in the cooperative at the beginning of each period.

In each period a sum of 1000 sucres/week is subtracted from harvest revenues to meet minimum consumption needs. As the year progresses the family's margin is allowed to increase and thus more capital is available for investment in planting activities and savings for the next year. Attempts to make this an equilibrium model, whereby operating capital, in addition to crops, is tied in a circular pattern from period four back to period one results in an unbounded solution. To avoid this problem, capital constraints are kept in a linear form with 6000 sucres in beginning capital given to start the model in period one. Successive periods are financed from capital inventories of the previous period, and in period four, final inventories are totaled and required to be great enough to cover the initial 6000 sucres.5/

To ensure that no land be kept in scallions for more than four years, the model requires that half a solar of new scallions be planted each year (PONION). The model can choose the optimum time to begin the rotation in either period one, two or three.

Results

The model was run twice, once without the requirement for a scallion rotation and next with the requirement. The initial solution of the model (without rotation) shows the family harvesting two solares of scallions in every period as the model requires. Two thirds of a solar of peas is planted in period one and one and one-third solares of land are left fallow. In period two, half a solar of potatoes is planted and the peas are harvested as sweet peas. One and a half days of labor are hired. In period three an additional solar of potatoes is planted along with half a solar of corn. Twelve days of labor are hired. In period four all crops are harvested. Due to its long growing cycle and low returns, barley is never planted (Table 4). The preference to hold land fallow in the first two periods in order to be able to harvest in period four is explained by the higher prices received by crops harvested in the dry season. This reflects the advantage of farmers in this zone, where heavy clay soils enable them to plant much later and maintain crops in the dry season.

The shortage of land becomes quite apparent in periods three and four when the marginal value product or shadow price of an additional solar of land rises from zero to a total for the year of 17576 sucres. This translates into a yearly rental rate of approximately 1172 dollars an acre at the 1980 exchange rate of 30 sucres to the dollar. Due to the land shortage, the family is left so underemployed, it choses to sell 34 days of labor in the dry season and an additional 7 days in the first period. Since labor is relatively scarce in periods two and three, farmers chose the dry season (period 4) as the time to build houses.

It is surprising to see how little the productive mix changes when a crop rotation is required (Table 5). The half solar of new scallions is planted in periods two and three and harvested in periods four and one (it takes about six months for newly planted scallions to mature). To help with the scallion plantings in periods two and three, 30 additional days of labor must be hired.

5/ For a more detailed presentation of the capital constraints and the model in general see the complete matrix of productive activities and constraints in the Appendix.

Table 4. SUMMARY OF RESULTS FOR MODEL WITHOUT ROTATION

	Period 1	Period 2	Period 3	Period 4
	solares			
Scallions	2.0	2.0	2.0	2.0
Plant peas	.69			
Harvest peas		.69		
Plant corn			.50	
Harvest sweet corn				.50
Plant potatoes		.50	1.0	
Continue potatoes			.50	
Harvest potatoes				1.50
Fallow hand	1.31	.81		
	days			
Hire labor		1.6	12.0	
Sell labor	7.0			34.0
	sucres			
Capital inventory	8600	14024	8600	55010
Savings	0	1621	5037	10421

Table 5. SUMMARY OF RESULTS FOR MODEL WITH ROTATION

	Period 1	Period 2	Period 3	Period 4
	solares			
Scallions	1.76	1.74	1.50	1.50
Plant new scallions		.26	.24	
Continue new scallions			.26	.24
Harvest new scallions	.24			.26
Plant peas	.69			
Harvest peas		.69		
Plant corn			.50	
Harvest sweet corn				.50
Plant potatoes		.50	1.0	
Continue potatoes			.50	
Harvest potatoes				1.50
Fallow hand	1.31	.81		
	days			
Hire labor		10.9	18.8	
Sell labor	6.8			35.2
	sucres			
Capital inventory	9078	12213	5200	52226
Savings	0	139	0	1865

Compared to the model with no rotation required, savings fall by 91 percent in period two when the new scallions are planted and are totally depleted in the third period. Year end savings are a mere 1865 sucres as opposed to the earlier 10421 sucres. Due to the harvesting of new scallions in period one, capital inventories are higher. However, they fall to levels 13 percent and 60 percent lower than the model without rotation in the second and third periods, respectively. With the dry season harvest of all but .24 solares of new scallions, capital inventories in period four rise to within five percent of their previous level. However, by rotating onions, yearly family income falls by 17.3 percent from $774 per capita (US $ equivalent) to $640 (Table 6).

Table 6. PER CAPITA INCOME FOR TWO FARM MODELS

	Without Rotation	With Rotation
Objective function, sucres	59746	48148
Savings (period 4 principal), sucres	+10421	+ 1865
Beginning capital, sucres	- 6000	- 6000
Consumption demand, sucres	+52000	+52000
Net family income, sucres	116167	96013
1980 Exchange rate	÷ 30	÷ 30
Net family income, dollars	3872	3200
Family size	÷ 5	÷ 5
Per capital yearly income, dollars	774	640

The marginal value products or duals[6/] for the capital constraints show that harvest revenues in one period are tied to planting costs in the next period by the value of the interest rate for the remainder of the year (interest compounded each period). With the scallion rotation requirement however, operating capital becomes more constraining and the duals for all cost and consumption constraints in the wet season increase. The marginal value product of labor in periods two and three rises to a level more than 76 percent higher than the cost of hiring labor but the value of land, as reflected in its dual values, falls by 4402 sucres ($147 US) (Table 7).

One concludes then that although rotating onions does reduce the final yearly income for a family as well as increase labor hiring and tighten capital flow, it is by no means prohibitive even on a small farm. Consumption demands can still be met in each period and remarkably, practically the same productive activities are carried out. Moreover, the potential for maintaining scallion yields at the level postulated in the model is greatly enhanced. Although the 30 percent increase in scallion yields needed to cover rotation costs is probably greater than the yield benefits to be gained from rotation; if farmers begin fertilizing their scallion fields, local experimental results show that yield increases of more than 30 percent can be expected (Portch). Moreover, if rotation is not practiced, scallion yields can be expected to continue to fall causing family income to drop well below the level achieved in the model without rotation.

6/ The marginal value product, dual or shadow price of a fully utilized resource indicates the additional return or value to be gained by using one more unit of a resource at the margin.

Table 7. DUAL VALUES FOR TWO FARM MODELS

	Land	Labor	Consumption Demand	Planting Costs	Harvest Revenues
Period 1 (Jan. 15-Mar. 31)					
Without rotation	0	127.8	2.56	1.56	.065
With rotation	0	215.0	4.30	3.30	.791
Period 2 (Apr. 1-June 15)					
Without rotation	0	74.5	1.065	.065	.047
With rotation	0	125.4	1.79	.791	.762
Period 3 (June 16-Aug. 31)					
Without rotation	3644	73.3	1.05	.047	.030
With rotation	615	123.3	1.76	.762	.030
Period 4 (Sept. 1-Jan. 14)					
Without rotation	13931	51.5	1.03	.030	0
With rotation	12559	51.5	1.03	.030	0

Sensitivity Analysis

Sensitivity analysis shows how sensitive the optimum solution is to changes in the quantity of resources available or to changes in the costs or returns for the various productive activities. In both these models the sensitivity analysis primarily shows the change in costs or returns in the various periods sufficient to cause a crop to be produced in a different period. In general, hiring and selling activities for labor are very sensitive to the amount of land in scallion production.

The amount of operating capital needed at the beginning of the production year can only be increased within the model by harvesting dry corn or new scallions in period one. Consequently, as consumption demands rise or harvest revenues fall, less new scallions can be planted in period two due to lack of capital for hiring the necessary additional labor. Thus, consumption demands in each period, especially the constraint that half this demand be satisfied from revenues available from the previous period, limit the choice of when to plant and harvest individual crops and in what amounts.

To test the sensitivity of the solution to the quantity of operating capital available in the first period a parametric option was run. Beginning capital is allowed to vary from 5,000 to 15,000 sucres. When only 5000 sucres of beginning capital are supplied, operating capital becomes so scarce in period one that over 40 percent of the family's land must be left fallow. Corn, normally harvested and sold in the dry season at the higher sweet corn price, is now partially allowed to dry and is harvested in period one to provide the needed operating capital.[7] As higher levels of beginning capital are supplied dry corn is no longer harvested in period one and more peas are planted. Thus, less land is left fallow. As more peas are planted, capital inventories and family labor sales in the first period fall (Table 8).

Table 8. RESULTS AT BASIS CHANGES OF PARAMETRIC OPTION FOR BEGINNING CAPITAL IN MODEL WITH SCALLION ROTATION

	Level of Beginning Capital						
	5000	5116	5327	6044	6863	9294	15000
Objective Function (sucres)	44640	45098	45927	48294	49355	51130	51603
Period 1							
Scallions a/	1.50	1.5	1.57	1.77	1.74	2.0	2.0
New scallions (harvest)	.50	.50	.43	.23	.26	0	0
Harvest dry corn	.03	0	0	0	0	0	0
Plant peas	.31	.36	.44	.70	1.0	1.0	1.0
Fallow land	1.66	1.64	1.56	1.30	1.0	1.0	1.0
Sell labor b/	12.0	11.7	10.6	6.5	1.7	2.0	2.0
Capital inventory c/	9963	9600	9462	9052	9122	8600	8600
Savings	0	0	0	0	0	2444	8150
Period 2							
Scallions a/	2.0	2.0	1.93	1.73	1.76	1.5	1.5
New scallions	0	0	.07	.27	.24	.50	.50
Plant potatoes	.50	.50	.50	.50	.50	.50	.50
Harvest peas	.31	.36	.44	.70	1.0	1.0	1.0
Fallow land	1.19	1.14	1.06	.80	.50	.50	.50
Hire labor b/	0	0	0	11.6	15.1	24.5	24.5
Sell labor	4.6	3.7	0	0	0	0	0
Capital inventory c/	11018	11430	11571	12256	14825	13050	13050
Savings	3321	2917	2247	0	0	0	5802
Period 3							
Scallions a/	1.5	1.5	1.5	1.5	1.5	1.5	1.5
New scallions	.50	.50	.50	.50	.50	.50	.50
Plant potatoes	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Continue potatoes	.50	.50	.50	.50	.50	.50	.50
Plant corn	.50	.50	.50	.50	.50	.50	.50
Hire labor b/	30.0	30.0	27.0	18.2	19.7	8.5	8.5
Capital inventory c/	5200	5200	5200	5200	5200	5200	5200
Savings	0	0	0	0	2296	2560	8459
Period 4							
Scallions a/	1.5	1.5	1.5	1.5	1.5	1.5	1.5
New scallions	.5	.50	.43	.23	.26	0	0
New scallions (harvest)	0	0	.07	.27	.24	.50	.50
Harvest potatoes	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Harvest sweet corn	.47	.50	.50	.50	.50	.50	.50
Continue corn	.03	0	0	0	0	0	0
Sell labor b/	36.3	36.0	35.8	35.2	35.3	34.5	34.5
Capital inventory c/	47782	48360	49382	52414	51897	55760	55760
Savings	1804	1800	1817	1868	4195	4528	10525

a/ Solares. b/ Days. c/ Sucres.

7/ This is an example of the disadvantages of a disequilibrium model where harvest earnings in period four are not connected to period one as capital inventories available to finance planting expenses. If the model were an equilibrium model, corn most certainly would continue to be harvested at the higher sweet corn price in period four, the dry season.

In the second period, capital inventories rise as more peas are harvested. The planting of new scallions, previously limited to period three due to lack of the necessary operating capital earlier in the year, is divided between periods two and three as more beginning capital is provided and eventually concentrated in period two alone. As a result, less land is left fallow in this period, labor hiring increases and savings fall to handle the high labor and capital requirements of the new scallion plantings.

When the amount of beginning capital supplied reaches 6863 sucres, positive savings appear for the first time in the third period. Beyond the level of 9294 sucres of beginning capital, however, the family is no longer constrained by a shortage of operating capital but instead by a lack of additional land. Any extra funds provided beyond this point can only be put into savings. Hence, the most profitable level of capital investment for this size of farm given these cropping alternatives has been reached. Thus the model's sensitivity to changes in the level of beginning capital is reflected in the timing of new scallion plantings, the amount of dry corn harvested, peas planted, fallow land, and labor hired and sold.

Limitations of the Model

The biggest limitation of this model is its inability to reflect the uncertain environment in which small farmers operate. This model assumes that if the farmer plants in February, he knows exactly what his costs, production and returns will be. Such foresight is hardly realistic in agriculture. Indeed, risk and variability in yields and prices are not incorporated in this model. To make the model more realistic would require including random disturbances in prices and production levels as done by Crawford, to see what would be the most stable solution in the uncertain environment experienced by agriculture in this area.

Although the purpose of the model is to measure the effects of a planned scallion rotation on exterior family income, in reality, many of the crops grown are used for home consumption. In fact these crops may be grown even when they can be bought for less in the market. This is partially accounted for by the requirement that at least one solar of potatoes and half a solar of corn be planted.

Since the model does not include all the activities carried out by the farm household, such as the production of small animals and dairy cows, for example, it may not be an accurate reflection of labor or capital availability. Milk cows are not included since feed conversion ratios are not known and usually families with as little as four solares of land do not have cows because they can not afford to devote any land to pasture. Fruit trees are also quite popular among farmers of the area. However, since fruit trees need anywhere from one and a half to seven years before they come into full production, it would be hard to incorporate them into a simple model limited to a one year time horizon.

To include a credit option rather than simply starting the model with a quantity of operating capital would be interesting especially to see if farmers prefer low interest credit (9%) from the national development bank which has a lag time of about two months or higher interest credit (14%) from the local cooperative which is more timely. This option is not included because the model has been developed in such a way that credit is only needed in the first period. This would force the choice of obtaining credit from the local cooperative.

Conclusion

Given the purpose of this model, to determine if the use of a scallion rotation is feasible on a small farm, the limitations mentioned above are probably not critical. To view the farmers as primarily commercial in orientation rather than as some combination of commercial and subsistence in motivation is probably satisfactory because subsistence needs are expressed in monetary terms and the farmers in this region are well integrated into the wider economy.

A 17 percent drop in monetary income as a result of the scallion rotation may seem like too large a decrease for the average family to take. Yet, the model only considers alternative crops planted with modern technologies which, in fact, were found to yield higher than average family incomes. If income after rotation were compared with income at present using traditional technologies, the difference would be much smaller and net incomes equivalent to current levels would be likely. Moreover, sustained yields for scallions cannot be expected unless some form of crop rotation is followed.

The fact that scallion rotation is feasible given the constraints of operating capital and family consumption requirements gives hope for the scallion growers of Píllaro and their ability to continue to provide for their families through farming despite their limited resources of labor, capital and land.

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APPENDIX

Complete Matrix
of the
Polyperiod Linear Programming Model*
of
Small Scallion Farmers, Ecuador, 1980

* With rotation requirement.

Activities / Constraints	NEGL	ONION1	PONION1	HONION3	PPOT1	PBAR1	HDCORN3	PPEA1	FALLOW1	HRLAB1	SELLAB1	BEGCAP1	DEMANDH1	DEMANDP1	SAVING1	CAPINV1	ONION2	PONION2	CONION1	PPOT2	COPOT1	PBAR2	COBAR1	PCORN2	PPEA2	HPEA1	FALLOW2	HRLAB2	SELLAB2	DEMANDH2	DEMANDP2	SAVING2	CAPINV2	ONION3	PONION3	CONION2	HONION1
		Period 1: January 15 - March 31															Period 2: April 1 - June 15																	Period 3:			
1. OBJFUNC (OBJ)	N	6800	-5000	8800	-3740	-1200	11050	-1950	0	-70	50	0	-1	-1	0168	0	6800	-5000	-200	-3740	-450	-1200	-150	-1660	-1950	7850	0	-70	50	-1	-1	0168	0	6800	-5000	-200	7800
2. POT	G				1															1																	
3. CORN	G																							1													
4. ROTON	E		1															1																	1		
5. LAND1	E	1	1	1	1	1	1	1	1																												
6. LABOR1	L	21	57	22	17	7	17	16		-1	1																										
7. RETURN1	E	r		r			r						-1			-1																					
8. COST1	E		r		r	r		r		r	r	1		-1	-1																						
9. DEMAND1	E												1	1																							
10. BEGCAP	E											1																									
11. MAXDH1	L												1																								
12. ON1	E	1	1	1																																	
13. LBAR1	L					1																															
14. LPOT1	L				1																																
15. LPEA1	L							1																													
16. LAND2	E																1	1	1	1	1	1	1	1	1	1	1										
17. LABOR2	L																21	57	14	17	10	7	2	16	16	16		-1	1								
18. RETURN2	E																r									r				-1			-1				
19. COST2	E														1+r	1		r	r	r	r	r	r	r	r			r	r		-1	-1					
20. DEMAND2	E																													1	1						
21. MAXDH2	L																													1							
22. ON2	E																1	1	1																		
23. LBAR2	L																					1															
24. LPOT2	L																			1																	
25. LPEA2	L																								1												
26. LCOR2	L																							1													
27. LAND3	E																																	1	1	1	1
28. LABOR3	L																																	21	57	14	22
29. RETURN3	E																																	r			r
30. COST3	E																															1+r	1		r	r	
31. DEMAND3	E																																				
32. MAXDH3	L																																				
33. ON3	E																																	1	1	1	1
34. LBAR3	L																																				
35. LPOT3	L																																				
36. LPEA3	L																																				

Note: In the rows labeled "Return" or "Cost", the letter "r" stands for the contribution margin (positive or negative) of each productive activity as shown by the objective function coefficient in the column representing that activity.

June 16 - August 31																	Period 4: September 1 - January 14																				
PPOT3	HPOT1	COPOT2	PBAR3	HBAR1	COBAR2	PCORN3	COCORN2	PPEA3	HPEA2	FALLOW3	HRLAB3	SELLAB3	DEMANDH3	DEMANDP3	SAVING3	CAPINV3	ONION4	HONION2	CONION3	HPOT2	HPOT3	HBAR2	HBAR3	HSCORN2	HSCORN3	HDCORN2	COCORN3	HPEA3	FALLOW4	HRLAB4	SELLAB4	DEMANDH4	DEMANDP4	SAVING4	CAPINV4	RHS	Constraint Number
-3740	14700	-450	-1200	4760	-150	-1660	-340	-1950	7850	0	-70	50	-1	-1	.0168	0	13300	14800	-400	24700	24250	4760	4610	17860	17620	11050	-340	9850	0	-70	50	-1	-1	.0302	0		1.
1																																				1	2.
						1																														.5	3.
																																				.5	4.
																																				4	5.
																																				60	6.
																																				0	7.
																																				0	8.
																																				10000	9.
																																				6000	10.
																																				5000	11.
																																				2	12.
																																				1	13.
																																				1	14.
																																				1	15.
																																				4	16.
																																				60	17.
																																				0	18.
																																				0	19.
																																				10000	20.
																																				5000	21.
																																				2	22.
																																				1	23.
																																				1	24.
																																				1	25.
																																				1	26.
																																				4	27.
1	1	1	1	1	1	1	1	1	1	1																										60	28.
17	13	10	7	13	2	16	8	16	16		-1	1																								0	29.
	r			r					r				-1			-1																				0	30.
r		r	r		r	r	r	r			r	r		-1	-1																					10000	31.
													1	1																						5000	32.
													1																							2	33.
																																				1	34.
			1																																	1	35.
1																																				1	36.
								1																													

Period 1: January 15 - March 31 | Period 2: April 1 - June 15

Constraints \ Activities	NEGL	ONION1	PONION1	HONION3	PPOT1	PBAR1	HDCORN3	PPEA1	FALLOW1	HRLAB1	SELLAB1	BEGCAP1	DEMANDH1	DEMANDP1	SAVING1	CAPINV1	ONION2	PONION2	CONION1	PPOT2	COPOT1	PBAR2	COBAR1	PCORN2	PPEA2	HPEA1	FALLOW2	HRLAB2	SELLAB2	DEMANDH2	DEMANDP2	SAVING2	CAPINV2	ONION3	PONION3	CONION2	HONION1
37. LCOR3	L																																				
38. LAND4	E																																				
39. LABOR4	L																																				
40. RETURN4	E																																				
41. COST4	E																																				
42. DEMAND4	E																																				
43. MAXDH4	L																																				
44. MXSELAB4	L																																				
45. CAPINV	G																																				
46. ON4	E																																				
47. O1	E	1																																			
48. O33	E		-1															-1																			
49. POT1	E			1																																	
50. BAR1	E				1															-1																	
51. CORN33	E					-1																-1															
52. PEA1	E						1																														
53. O11	E																								-1												
54. O2	E																	1																		-1	
55. POT11	E																1																		-1		
56. POT2	E																			1																	
57. BAR11	E																		1																		
58. BAR2	E																					1															
59. CORN2	E																				1																
60. PEA2	E																						1														
61. POT22	E																							1													
62. O22	E																																				
63. O3	E																																	1			
64. POT3	E																																1				
65. BAR22	E																																				
66. BAR3	E																																				
67. CORN22	E																																				
68. CORN3	E																																				
69. PEA3	E																																				

Note: In the rows labeled "Return" or "Cost", the letter "r" stands for the contribution margin (positive or negative) of each productive activity as shown by the objective function coefficient in the column representing that activity.

June 16 - August 31

Period 4: September 1 - January 14

PPOT3	HPOT1	COPOT2	PBAR3	HBAR1	COBAR2	PCORN3	COCORN2	PPEA3	HPEA2	FALLOW3	HRLAB3	SELLAB3	DEMANDH3	DEMANDP3	SAVING3	CAPINV3	ONION4	HONION2	CONION3	HPOT2	HPOT3	HBAR2	HBAR3	HSCORN2	HSCORN3	HDCORN2	COCORN3	HPEA3	FALLOW4	HRLAB4	SELLAB4	DEMANDH4	DEMANDP4	SAVING4	CAPINV4			RHS	Constraint Number
						1																																1	37.
																	1	1	1	1	1	1	1	1	1	1	1	1	1									4	38.
																	30	29	26	13	23	13	15	9	17	17	8	16		-1	1							132	39.
																	r	r		r	r	r	r	r	r	r		r				-1			-1			0	40.
															1+r	1			r								r			r	r		-1	-1				0	41.
																																1	1					22000	42.
																																1						17000	43.
																															1							40	44.
																																		1+r	1			6000	45.
																	1	1	1																			2	46.
																																						0	47.
																			1																			0	48.
																																						0	49.
																																						0	50.
																											1											0	51.
																																						0	52.
																																						0	53.
																																						0	54.
	-1																																					0	55.
		-1																																				0	56.
				-1																																		0	57.
					-1																																	0	58.
							-1																															0	59.
									-1																													0	60.
		1																		-1																		0	61.
																		-1																				0	62.
																			-1																			0	63.
1																					-1																	0	64.
					1																	-1																0	65.
			1																				-1															0	66.
							1																	-1		-1												0	67.
						1																			-1		-1											0	68.
								1																				-1										0	69.