LEGUME INTERCROPS AND WEED CONTROL IN SUN-GROWN COFFEE PLANTINGS IN THE BOLIVIAN YUNGAS

BY

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Small holder farmers in the Yungas of Bolivia can increase production by applying intermediate technology to sun-grown coffee plantings if marketing constraints are removed and a just price is received for their product.

Natural vegetation cover adversely affected recuperation of mismanaged coffee plants when compared with conscientious weed control programs. Coffee plants with weed control yielded an average of 150% more coffee than a natural vegetation control after 5 years of intensive management. Use of the chemical herbicides paraquat (1,1'-dimthyl-4,4'bipyridinium ion) at 0.6 kg a.i./ha and glyphosate (N-(phosphonomethyl)glycine) at 5.0 kg a.i./ha, applied 5 times a year, did not significantly increase

parchment coffee yields when compared to a glyphosate treatment applied 3 times a year.

Use of chemical herbicides reduced weed control labor requirements by an average of 74%. Although production costs increased 188% with handweeding and an average of 237% with chemical weed control, increased net returns per hectare (283% and 281% respectively) were sufficient to offset the increased costs.

The legume cover crop, *Stylosanthes guianensis* Swartz, did not adversely affect the recuperation of low-producing, mismanaged coffee plants when compared to paraquat and hand-strip weeding. In addition, dry matter production of 4.5 mt/ha/yr fixed approximately 120 kg N/ha/yr.

The grain legumes, lima bean (*Paseolus limensis* Macf.), cowpea (*Vigna unguiculata* (L.) Walp.), soybean (*Glycine max* L.), peanut (*Arachis hypogaea* L.), and pigeonpea (*Cajanus cajan* (L.) Millsp.) yielded 332, 91, 330, 308, and 573 kg/ha when intercropped with recuperating coffee plants the first year. Parchment coffee production and foliar content of N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, and Al were not significantly affected by the intercrop (.05 level) when compared to foliar nutrient levels from a coffee monoculture control.

INTRODUCTION

The two decades prior to the 1970's seemed to indicate an increasing capacity for the world to produce more food more efficiently. Food surpluses, stable or declining food prices, large grain stores, and large amounts of food aid substantiated the belief in this increased production capacity.

In 1972, food prices rose sharply, food shortages developed, food aid shipments declined, and grain stocks fell to dangerously low levels. Diminished food surpluses linked to the energy crisis and droughts sparked world concern that agriculture might be approaching its capacity to produce sufficient food for the growing world population.

By 1974, major studies had been undertaken to assess the world food problem. Low yields were not the only reason for deficient diets among the world's poor. Post-harvest losses, lack of adequate marketing channels and transportation, disease, cultural taboos, and low incomes all were found to contribute to making needed nutrients unavailable to hungry people (Harris and Lindblad, 1978; National Academy of Sciences, 1978).

Many studies, including the United Nation's World Food Conference in Rome, did not find the situation to be as catastrophic as the popular belief of imminent mass starvation. Conclusions were reached indicating more food could be produced and the present supply problems could be corrected over the next decade (Walters, 1975; Whittwer, 1975; Brady, 1977).

Today, starvation is still a serious concern in parts of the world. One segment of the earth's population enjoys a more than adequate diet, while millions more are consigned to almost perpetual hunger due to protein and calorie deficiencies. No simple reason can be given for the current food problems facing a growing world population, nor are the solutions to be found readily (USDA, 1974; Brady, 1977).

It may be feasible to increase agricultural yields with high energy inputs that are derived from fossil fuels, but as energy and petroleum based agrochemical products increase in price, their employment by developing countries will become more difficult. Widespread implementation of energy-intensive agriculture would be a quantum leap for most developing countries and is not to be expected in the near future (Heichel, 1980; Brady, 1981; Harwood, 1981).

Yields are higher in developed countries for all major agronomic crops (FAO, 1980). However, increases have been reported in developing countries when appropriate technology has been employed (Sanchez, 1976).

Reaching the food producers with appropriate technology will be necessary to achieve yield increases to meet the needs of the world. Agricultural development strategies that stress appropriate technology could increase available food significantly in the developing world (Bradfield, 1981; Harwood, 1981).

Cropping system research on small coffee holdings is needed. Intercropping strategies for the small producer that utilize coffee in wide row spacings as an upper story crop with interplantings of annual subsistence, cover, and cash crops can be of particular importance during the establishment of a new coffee planting or during drastic cultural pruning. Intercropping effectively diversifies a establishment of a new coffee plan agricultural production during non-productive coffee growing periods (Mwakka, 1960; Lavabre, 1972; Oladokun, 1980).

Establishment of new or rejuvenation of older plantings is difficult for the small coffee producer in Bolivia. Objectives of this study were to investigate (1) the economic feasibility of a more intensive coffee culture that utilizes fertilizer and chemical weed control and (2) the potential use of leguminous forage and grain crops with sun-grown coffee on the sloping lands of the Yungas to provide additional food and feed, enhance soil fertility, and to aid in weed and erosion control.

LITERATURE REVIEW

Agriculture in Bolivia

Overview

Bolivia is a landlocked South American country located on the Andean Cordillera and the slopes and plains to the east. In 1978, its population was estimated at 5.2 million people living on a land area of 1,098,581 km^2. Historically, its economy has been based on exploitation of non-renewable mineral resources. More recently agricultural production has become more important as mineral resource production decreases.

The country has varied ecological life zones, determined principally by altitude and rainfall, and the agricultural sector presents a diverse and flexible range of possibilities for development. Bolivia is generally divided into 3 agricultural areas: mountains, valleys, and lowlands. Eighty four percent of the population inhabits the mountain plateaus and valleys. Recent development projects have concentrated their efforts in the flat lowland areas where more intensive agricultural systems can be utilized. The Bolivian government has initiated, with foreign economic and technical assistance, colonization programs in an attempt to encourage migration to the lower altitudes and help in the development of arable lands in the underpopulated eastern part of Bolivia (Barja and Gonsalez, 1971; Wennergren and Whitaker, 1975).

The valley areas are climatologically suitable for fruit and vegetable production but small land holdings and land and crop mismanagement account for low yields with most small holder farmers producing at subsistence levels. The implementation of agricultural development programs in the lower mountain valley regions has not been a priority because of interest in colonization and development of the lowland regions. Population pressure and soil fertility decline are encouraging people to migrate to the lower altitudes.

The Yungas is an unusual agricultural area, lower than the high valleys but more precipitous topographically. It is located on the eastern slopes of the cordillera and has climatic conditions favorable for the production of tropical perennial and annual crops.

In the Yungas, major cash crops include coffee (*Coffea arabica* L.), various citrus crops, and coca (*Erythroxylum coca* Lam.). These crops provide cash income to the farmers. Poor yields and low quality (coca excepted) result in low incomes and poor nutritional status. The basic diet consists predominately of root and tuber crops such as cassava (*Manihot esculenta* Crantz), cocoyam (*Xanthosoma sagittifolium* Schott), taro (*Colocasia esculenta* Schott), and the Andean carrot (*Arracacia xanthorrhiza* Bancroft). Plantain (*Musa* spp. L.) and squash (Cucurbita spp. L.) are also consumed in quantity. Broad bean (Vicia fava L.), pea (Pisum sativum L.), and peanut (Arachis hypogaea L.) together provide the principal amounts of protein for the poor families of the area (Barja and Gonsalez, 1971; National Academy of Sciences, 1975).

It is possible to grow maize (Zea mays L.), soybean (Glycine max Merr.), peanut, pea, common bean (Phaseolus spp. L.), and a variety of vegetables. These products are, for the most part, supplied to the Yungas from other agricultural areas of Bolivia via the markets of La Paz (Knoerich, 1969; Guzman, 1976).

Annual production statistics (1979) for selected agricultural products in Bolivia are given in Table 1. Only peanut and pea have yields that are above the world average. Overall, nearly 72% of Bolivia's arable land has not been developed (Wennergren and Whitaker, 1975; FAO, 1980). Low yields, lack of productive agricultural land, credit, and infrastructure development reduce Bolivia's ability to meet its food production demands.

Yungas Soils

Soils of the Yungas are formed from Paleozoic sediments that were uplifted during the formation of the Andes Mountains in the Tertiary Period of the Cenozoic Era. The Paleozoic Block or Eastern Cordillera, that rises to heights of 6,000 m, towers above the Yungas, and igneous intrusions and extinct volcanos contribute to the parent

Table 1. Bolivian agricultural production (1979).

Crop	Area	Production	Yield	
			Bolivia	World
	(ha x 1000)	(mt x 1000)	(kg/ha)	(kg/ha)
Grains				
Rice	72	102	1420	2615
Wheat	87	87	646	1782
Maize	255	255	1298	3271
Quinoa[+]	(15)	(10)	(667)	----
Legumes/Pulses				
Broadbean	11	11	991	1053
Pea (dried)	4	4	1048	1169
Bean (white)	3	3	800	580
Peanut	14	14	1321	1016
Roots and tubers				
Potato	13	800	6154	15503
Cassava	25	300	6040	8748
Arracacha				
Cocoyam		(NO DATA AVAILABLE)		
Taro				

[+]Estimated production figures (Wennergren and Whitaker, 1975).
FAO, 1980

materials forming the soils of the Yungas. Time and weather have converted this parent material to fine lutites and sands (Schlater and Nederhoff, 1966).

The soil survey conducted by the British Agricultural Mission in Bolivia and led by Thomas Cochrane include a detailed mapping of land systems that is based on similar characteristics of topography, vegetation, soils and climate (Cochrane, 1973). It is a method that was developed and used in Australia by Christian and Stewart (1953).

Montenegro (1979) considers the Yungas soil to be fertile initially but nutrient depletion occurs rapidly through mismanagement. The continuous cropping of the steeply sloped lands contributes to severe erosion and loss of fertility. He also mentions the constant burnings that are practiced that prevent the establishment of shrubs and other woody perennials, increasing the rate of erosion.

Several short term consultants for the University of Florida/State Department Contract have commented on the soils of the Yungas.

Abruna (1976) described the topography as undulating to mountainous and classified the deep red, leached, acid soils with good physical structure as Ultisols and the severely eroded, shallow soils as younger Inceptisols. For fertilizer trials in coffee he recommended additions of nitrogen, phosphorus, potassium, and magnesium.

Guzman (1976), commenting on vegetable production in the area, after reviewing available soil data, concluded the soils would require liming to be productive because of the low pH (4.6-5.2). Addition of nitrogen, phosphorus, and potassium was recommended to enhance fertility and improve production.

A more thorough study was conducted by Calhoun (1976) in which soil samples were collected and analyzed at the University of Florida (Tables 2, 3, and 4). The soils were described as being derived from acid slates, shists, and sandstones and classed as loams. Clay content was in the 20-25% range with an available water capacity of between 15 and 20%.

Exchangeable calcium was low, exchangeable magnesium was not necessarily a problem except in one area sampled, and exchangeable potassium was adequate for most field crops.

The Yungas soils were found to contain about 700 ppm total phosphorus; however, available phosphorus was low. Soil reactions averaged about pH 5.0 in water and indicated the need for liming.

Blue (1977) commented on the results of the soil analysis and found indications of aluminum toxicity in several of the Yungas samples. He also concluded reduced solubility of phosphorus was due to high levels of aluminum and iron. He recommended field trials that included several levels of a 2-1-1 fertilizer ratio for nonlegumes and suggested that K might not be needed initially.

Table 2. Some physical characteristics of soils from 6 selected areas[+] in the Yungas of Bolivia.

Soils	Horizon	Sand	Silt	Clay	Texture
		---------	%	---------	
Coroico (Lower Station)	A	30.6	45.7	23.7	Loam
Coroico (Lower Station)	B	14.8	46.1	39.1	Silty Clay Loam
Coroico (Upper Station)	A	13.2	68.6	18.2	Silt Loam
Coroico (Upper Station)	B	31.0	57.7	15.3	Silt Loam
San Pablo	A	18.5	45.8	35.7	Silty Clay Loam
Carmen Pampa	A	16.4	57.8	25.8	Silt Loam
Chulumani	A	37.6	43.7	18.7	Loam
Irupana	A	28.8	47.5	23.7	Loam

[+]A composite sample from each location was analyzed in duplicate.

Source: Calhoun, 1976.

Table 3. Organic matter, nitrogen, and pH of soils from 6 selected areas[+] in the Yungas of Bolivia.

Soils	Horizon	pH		Organic Matter	Nitrogen[‡]
		H_2O	1N KCl		
				----------%----------	
Coroico (Lower Station)	A	5.3	4.6	3.2	0.18
Coroico (Lower Station)	B	5.0	3.7	2.2	0.12
Coroico (Upper Station)	A	3.9	3.7	18.9	1.07
Coroico (Upper Station)	B	4.8	4.8	3.3	0.19
San Pablo	A	5.1	4.0	4.3	0.24
Carmen Pampa	A	4.8	3.9	11.6	0.66
Chulumani	A	6.0	5.1	3.4	0.19
Irupana	A	4.7	4.0	5.9	0.51

[+]A composite sample from each location was analyzed in duplicate.
[‡]Percent N derived from organic matter (1:17.65 conversion).
Source: Calhoun, 1976.

Table 4. Some chemical characteristics of soils from 6 selected areas in the Yungas of Bolivia.

Soils+	Horizon	NH_4OAC (pH 7.0) Ca	Mg	Na	K	Sum	KCl Al	NH_4OAC P
		meq/100g						ppm
Coroico (Lower Station)	A	4.92	1.34	0.01	0.26	6.53	0.33	0.0
Coroico (Lower Station)	B	0.92	0.57	0.03	0.21	1.73	4.44	0.0
Coroico (Upper Station)	A	0.32	0.19	0.05	0.38	0.94	13.35	0.0
Coroico (Upper Station)	B	0.05	0.05	0.05	0.13	0.28	1.17	0.0
San Pablo	A	1.90	0.59	0.01	0.30	2.87	2.17	0.0
Carmen Pampa	A	3.41	1.54	0.01	0.64	5.60	2.84	0.0
Chulumani	A	2.75	3.31	0.03	0.49	6.58	0.00	0.0
Irupana	A	2.24	1.14	0.05	0.54	4.27	0.78	1.4

+A composite sample from each location was analyzed in duplicate.
Source: Calhoun, 1976.

Fertilizer recommendations for sun-grown coffee made by the British in the early 1970s were preliminary and not based on actual field trials. Nitrogen and phosphorus applied as ammonium phosphate (18-46-0) at a rate of 64 kg/ha of fertilizer was recommended for new plantings, three months after transplanting to the field. Potassium was considered to be present at sufficient levels for proper growth. Subsequent applications of ammonium nitrate in November and Februrary in increasing yearly increments of 64, 128, and 256 kg/ha was considered an adequate fertlization schedule until field trials in different coffee growing zones in the Yungas could be performed (Ballantyne *et al.*, 1971; Penn, 1972).

Agriculture In The Yungas

Yungas is an Aymara word for valley and describes the steeply sloped mountains cut by the Rio Coroico, Rio La Paz, and Rio Beni. The Yungas area ranges from Subtropical Premontane Wet Forest to Subtropical Lower Montane Moist Forest according to the Holdridge classification of world life zones (Unzueta, 1975). Ecological zone transitions are sharp. Temperature and precipitation change with elevation but moisture is also drastically affected by precipitation shadow effects (McCloud, 1976).

Mean annual temperatures range from 18-25 C in the lower areas and 15-20 C in the higher valleys. Crops are grown at altitudes ranging from 600 m above sea level to close to 2000 m (Barja and Gonsalez, 1971; Unzueta, 1975).

The agreeable climate attracts vacationers from the higher altitudes and historically its mineral and agricultural potential have been exploited. Landslides and flooded land near rivers during the rainy season (November - March) make transportation uncertain and, consequently, agriculture production has evolved towards products that are light in weight and stable. Citrus is an exception to this general statement (Figueras, 1978).

Many of the small farms in the area appear relatively prosperous with well-kept buildings but utilization of agronomic crops in small multiple-cropped gardens appears to supplement the household rather than be a source of subsistence production (McCloud, 1976).

The development of small farmer agriculture in the Yungas followed the National Revolutionary Movement (MNR) revolution led by Paz Estenssoro in April 1952. The Agrarian Reform Law of 1953 completely altered land tenure by dividing the large pre-revolutionary period hacienda land holdings among the Indian peasants (Heath, 1973; Graeff, 1974; Leons, 1975).

Absentee land ownership predominated prior to the revolution, with coca, coffee, and citrus as the main agricultural cash crops. Labor to manage the extensive coca crop was reduced and less coca was produced following the revolution, as land was parceled to the Indians (<u>colonos</u>) bound to the hacienda lands. The Bolivian <u>campesino</u>, as the Indian was now called, lacking necessary agricultural and marketing skills, found it difficult to integrate successfully into the new posthacienda market economy. Abuses by former hacienda owners confused and alienated the recently freed Indians and seriously retarded the development of a viable small farm agricultural system (Heath, 1973; Graeff, 1974; Cullen, 1980).

Ten years after the agrarian reform, the situation had stabilized with a new order of chollos and former hacienda owners controlling the marketing of agricultural products. Chollos were former colonos that had migrated to the towns in the Yungas from the haciendas to become urban dwellers. This new "chollo" class entered into business, trades, or became domestics.

The new order did not improve the condition of the campesinos, to any great extent. The Bolivian government began efforts in the 1960s to improve the conditions of the small farmer through organized development projects.

Coffee Production in Bolivia

The decision by the British Agricultural Mission in 1965, to organize and improve export crops in the Yungas was of considerable impact. A survey was made in that year to study the various cash crops produced in the area. Originally tea (*Camellia sinensis* L.) and cacao (*Theobroma cacao* L.) were considered to be the crops of emphasis. It was decided, however, after coffee samples (*C. arabica* cultivars) were processed and sent to London for evaluation and found to be of premium quality, to develop the coffee producing potential of the Yungas for export markets in London, New York, and South Africa.

An ambitious coffee processing and marketing cooperative program was initiated by the British and United States governments that included technical assistance by both British agricultural officers and cooperative training by the US Peace Corps (Cullen, 1980).

Coffee, during the period 1962-1972, was the principal agricultural export of Bolivia, averaging 31% of the total. The Department of La Paz produced about 98% of the total national production with about 80% coming from the North Yungas Province (Figueras, 1976).

Coffee farming in Bolivia is exclusively a small farmer operation with less than 2 hectares dedicated to the enterprise on farms ranging from 1-5 hectares. The small coffee producer in Bolivia is characterized as (1) lacking technical knowledge on coffee culture; (2) producing a final product of variable quality due to primitive processing; and (3) receiving very little for his product because of the marketing structure and its constraints (Figueras, 1976; Buitrago, 1979; PRODES, 1979; Hanrahan _et al_., 1980).

Over 65% of the coffee plantings are old and poor producers with poor management the general rule. Figueras (1976) surveyed the coffee situation and concluded that yield data were extremely unreliable. Estimates range from

6 to 20 quintales (100 pounds in Bolivia, abbreviated qq) of dry parchment coffee per hectare. Probably the most reliable figure has been established by the Asociacion Nacional de Productores del Cafe (ANPROCA) (a Bolivian coffee growers association) from data obtained from its members (Vera, 1980). ANPROCA membership includes about 50% of the farmers if one assumes that there are between 15,000 and 20,000 families actively involved in coffee production in Bolivia. The average ANPROCA member farmed 1.7 ha and had a yield of 8.4 qq/ha of dry parchment coffee. Presently, the lack of economic incentives discourages cultural practice improvement (Buitrago, 1979; Hanrahan *et al.*, 1980).

The trend in coffee production and the amount exported from Bolivia during the period 1971-1980 are shown in Table 5. The appearance of coffee leaf rust (*Hemileia vastatrix* Berk & Br.) in 1978 could change the significance of the trend in the future.

Coffee production statistics for the year 1976 are summarized in Table 6 (Figueras, 1978). The North Yungas Province produces more than half of the coffee grown in the the La Paz Department. Yields are given in quintales of parchment coffee per hectare. The yields appear somewhat higher than more recent data (Vera, 1980) and more likely represent *corriente* coffee (30-40% moisture).

Table 5. Bolivian coffee production and exports 1971-1980.

Year	Production	Exports
	(mt)	(mt)
1971	12,000	-----
1972	13,000	-----
1973	13,000	-----
1974	14,000	3,164
1975	16,000	5,200
1976	18,000	4,798
1977	22,000	4,465
1978	22,000	5,750
1979	17,000	7,528
1980	23,000	5,500

Source: FAO Production Year Book 1971-1980.

Table 6. Production, area, and yield of parchment coffee in Provinces of the Department of La Paz, 1976.

Province	Production	Percent	Area	Yield
	(qq)	(%)	(ha)	(qq/ha)
North Yungas	147,000	56.5	8,300	17.7
South Yungas	97,200	37.4	6,400	15.2
Inquisivi	4,300	1.9	350	12.5
Franz Tamayo	6,500	2.5	550	11.8
Total	260,000	100.0	16,000	

Source: Figueras, 1978.

Weed Control

It is estimated that weeds cause a loss of at least 11.5% of the world's food crop each year and these losses are greater in crop production systems that are primitive or intermediate in technology (Parker and Fryer, 1975). Weed control has become one of the most costly cultural practices in tropical agriculture. Effective control of weeds is considered the major factor influencing crop yield as compared to other forms of pest control. Competition for needed nutrients, moisture and sun light by weeds can reduce yields drastically. Experiments in Kenya and elsewhere have demonstrated the importance of weed control in coffee. Annual production in coffee was doubled (750 kg/ha) in weed free plots compared to plots cleared twice a year (345 kg/ha) (Reynolds, 1968). Jones and Wallis (1963) found similar reductions in yield and also a reduction in coffee quality if weeds were not hand cleared during the rainy season.

However, on steeply sloping lands where heavy rainfall is common, erosion can be costly if weed control practices bare the soil and allow precious topsoil to be carried away. Soil-erosion experiments at Chinchina, Colombia where designed to compare clean cultivation by hoeing, slashing by machete, mowed pasture cover, and use of terraces, silt pits and shade in coffee plantings of varying slopes. Monthly clean hoeing produced the greatest loss of topsoil when compared to the other strategies. Erosion was less on mowed pastures and machete slashed plots and also decreased when the interval between treatments was increased to three months. Erosion was nil in plots with well established shade and terraces and silt pits loss only slightly more than the shade plots (Suarez de Castro, 1951).

Grasses and sedges, particularly the former having subterranean rhizomes (e. g. Imperata cylindrica Beauv., Panicum repens L., Cynodon dactylon (L.) Pers. and Cyperus esculentus L.) are weed problems that are not controlled with traditional methods.

It is important to consider (1) the maintanence of an adequate cover and (2) the composition of the weed flora when implementing a weed control program. The program should minimize weed competition but not at the expense of good erosion control. Clean weeding around young plants with mulching and slash mowing or a knock-down herbicide around older plants are recommended (Ochse et al., 1961).

Manual weed control, in developing countries, can be one of the most costly inputs made into a system, no matter how primitive. While effective and generally always performed, the manual removal of weeds depends on an adequate labor supply. Labor conflicts during peak harvest periods can reduce the ability to control weeds effectively and therefore, be less effective (Parker and Fryer, 1975; Figueras, 1978).

High rainfall conditions in tropical areas cause serious problems with weed control. Traditional forms of weed control may favor the growth of problematic perennials (Rincon, 1961). Herbicides can help peasant farmers by increasing yields from improved and more timely weed control, releasing labor from time consuming manual weeding for cultivation of other crops or increased land use (Hammerton, 1974).

A small farmer, without sufficient funds or credit, is denied access to intermediate technology now available in weed control and other aspects of crop culture. Ignorance and lack of proper training and advisement also keep him from incorporating new research findings into his small business enterprise. (Figueras, 1976; Hanrahan et al., 1980).

Coffee culture in the Yungas is primarily a shade culture. The utilization of shade reduces weed growth and the need to expend much energy for their control. However, shade culture is not as productive as coffee grown in the sun. The use of higher technology methods becomes practical when high yields are considered. Utilization of chemical herbicides can free labor for other cultural practices such as pruning and harvesting in addition to being more effective.

So important is weed control in sun-grown coffee that research in this area has become more prevalent during the last 2 decades. The use of herbicides is being incorporated into research programs at experiment stations and universities in the major coffee producing areas of the world. Labor cost is so high in some areas that more efficient means of weed control are constantly being sought.

Weeds are a problem in coffee plantations. Grasses predominate in new plantings but give way to broadleaf weeds as coffee trees mature. Wellman (1961) discusses weeds of the *Gramineae* prevalent in Angola, India, Java, and the Philippines and cites bermudagrass (*Cynodon dactylon* (L.) Pers.) and *Paspalum fasciculaum* Willd. ex Fluegge as serious weeds in Central America. Mitchell (1968) categorized *Digitaria scalarum* Chiov. and *Cynodon dactylon* (L.) Pers. as problem weeds in Kenya. Diuron (3-(3,4-dichlorophenyl)-1,1-dimethylurea) and linuron (3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea) (2.5 kg/ha) were used to control *Digitaria sanguinalis* (L.) Scop. in Brazil (Leiderman *et al.*, 1968).

Wellman (1961) discusses the problem of erosion and weed control. Evidence suggests chemical control of weeds causes less disturbance of the soil than hand or mechanical weeding (Uribe, 1971;Mondardo *et al.*, 1977; Lavabre, 1978).

Herbicides have given very good results in controlling weeds in established coffee plantings. Applications of 2,4-D (2,4-dichlorophenoxy acetic acid) or simazine (2-chloro-4,6-bis(ethylamino)-s-triazine) (2 kg/ha) gave excellent control (90%) in Brazil. Reducing the quantity by one-half and spraying on cleaned plots was more effective than traditional weeding methods. Simazine was twice as effective as 2,4-D (Medcalf and de Vita, 1969).

Glyphosate (N-(phosphonomethyl)glycine) used at rates of 0.62, 1.24, and 2.48 kg/ha controlled weeds effectively and was especially effective in controlling *Cyperus rotundis* L. in coffee plantings in Brazil. The medium rate gave slightly better control than the higher rate (Siqueira and Teixeir, 1977).

Foster and Green (1968) found paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) effective against *Digitaria* spp. and *Portulaca* spp. when a surfactant was added. However, 90% of 4-year-old coffee trees died when bromacil (5-bromo-3-sec-butyl-6-methylracil) (5 lb/A) was added to the paraquat (0.25 lb/A) (Blore, 1965).

Cover Crops

Lavabre (1972) reviewed the literature and concluded that weeds could be controlled in coffee with the judicious use of cover crops. However, the literature also shows that cover crops can be detrimental to coffee culture (Ochse *et al.*, 1961; Wellman, 1961; Haarer, 1962).

Calopagonium and *Centrosema* retarded vegetative growth of young coffee trees in Malaysia and *Desmodium ovalifolium* (Prain) Wall. ex Ridley has been reported to be detrimental to coffee production in Costa Rica (Wellman, 1961). However, *Pueraria phaseoloides* Benth., *Centosema pubescens*

Benth., Calopogonium caeruleum Desv., and Mucuna cochinchinensis Adans have been used successfully in rubber (Hevea brasiliensis Muell.) and Oil Palm (Elaeis guineensis Jacq.) to control weeds (Teoh et al., 1978; Liu Sin, 1979). Oladokun (1980) reported on the same legumes and Vigna unguiculata (L.) Walp. used in the establishment of robusta coffee.

Thirty-seven tropical legumes were screened for tolerance to acid soil. Stilozobium deeringianum P., Dolichos lablab L., Cajanus cajan Millsp., and Crotalaria spectabilis Roth were selected on the basis of adaptation in Colombia (Suarez-Vasquez, 1975).

Trials performed in Cameroon with Arabian coffee showed creeping covers did not significantly increase coffee yields. In addition, Stylosanthes spp. did not adequately control weed encroachment and Mimosa spp. increased fire risk and competed for moisture (Bouharmont, 1979). However, earlier work showed the same cover crops gave increased yields in robusta coffee over natural cover (Bouharmont, 1978).

Grain Legumes

Protein deficiencies in developing countries are common. Agricultural research has directed its energies toward the cereal grains for the most part, which are lower in protein content and quality. Research has been done on certain grain legumes, e.g. peanut and soybean; however, many less well-known crops could supply needed vegetable protein in the diets of hungry people if research were directed to their cultivation (National Academy of Sciences, 1979).

Grain legumes (pulses) are surpassed only by the cereal crops as sources of food. Nutritionally, they are richer in protein than cereal grains and also may be excellent sources of oil (peanut and soybean). Many grain legumes are used as food in specific locations but they may not be widely consumed (Berry, 1981). Dried common bean (*Phaseolus vulgaris* L.) is very common in Central and South America. Cowpea (*Vigna unguiculata* (L.) Walp.), lima bean (*Phaseolus limensis* Macf.), lentil (*Lens esculenta* Moench), broad bean (*Vicia faba* L.), pea (*Pisum sativum* L.), chickpea (*Cicer arietum* L.), and pigeonpea (*Cajanus cajan* (L.) Millsp.) are consumed in many parts of Latin America. Soybean (*Glycine max* (L.) Merr.) is more commonly used in the Oriente (Sanchez, 1976).

Successful growth of legumes under primitive management conditions depends, to a great degree, on soil conditions appropriate for growth of bacteria (*Rhizobium* spp.) for symbiotic nitrogen fixation. Highly leached soils with toxic levels of aluminum (greater than 1 ppm) are prevalent in the tropics. Munns and Keyser (1981) studied the effects of acidity and aluminum on synchronous cultures of *Rhizobium* spp. (cowpea group) and found that acidity and Al reduced the frequency of cell division. The reduction in multiplication rate was the effect most important for colonization of soils and roots. Variation among strains of rhizobia is important when selecting for tolerance to soil acidity.

Spain et al. (1975) studied tropical grain legumes on Oxisols in Colombia and found varietal tolerance to acid soils. Cowpea showed greater tolerance than either soybean or field bean. However, black skinned bean showed more tolerance than white or brown varieties. Pigeonpea was also quite tolerant of the acid soil conditions.

Acid soils in the tropics may cause toxic levels of manganese and aluminum to be present in the soil solution. Soybean was found to be effected by high aluminum concentrations but not by low calcium and low pH, suggesting plant sensitivity rather than a rhizobial problem (Munns et al. 1981). Variation among soybean cultivars to managanese deficiencies and toxicities is well documented (Heenan and Carter, 1976: Ohki et al., 1980).

Variation among cowpea cultivars in root growth under nitrogen, phosphorus and potassium deficiencies suggest certain cowpea cultivars can be selected for use in low-technology situations in Nigeria (Adepetu and Akapa, 1977).

Zinc deficiencies are not generally a production problem in peanuts, however, toxic levels of zinc have been reported to reduce plant growth (Reid and Cox, 1973: Keisling et al., 1977).

There was a tendency to higher yields in pigeonpea when pH was raised by liming or adding phosphorus fertilizers to acid soils in Brazil. No advantage to adding nitrogen was found. This suggested yields can be increased on acid soils by reducing the acidity. Zinc uptake was also reduced (Dalal and Quilt, 1977).

The benefits of grass-legume associations for improved pastures have been well documented (Shaw and Norman, 1970; Sanchez, 1976). Results with other legume associations have not been consistent. Nitrogen-fixing capacity, degree of competition, and time of planting have been shown to influence results (Sanchez, 1976).

The use of grain legumes as intercrops in coffee has proven successful in several studies. No effect was measured on coffee growth until the third planting when stumped coffee (drastic pruning) was interplanted with field beans and yields were higher with double-row plantings between trees than single row plantings (Mwakha, 1980). Pigeonpea has been intercropped successfully in new coffee plantings, a good example of the use of a deep-rooted crop between rows of a shallow-rooted one (Llorens _et al._, 1976; Lugo-Lopez and Abrams, 1981).

Tree Intercrops

Intensive, high yielding agricultural production systems are highly energy dependent and do not reflect the native ecological communities in which they coexist.

Extensive, low-yielding cropping systems, more prevalent in developing countries, mimic to a greater degree the natural ecological communities that surround them.

Traditionally, sequential and intercropping strategies have been used by small holder farmers in many developing countries to survive under conditions of scarce land and monetary capital, unfavorable price structures, and unsophisticated markets and infrastructure. Growing rain-fed crops in mixtures has proven to be a way for the small farmer to maintain a relatively stable, low production, marginal income enterprise while minimizing economic risk.

Future food demand pressures require that these relatively low producing farms supply more food to both the rural and urban population centers. Research to upgrade these farming systems requires emphasis at both the farm and infrastructure levels to achieve stable increases in the world food supply (Andrews and Kassam, 1976; Brady, 1977).

Understanding the basic plant interactions in these mixed systems will be necessary to make sound recommendations to the small holder farmer. The effects of the interactions on the physiology of the crops recommended will be the major influencing factor on crop yield (Andrews and Newman, 1970; Andrews and Kassam, 1976; Schrader, 1980; Bradfield, 1981).

The use of companion crops in perennial tree crops is becoming a common practice in many parts of the world. Probably the most studied crop is rubber. Long establishment periods make it economically practical to consider catch cropping, the simultaneous cultivation of crops other than the principal stand. Banana and cassava have been grown in young rubber plantings with success (Pillar, 1974). On small holder lands in Malaysia, farmers have economically grown peanut and maize with their rubber (Chee, 1974).

Coconut (*Cocos nucifera* L.) and cacao have been grown with beneficial results in India (Nair *et al.*, 1975) and coconut and oil palm have shown promise together in Malaysia (Denamany *et al.*, 1979). Intercropping coconut plantations with pasture grasses has been studied in the Philippines and is considered a viable means of optimizing land use (Creencia, 1979). Studies with coconut-cacao associations have given good results in the Philippines, also (Creencia, 1979).

Intercropping of citrus is becoming a popular agricultural strategy in India (Sekhon *et al.*, 1977; Nijjar, 1980). Macadamia (*Macadamia ternifolia* F. Muell.) is being considered as a possible shade and diversification crop for Costa Rican coffee (CATIE, 1974). In California, research is being conducted on guava (*Psidium guajava* L.) as a companion crop for avocado (*Persea americana* Mill.) (Sweet, 1979).

Coffee Intercropping Systems

Historically, coffee (*Coffea arabica* L.) has been grown under shade at higher elevations in the tropics. Generally, legume trees are utilized to provide shade for the coffee plants (Coste, 1968; Wellman, 1961; Haarer, 1962).

Alternative strategies are being investigated that incorporate non-Arabian coffee as an intercrop in taller cultivated plants such as rubber, cacao, and coconut (Coste, 1968; Creencia, 1979; Haarer, 1962; Lavabre, 1972; Paillar, 1974). This plantation culture, however, is directed to the large landed agriculturist, e.g. those with 10-30 hectare farms, in many developing countries.

Intercropping coffee during planting establishment and drastic pruning could increase small holder agricultural productivity not only of secondary "catch crops" but also of coffee by improving coffee culture practices.

Low leaf area and small plant size allow considerable solar radiation to reach the soil surface unproductively once land preparation is complete and young coffee seedlings are transplanted to the field. Weed control becomes an important crop management problem at this time to prevent competition with weeds for sunlight, moisture, and nutrients. Cultural inputs to establish and maintain the non-productive plants create a negative cash flow in the farm budget, given the length of time (3-4 years) for the young coffee plants to begin to bear a harvestable crop.

Agro-economic studies in Puerto Rico have shown coffee can be intercropped with plantain (*Musa sp*.) at this stage, generating sufficient returns to net the farmer income after considering the cost of establishment of the planting. The growth of this crop stabilizes the soil and reduces weed management problems in addition to generating a marketable product (Serra *et al*., 1971).

Root extension and plant size no longer permit intercropping once the coffee planting has reached bearing age. The area surrounding the coffee plants may be sown, at this stage, to a legume cover crop for soil fertility maintenance and erosion control. The cover crop also may compete effectively with noxious weed species.

A second period of intercropping is possible after 7-10 years if a drastic pruning of old growth is performed when production begins to decline (Coste, 1968; Chandler *et al*., 1968). High coffee production per tree depends on continued vegetative renewal of the coffee plant. Coffee plant leaf area is greatly reduced, at this point, as in the first 1-3 years of the planting. Lack of ground cover allows the intercropping strategy to be repeated to generate a "catch crop" allowing the coffee field to remain agriculturally productive.

This agricultural system is similar to the small farmers' traditional practices and effectively diversifies his enterprise making him less dependent on coffee as a cash crop. Added benefits include cultivation of vegetable proteins to improve his protein/calorie deficient diet, incorporation of nitrogen fixing plants into his cultural scheme that enhance soil fertility and reduce soil erosion, effective weed control, a reduction in plant pest and disease problems associated with monocultures, and increased production per land unit (Andrews and Kassam, 1976; Bouharmont, 1979; Enyi, 1973; Lavabre, 1972; Mwakka, 1980; Oladokun, 1980).

Malnutrition in Bolivia

Puffer and Serrano (1975) concluded malnutrition, in developing countries, to be the principal cause of mortality in 50% of child deaths before the age of 5. Both gastro-intestinal disease and malnutrition form a vicious cyclic pattern contributing to poor nutritional status and subsequent death. Nutritional studies in Bolivia support these findings and malnutrition is considered serious.

Several factors have been identified in Bolivia that are considered instrumental in predisposing a given population to malnutrition. Variations within a city or rural area can be attributed to social class, eating habits, or the availability of food. Lowland colonization areas are noted for their lack of protein sources and predisposition of children to intestinal parasites. The economic condition of the family in most rural areas, even though protein sources may be produced on the homestead and available such as eggs, chicken, and meat, may force nutritive production to be sold for cash or exchanged in barter, rather than consumed at home (USAID/Bolivia, 1978).

METHODS AND MATERIALS

Site Description

Selection

This research study was conducted on land owned by the San Francisco Xavier Rural School administered by the Xavierian Brothers, a Roman Catholic religious order of working men who devote themselves to education. The school is under the jurisdiction of the Bishop of Coroico.

The location of the Yungas area within Bolivia is depicted in Figure 1. The school is located approximately 15 kilometers southwest of the town of Coroico, on a secondary road that connects Coroico with another North Yungas town, Coripata. The Coroico area is considered the principal coffee growing center of Bolivia. Coripata, located in a somewhat drier climate, is considered the primary coca cultivation area of the Yungas.

The main reason for selecting this area was the historical involvement of the school in coffee research and the stability of the institution. The British Agricultural Mission to Bolivia began its preliminary project in coffee cooperatives at this site in 1963, and established demonstration plots of sun-grown coffee and a coffee wet processing plant. The demonstration plots deteriorated

Fig. 1. Location of experimental site area in Bolivia.

after 1972, due to a lack of fertilization but the coffee cooperative has survived, in spite of the political and financial problems that occurred after the departure of the British.

Another reason for the selection of this site is the availability of labor that is supplied through the rural school. The young, predominately male student body has scheduled field work in vegetable gardening and coffee culture as part of its curriculum.

The school has one of the few producing coffee plantings in Bolivia that is grown in full sun, a remnent of the British attempt to establish sun-grown coffee culture to increase production of the premium quality coffee that can be obtained in the area.

Climate and Soils

The Carmen Pampa site is considered a Subtropical Premontane Wet Forest according to the Holdridge classification of life zones. The school and its agricultural land is located, at an elevation of 1650 m to 2000 m, on the western slope of the mountain Uchumachi (3,000 m). Annual average precipitation and extremes, and average temperature and extremes recorded at the San Pedro de la Loma Agricultural Experiment Station (1972-1980) located approximately 2 kilometers from Carmen Pampa are shown in Figures 2 and 3. The available climatic data are summarized in Table 7.

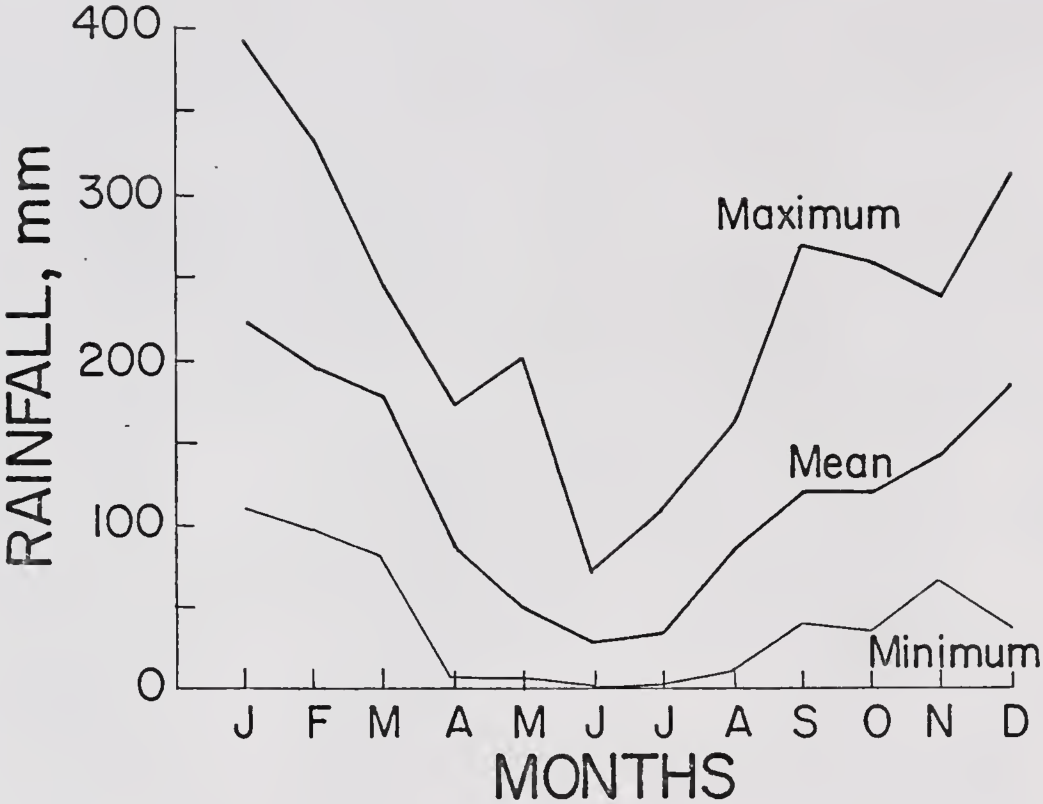

Fig. 2. Mean monthly precipitation and extremes at the San Pedro Experiment Station (1973-1980).

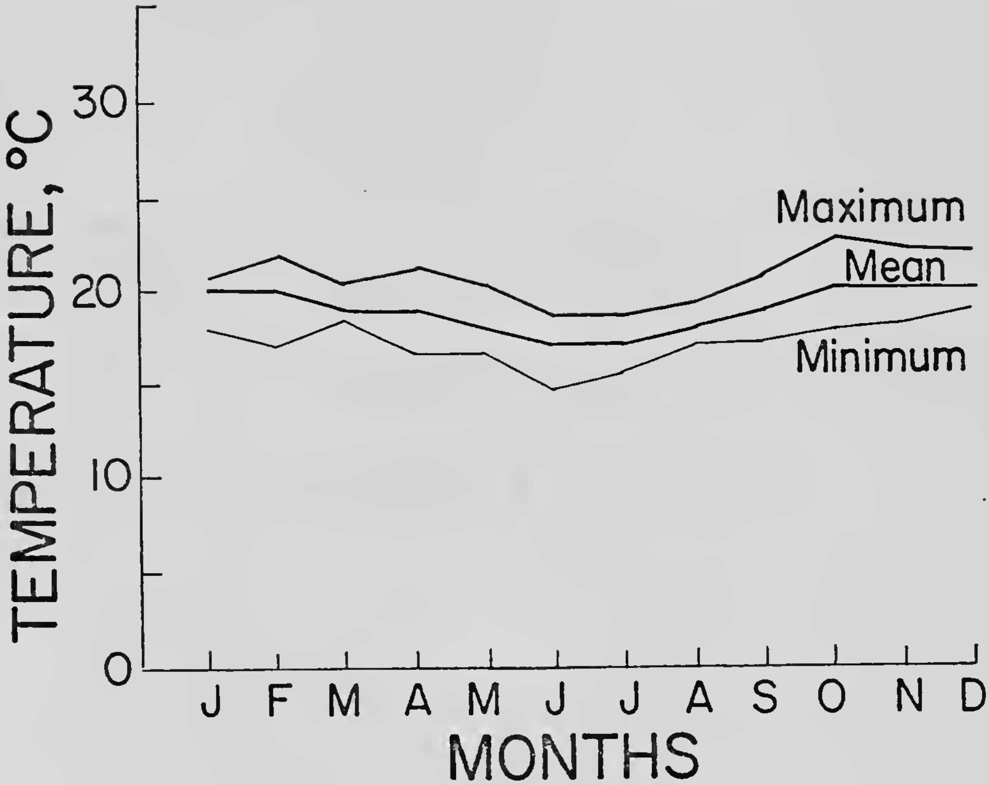

Fig. 3. Mean monthly temperature and extremes at the San Pedro Experiment Station (1973-1980).

Table 7. Summary of climatic factors at Carmen Pampa and the San Pedro Agricultural Experiment Station. (16° 08' S. Latitude, 67° 46' W. Longitude)

Factor	Carmen Pampa	San Pedro
Altitude	1660 m	1740 m
Mean annual temperature	21 C	21 C
Mean maximum	27 C	26 C
Mean minimum	15 C	15 C
Annual precipitation	1941 mm+	1487 mm‡

+Precipitation (Aug-Mar) is 91% of total.
‡Precipitation (Aug-Mar) is 85% of total.
Sources: San Pedro Experiment Station Annual Reports (1979-1980); Hammer, 1980 (unpublished).

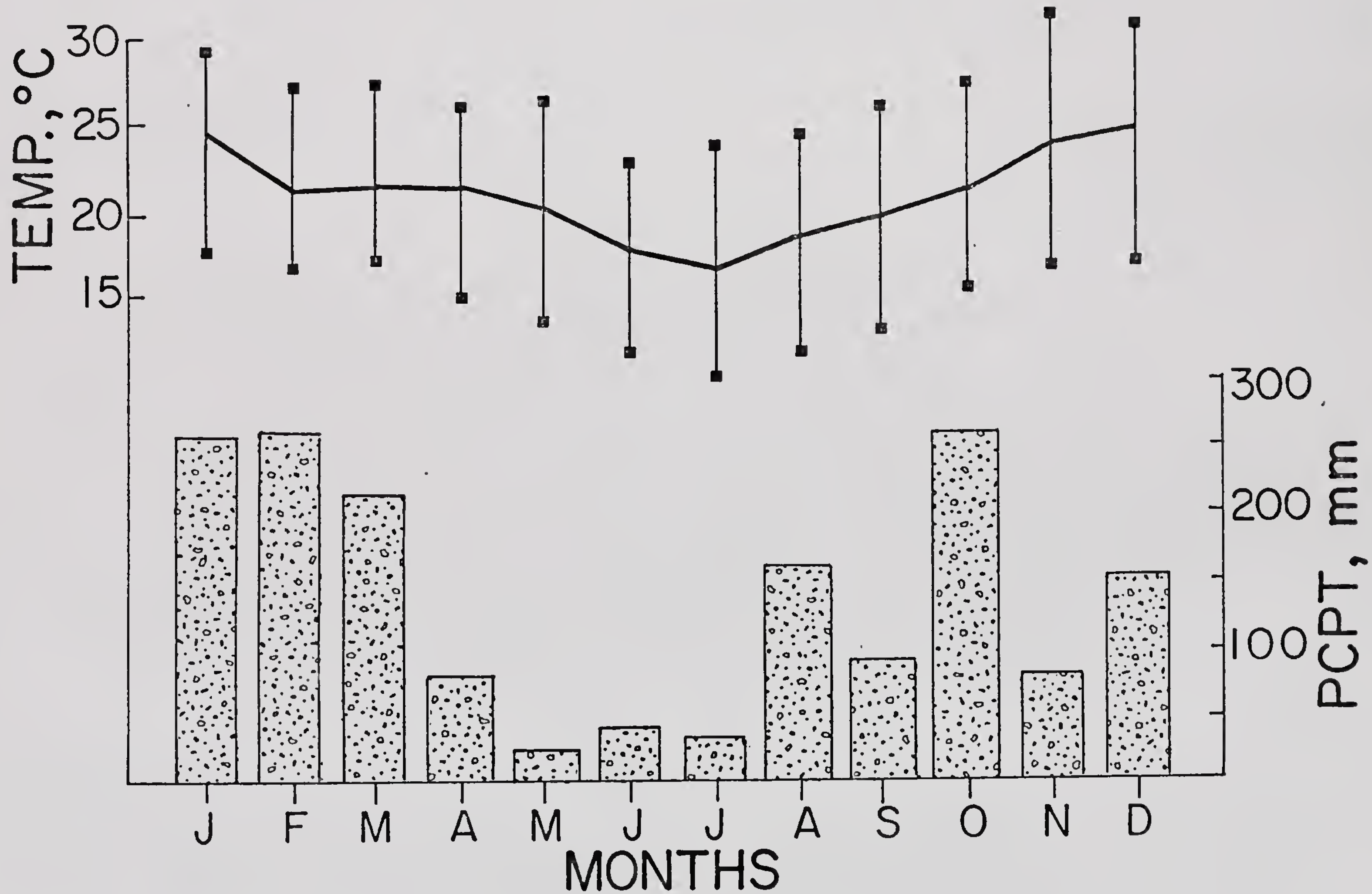

Fig. 4. Mean monthly temperature and extremes and rainfall at Carmen Pampa (1980-1981).

Carmen Pampa may represent a slightly more humid environment although located close to the experiment station. Unofficial records kept at the school indicate slightly more precipitation during the period of the study. In addition, experience at the site suggests topographic considerations influencing rainfall patterns. A nearby ridge appears to prevent movement of rain clouds resulting in rainfalls of longer duration. Travel from the experiment station to the school demonstrated this phenomenon frequently, as one went from sunshine following a rain shower to a heavy rainfall.

Recorded temperatures and precipitation (1980-1981) from Carmen Pampa are presented in Figure 4 and summarized, along with data from San Pedro in Table 7. Differences do not appear to be sufficient to consider different life zones.

Soils in the area around the town of Coroico, capital of the North Yungas Province, located near the area of the present study have been sampled and analyzed. The land system is described as moderately high valleys that are moderate in slope and fine textured. This system (Iil) encompasses an area of 17,000 hectares with altitude ranging from 1,400 m to 2,000 m. Ordovician period sediments predominate.

The soils appear very uniform due to the homogeneous nature of the parent material. Soil depth varies and organic matter content is greater at higher altitudes.

Accelerated erosion was noted at the site. A soil sample, taken approximately 6 kilometers from the study site, was analyzed and the data summarized in Table 8 (Cochrane, 1973). Soils of the site were described in Tables 2, 3, and 4.

Methodology

Philosophy

The main objective of the study was to determine the agro-economic feasibility of sun-grown coffee culture in the Yungas. Recuperation of the old demonstration plots was attempted to obtain relevant cost and production information. Superimposed over the recuperation attempt was a weed control study. In addition, it was considered important to evaluate the possibility of intercropping the recuperating coffee trees during their vegetative growth stage. Shade-grown coffee trees located alongside of the sun-grown plants were monitored to evaluate production.

Records of coffee purchases by the San Francisco Xavier Coffee Cooperative are presented graphically in Figure 5. This is used as a indicator of the coffee harvest period. The cooperative covers 3 communities, Chovacollo, San Cristobal, and Carmen Pampa. Traditionally, field preparation and planting of annual crops occurs in the dry season months of July through September. The end of the coffee season coincides with the traditional planting period (Fig. 5). The bulk of coffee purchased,

Table 8. Chemical characteristics, exchangeable cations, and cation exchange capacity of a soil sample from Coroico, North Yungas.

Soil depth	pH	Elect. Cond.	Free Carbonates	NH_4OAC (pH 7.0) Ca	Mg	Na	K	Acidity	CEC
----cm----		--mmho/cm--	----%---	--------------meq/100 g--------------					
3-10	4.1	35	0	5.3	1.6	0.06	0.35	7.7	15.0
15-25	3.8	14	0	0.5	0.2	0.02	0.15	8.6	9.5
30-40	4.1	5	0	0.2	0.1	0.02	0.10	5.5	5.9

Source: Cochrane, 1973.

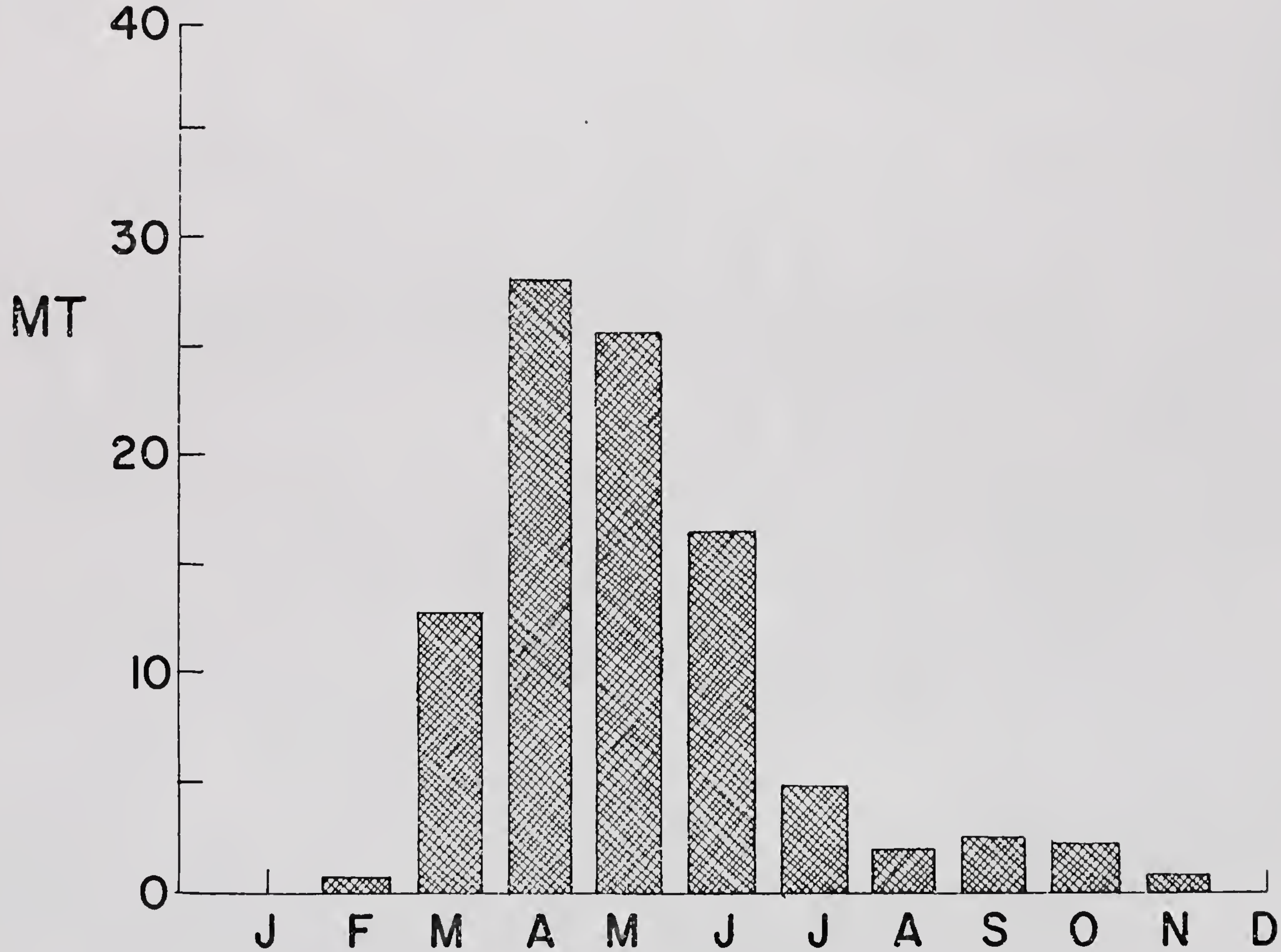

Fig. 5. Coffee purchases (fruit) at the San Francisco Xavier cooperative by month (1980-1981).

however, is produced in Chovacollo located on the east facing slope across the valley from Carmen Pampa. Purchases by the cooperative by community are shown in Figures 6, 7, and 8. Coffee in Carmen Pampa and San Cristobal is harvested in the traditional planting period, which compromises labor distribution and places a severe constraint on diversifying small farmer production in these communities.

An attempt was made in this study to determine the possibility of a later planting, specifically of grain legume crops, during the month of December. Rainfall data suggest that, although the rainy season is beginning, sufficient dry days are available to prepare land and plant. A strong consideration for this late planting is the availability of adequate moisture later in the growing season. Cool weather prolongs pod filling periods in the various legume crops.

Recuperation and Weed Control

Fifteen 16 X 16 m plots containing 16 coffee plants spaced 3 x 3 m were assigned weed control treatments (5) in a randomized block design. Treatment plots were replicated 3 times. Herbicides were applied using a CP3 backpack, hand pumped sprayer with pressure guage. Field labor was instructed in herbicide solution preparation procedures and sprayer calibration. Treatments applied and frequency of application are summarized in Table 9. All trees were

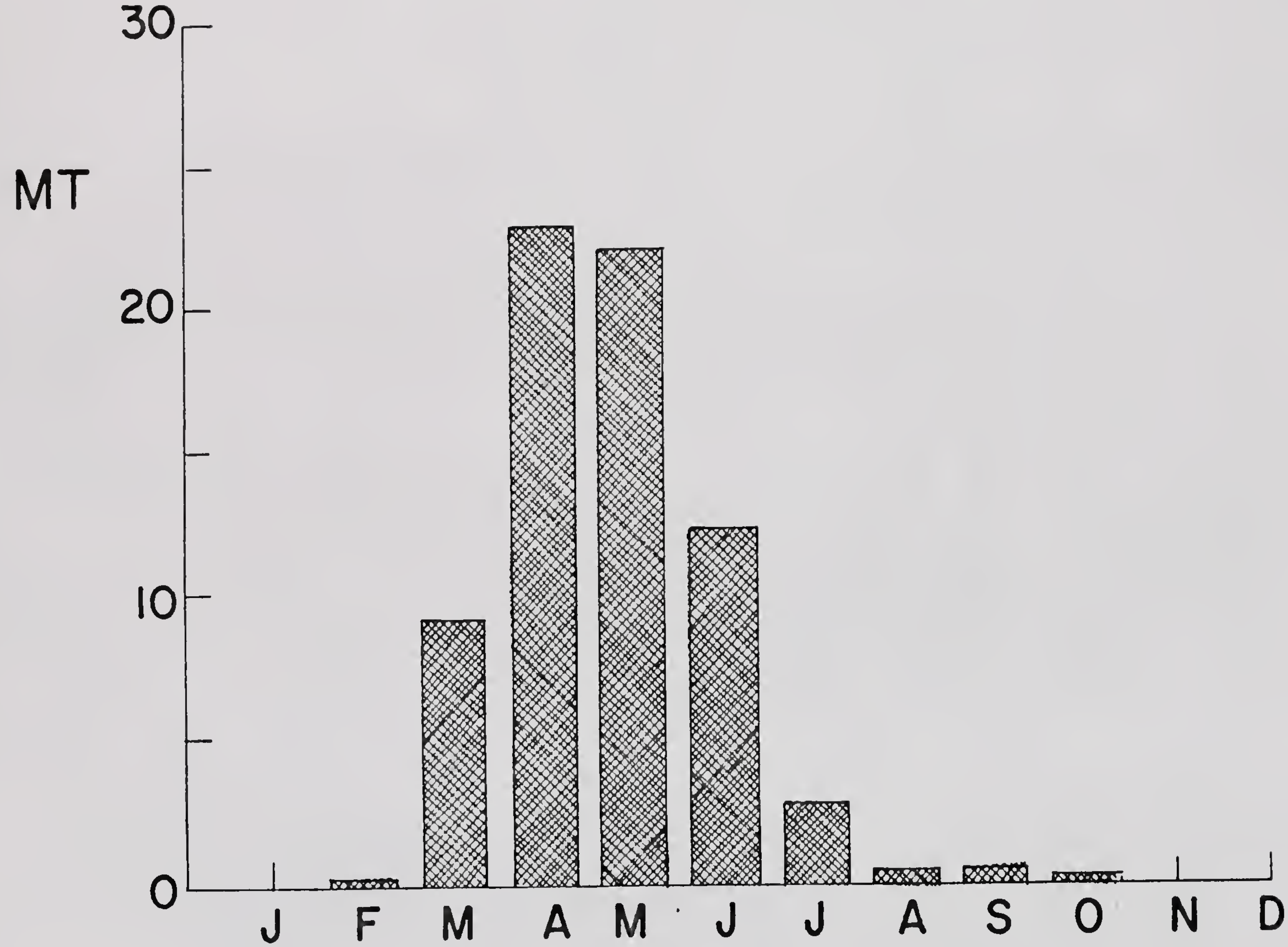

Fig. 6. Coffee purchases (fruit) originating at Chovacollo.

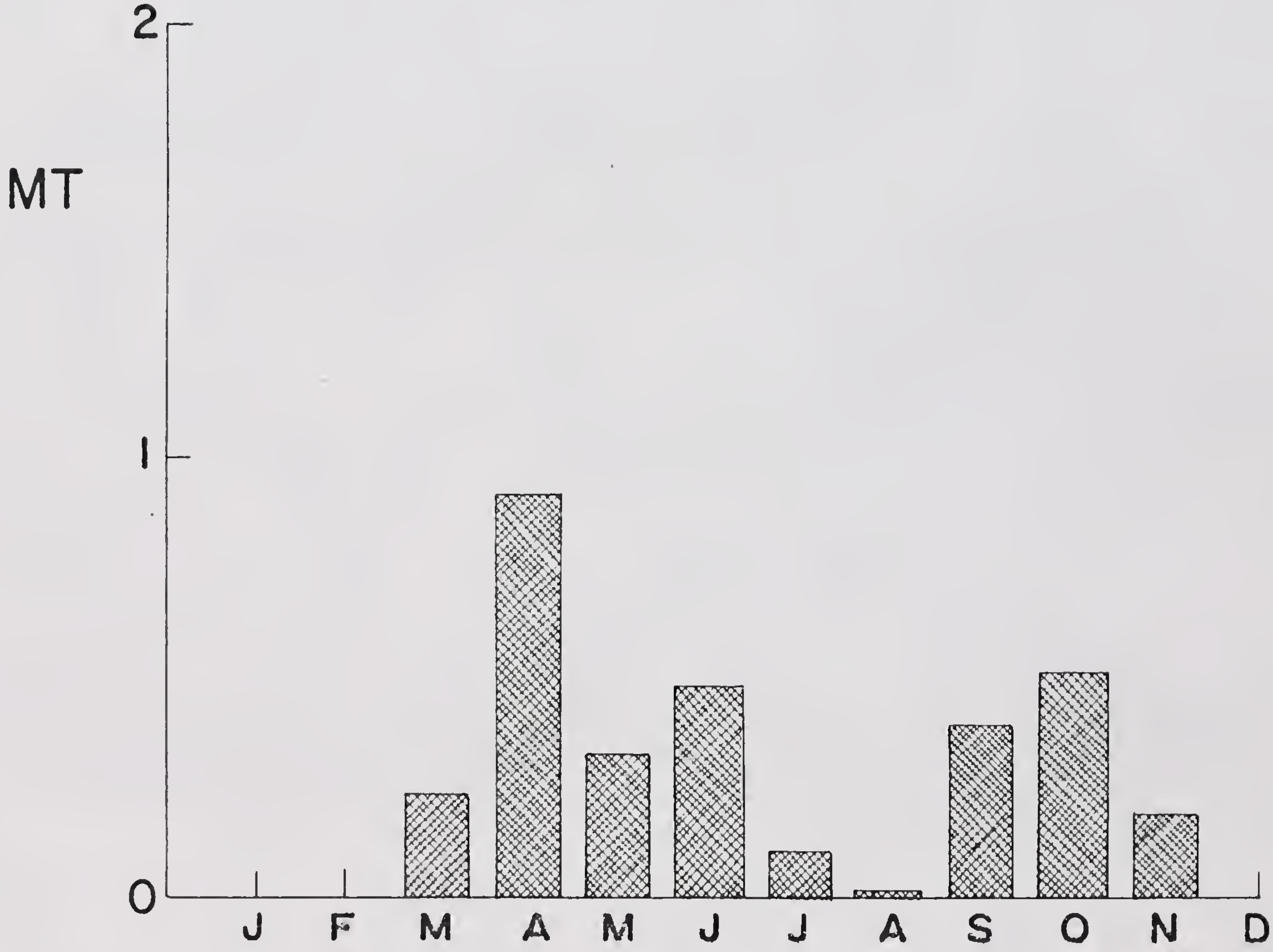

Fig. 7. Coffee purchases (fruit) originating at San Cristobal.

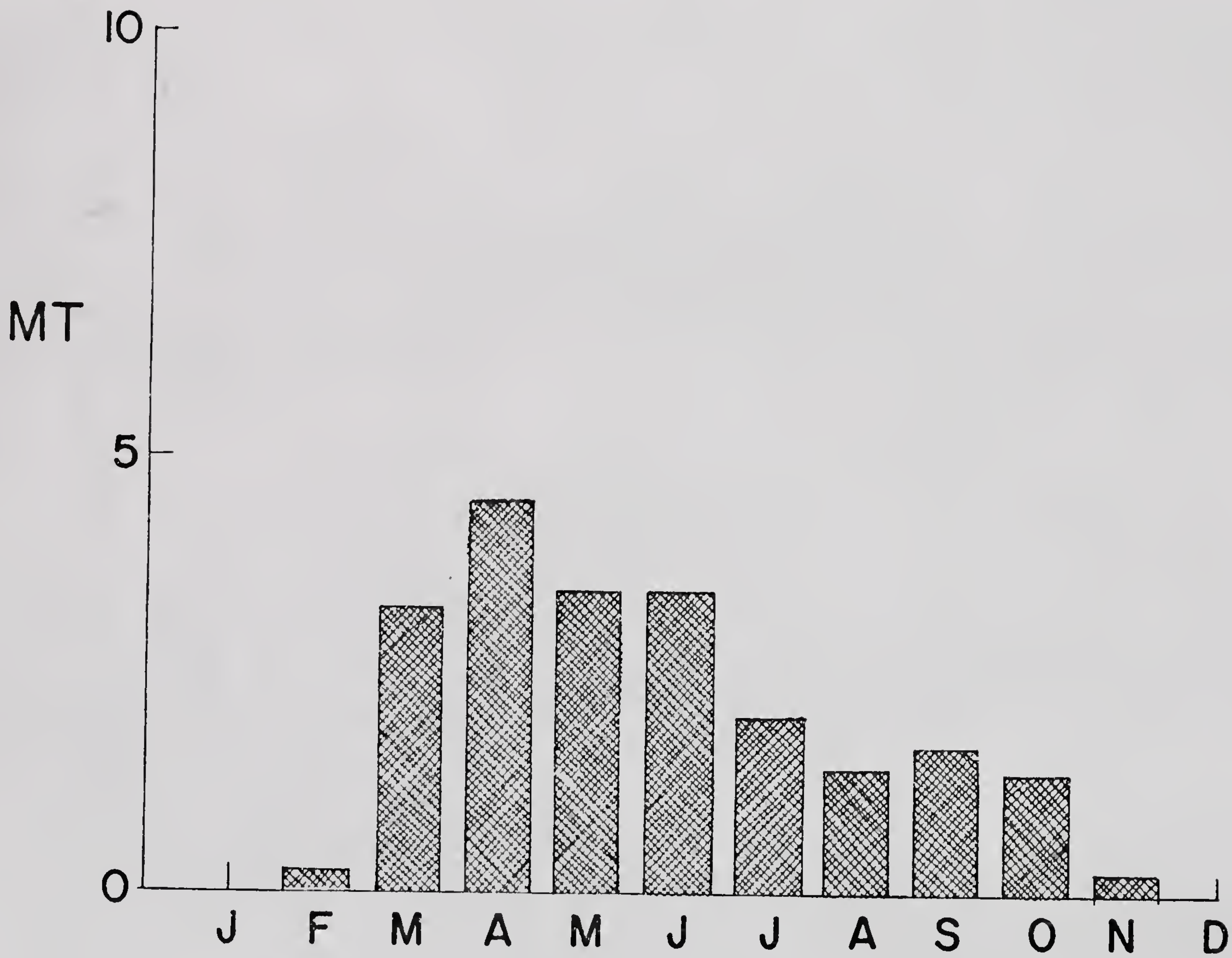

Fig. 8. Coffee purchases originating at Carmen Pampa.

Table 9. Summary of weed control treatments, frequency of applications, and rates of herbicides applied.

Treatment[+]	Frequency	Rate
		(kg a.i./ha)
Hand weed	Feb, Apr, Jun, Aug, Oct	
Diuron	Feb 1977	2.8
Paraquat	Feb, Apr, Jun, Aug, Oct	0.6
Glyphosate I	Feb, Jun, Oct	5.0
Glyphosate II	Feb, Apr, Jun, Aug, Oct	5.0

[+]Hand weeding was machete slashed; herbicides were applied with a hand-pumped CP3 backpack sprayer.

fertilized according to rates given in Table 10. Plot harvests were made on a periodic basis as sufficient coffee ripened. Treatments were maintained and data collected over a 5 year period (1976-1981).

Cover Crops

Initially, twenty 12 X 12 m plots containing 4 coffee plants and bordered by 12 coffee plants were assigned treatments (5) in a randomized block design. Treatments were replicated 4 times. Treatments included a hand strip weeding, a chemical herbicide (Paraquat 0.6 kg a.i./ha), and 3 leguminous cover crops (1) Stylosanthes guianensis Swartz; (2) Desmodium heterocarpon, D.C.; and (3) Pueraria phaseoloides (Willd.) Ohwi. Seeding rates were 5 kg/ha. Land was hand stripped and lightly tilled before broadcast sowing. Seeds were inoculated with Rhizobium spp. (Cowpea type). Only Stylosanthes guianensis was established successfully. A second planting was attempted but only a few, slow growing plants were found after a year. Coffee harvests were made periodically as needed. Trees were fertilized according to the rates given in Table 10 during the 1979-1981 growing seasons. The S. guianensis cover crop was harvested after 11 months to obtain fresh and dry weights.

Table 10. Summary of fertilization[+] regime during recuperation and weed control study.

Year	N	P_2O_5	K_2O	Formulation
		(kg/ha)		
1976	60			Urea
1977	30	30	30	15-15-15
	90			Urea
1978-80	50	50	50	15-15-15
	100			Urea

[+]Supplemental foliar fertilizer (1 g/tree) 12-12-17-2 + microelements (100 g/100 kg of Mg, S,B, Mn, Zn, and Co) applied annually by spray in September.

Grain Legume Intercrops

Twenty-four plots containing 6 coffee plants surrounded by 6 border trees were assigned treatments (6) in a randomized block design. Each treatment was replicated 4 times. Treatments included (1) non-cropped coffee control; (2) 'Altika' Peanut, (15 cm X 30 cm); (3) 'Jupiter' Soybean, (15 cm X 30 cm); (4) 'Jackson Wonder' Lima bean, (15 cm X 30 cm); (5) 'Pinkeye purple-hull' Cowpea, (15 cm X 30 cm); and (6)) 'Prine selection' Pigeonpea, (15 cm X 15 cm). Each legume was also sown as a monoculture crop on plots 2 X 5 m. Seeds were inoculated with *Rhizobium* spp. appropriate for the legume.

Coffee plants were fertilized at rates mentioned previously. Coffee harvests were made as needed. Grain legumes were maintained relatively weed free with occasional hoeing. Grain legume harvests were made at appropriate times for the given crop.

Shade Grown Coffee

Four plots containing 6 coffee trees and surrounded by border trees were identified in a shade grown coffee planting near the sun-grown coffee plots. No fertilizer was applied. Weeds were controlled with periodic slashing. Coffee harvests were made as necessary.

Laboratory Analyses

Soil Sampling

Soil samples were taken at the beginning of the above studies and after one complete agricultural year which runs from September to August). The recuperation and weed control study was not sampled. Samples were taken at 0-20 cm and 20-40 cm depths, except in the cover crop plots where only samples 0-20 cm deep were taken.

Soil Chemical Analyses

Soil pH was determined in water (1:2 soil:water suspension) and in KCl (1:2 soil: 1NKCl suspension) using a Corning Scientific Model 12 Research pH Meter with a Fisher Microprobe combination electrode.

Organic Matter was determined by the Walkley-Black wet oxidation method (Allison, 1955).

Extractable nutrients were determined using the double-acid solution (0.05N HCl + 0.025N H_2SO_4). Five grams of air-dried soil were placed in a 25 X 150 mm plastic centrifuge tube and mixed with 20 ml of the double-acid solution. The suspension was shaken for 5 minutes and then filtered through Whatman No. 41 paper. Solutions were analyzed for P colorimetrically. Potassium was determined by flame spectrophotometry, and Ca, Mg, Mn, Fe, Cu, and Zn by atomic absorption spectrophotometry.

Total nitrogen (%) was determined by micro-Kjeldahl. Soil samples were oven dried and passed through a 1-mm stainless steel sieve. The aluminum block digestion method, similar to that described by Gallaher *et al.* (1975) was used. Reagents and procedure were from Nelson and Sommers (1973). A 0.5 g of soil was used for analysis.

Foliar Sampling

Coffee foliar samples consisting of the third or fourth pair of leaves from the tip of primary lateral branches were used with 10 pairs of leaves selected from each plant for a total of 20 leaves per sample. Foliar samples were taken from designated coffee trees in the grain legume intercrop and the shade-grown coffee at the beginning and end of the study and taken from the designated covercrop trees only at the end of the study.

Foliar Chemical Analyses

Nutrients other than nitrogen were analyzed in the foliar samples. One gram of oven-dry, ground leaf tissue was ashed in a muffle furnace at 500 C for 8 hours, cooled, 20 ml of 5*N* HCl added and the solution heated to dryness on a hot plate. The residue was cooled, dissolved in 2.25 ml of 5*N* HCl plus 10 ml of deionized water, brought to boiling, and immediately filtered into 50 ml volumetric flasks, made to volume with deionized water and analyzed in the same manner as the soil solutions.

Total nitrogen (%) was determined by micro-Kjeldahl in the same manner as the soil samples. Foliar tissue was oven dried (65 C) and ground to pass a 1-mm stainless steel screen. A 0.2 g sample of foliar tissue was used for analysis.

Harvest Data

Coffee berries were harvested at the red stage and those from each tree or plot weighed. A conversion factor of 5:1 fruit:dry parchment coffee was used to calculate dry coffee production.

Grain legumes were air dried and weighed. The production from single plants was weighed individually and an average of 6 plants was used to calculate yield per hectare.

RESULTS AND DISCUSSION

Recuperation and Weed Control

Weed Control

Application of treatments during the years 1976 through 1981 resulted in an increase in coffee production. Initially, weed density was observed to be 179 plants per square meter. Species growing in the unweeded control plots in early 1977 are listed in Table 11. These are representative of the natural vegetation growing as cover in the sun-grown coffee. *Paspalum conjugatum* Bergius dominated the plant population at this time. The problem species in chemical-controlled plots, after weed control treatment were initiated, was the plantain, *Plantago hirtella* L. which began to dominate regrowth.

First conclusions were this species was resistant to herbicide treatments. Diuron was thought to be damaging the coffee plant, in addition to not controlling the *Plantago*. Diuron was abandoned and glyphosate was substituted.

It was decided upon close observation *Plantago* dominated due to the dessicating effect of the herbicide and the tremendous seed production of the *Plantago*. The

Table 11. Weed distribution and density from unweeded control plots at beginning of study.

Weed species[+]	Distribution
	----%----
Paspalum conjugatum Bergius	19
Laviada spp.	18
Setaria spp.	12
Plantago hirtella L.	8
Bidens pilosa L.	7
Paspalum spp.	7
Richardia scabra L.	6
Ageratum conyzoides L.	5
Stevia spp.	5
Digitaria spp.	4
Phyllanthus niruri L.	3
Sida acuta Burm. f.	2
Euphorbia heterophylla L.	1
Borreria laevis (Lam.) Grisebach.	1
Drymaria cordata (L.) Willd.	1
Galinsoga parviflora Cav.	1

Total	100

[+]Weed density 179/m^2

herbicide eliminated competition and allowed the germinating Plantago seeds to grow freely. The problem was corrected by applying herbicide prior to seed set on the Plantago. The use of glyphosate and timely applications prevented the dominance of this plant.

Glyphosate performed exceptionally well under both treatment regimes. Regrowth of vegetation over a two-month period during the rainy season (Jan-March, 1981) is plotted in Figure 9. Both glyphosate treatments effectively controlled weeds during this period. Paraquat application did not control weeds as well as the other treatments during the heavy rains. It is assumed regrowth occurred more rapidly since only above grown vegetation was killed. Hand-weeded plots were observed to regrow more rapidly than the glyphosate treated ones but more slowly than the paraquat treated ones.

Coffee Recuperation

Simple linear regression trend lines for the pattern of recuperation, as measured by coffee production during the study are shown in Figure 10 where it is obvious unweeded control plots did not recuperate as fast or to the extent of other treatments. Statistical analysis of the data (Table 12) shows that the slopes of the regression lines of the weed-control treatments are all highly significantly different from the unweeded control (.01 level). Intercepts were not different, indicating basically

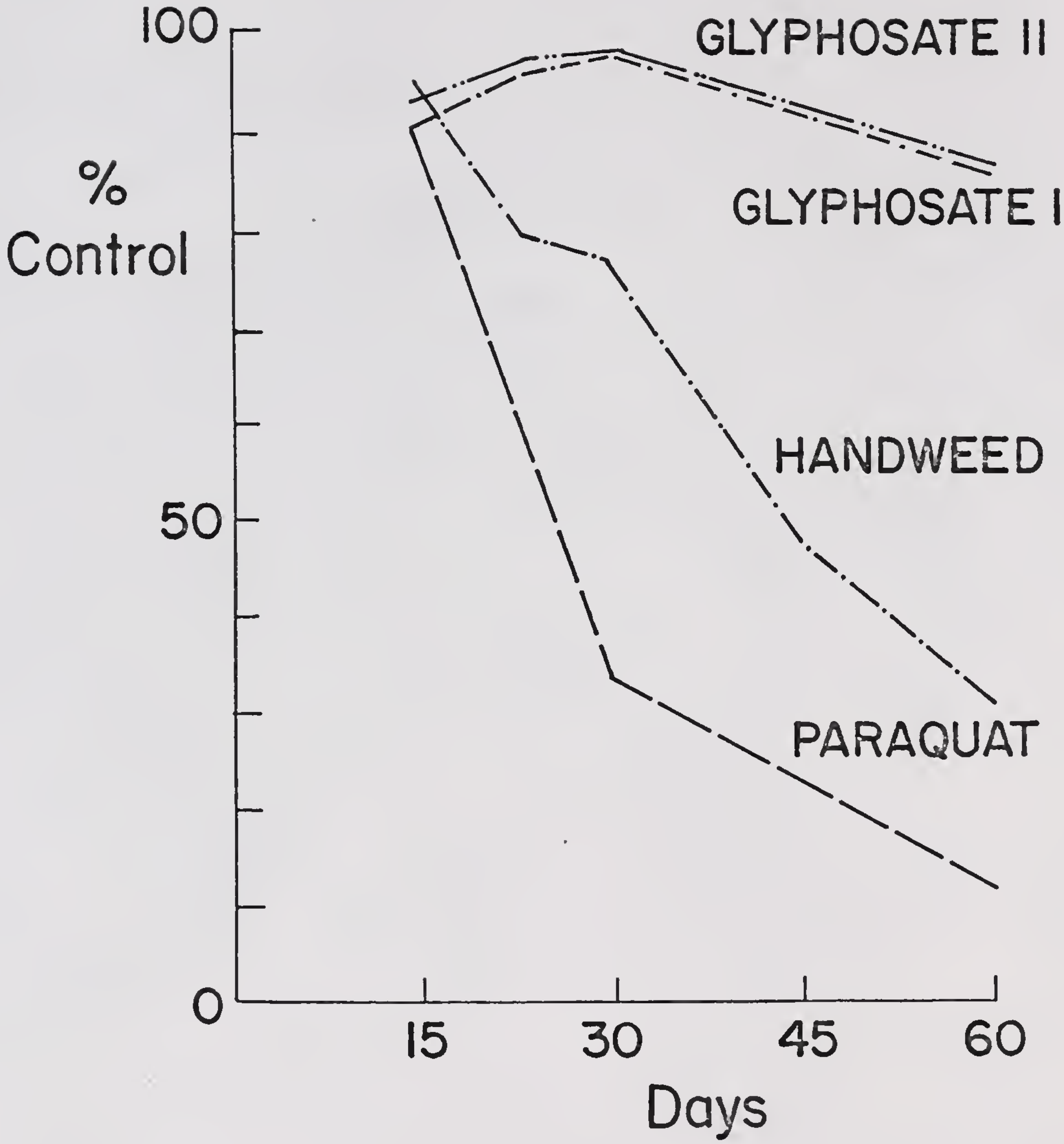

Fig. 9. Duration of weed control following treatment application January-March, 1981.

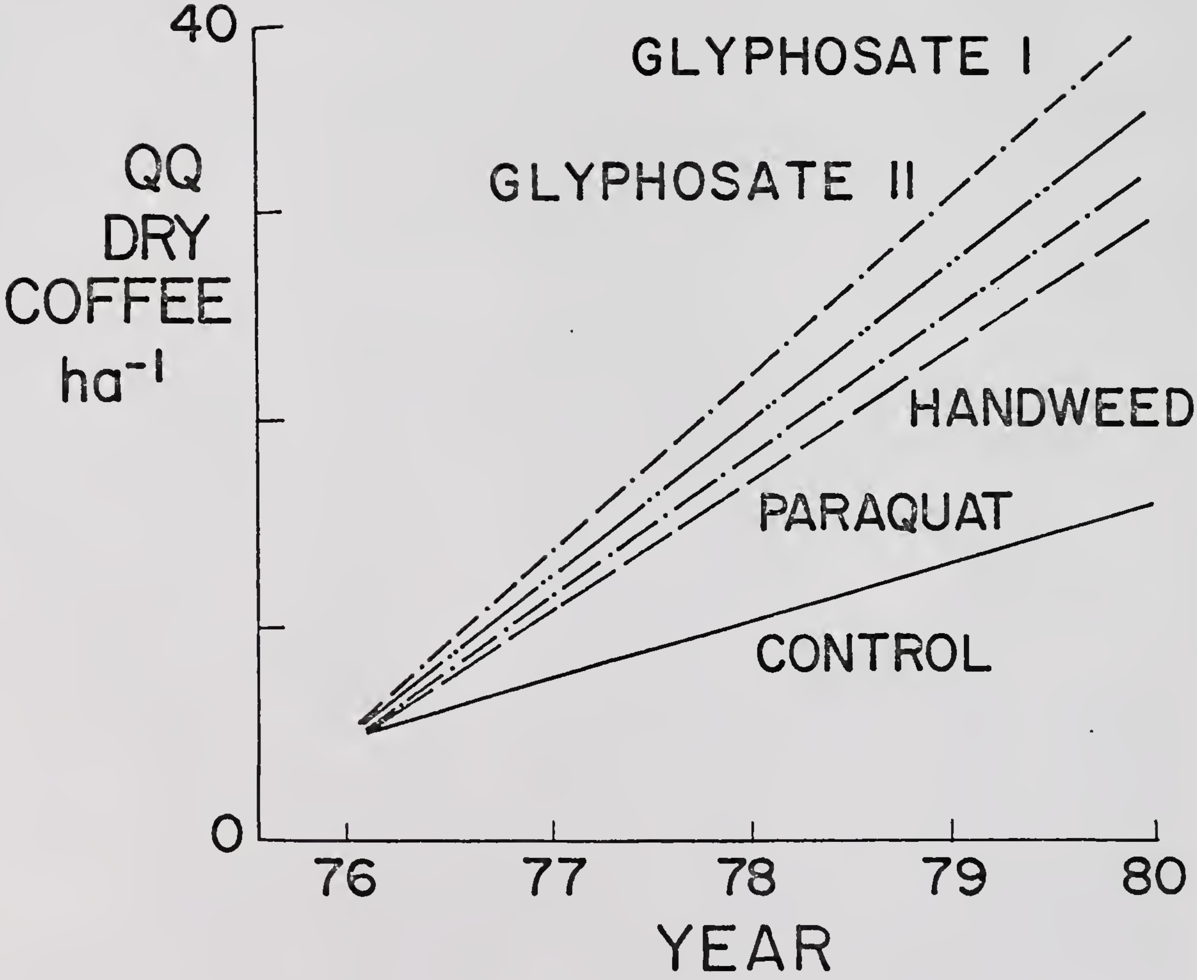

Fig. 10. Linear regression trend lines representing coffee production increase (qq/ha parchment coffee) during the 5 year study.

Table 12. Summary of regression trend line analyses for coffee production as a function of treatment during the years 1976-1981.

Treatment+	Slope	Intercept	r**
Control	2.9a+	0.4a	0.96
Hand weed	6.6b	0.8a	0.87
Paraquat	6.3b	1.1a	0.85
Glyphosate I	7.7b	-0.1a	0.79
Glyphosate II	8.7b	-0.6a	0.86

+ Control was machete-slashed, handweeding was handhoeing, herbicides were applied using a hand-pumped CP3 backpack sprayer. Glyphosate I treatment was applied in months of February, June, and October. All other treatments were applied in months of February, April, June, August, and October.

‡ Data in the same column not followed by the same letter are significantly different at the 0.5 level of probability according to Duncan's Multiple Range Test.

** Indicates r-value significant at the .01 level of probability.

that the plots were approximately equal at the beginning of the study. Highly significant correlations (r) were found in each instance. Significant differences were not found among weed control treatments.

Production data from the weed control plots analyzed on a year to year basis for statistical differences are summarized in Table 13. Differences were not significant during the first 2 years of the study but were significant in later years. This was a recuperation attempt, thus the coffee trees were not in a heavy bearing condition at the beginning of the study. The coffee plants entered a vegetative growth period upon fertilization and weed control and began to flower appreciably after a year. Yields were obtained by the end of the fifth year commonly expected in sun-grown coffee managed under the cultural conditions of this study.

Economic Considerations

The principal advantage of using chemical weed control is the reduction of labor. There may be times of scarce labor even in areas were labor is obtained at low wages and this is true in the Yungas (Figueras, 1978). Altiplano farmers will migrate to the Yungas during coca harvests and be generally available during coffee harvest time, although there is some overlap with coffee and coca harvests.

Labor requirements are summarized in Table 14. Three categories of labor are compared, labor required to control

Table 13. Comparison of coffee yield (qq parchment coffee/ha) by treatment and year.

Treatment[+]	1976	1977	1978	1979	1980
	(qq/ha)				
Control	0.2a[‡]	2.8a	7.5a	8.0a	11.9a
Paraquat	0.2a	7.6a	16.3b	17.5ab	26.7b
Hand weed	0.3a	7.1a	16.9b	18.1ab	27.6b
Glyphosate I	0.2a	6.2a	17.0b	22.3b	30.8b
Glyphosate II	0.2a	7.6b	15.2b	26.9b	34.3b

[+] Control was machete-slashed, handweeding was handhoeing, herbicides were applied using a hand-pumped CP3 backpack sprayer. Glyhosate I treatment was applied in months of February, June, and October. All other treatments were applied in months of February, April, June, August, and October.

[‡] Data in the same column not followed by the same letter are significantly different at the .05 level of probability according to Duncan's Multiple Range Test.

Table 14. Summary of labor requirements (mandays/ha)+ for sun-grown coffee.

	Treatment‡									
Activity	Control		Hand weed		Paraquat		Glyphosate I		Glyphosate II	
	Labor	%	Labor	%	Labor	%	Labor	%	Labor	%
Weed Control	19	27	113	53	16	14	5	4	8	6
Fertilization	17	24	17	8	17	15	17	15	17	14
Harvest	35	49	82	39	79	71	91	81	102	80
Total	71	100	212	100	112	100	113	100	127	100

+One manday is an 8½ hour period and earns $b 60.00 if the noon meal is not provided, $b 50.00 if noon meal is provided ($b 25.00 : $US 1.00).

‡Control was machete-slashed, hand weeding was handhoeing, herbicides were applied using a hand-pumped CP3 backpack sprayer. Glyphosate I treatment was applied in months of February, June, and October. All other treatments were applied in months of February, April, June, August, and October.

weeds, fertilization, and harvest. Control plots were slashed with machete to keep weeds down. Machete cultural practice is common all over the American tropics. Actual hand weeding required the most time at 113 man-days per hectare. Chemical herbicides drastically reduced the labor requirements. Paraquat applications were needed more frequently and greater care was required to cover effectively the foliage of the weeds, resulting in a greater time requirement. Glyphosate, on the other hand, is more easily applied because of its systemic action. Complete coverage of the leaf surface was not required and the person applying the herbicide with a backpack sprayer can move more quickly.

It should be noted the higher technology associated with sun-grown coffee culture adds fertilization as an additional labor component to the scheme. Coffee grown under shade is not fertilized in the Yungas, hence this labor requirement is an added cost of production. An irony of increased production is the increase in labor requirements for harvest. Higher yields require more time and increases manpower needs. Coffee harvesting is more efficient if the picker is gathering berries from heavy-bearing plants, however. All chemical control treatments required less labor than the hand weeded treatment (Table 14). Labor requirements were lowest for the control plot, but production was also lower.

Production costs including labor, for sun-grown coffee during the 1980-1981 growing season when the plants gave their greatest production are summarized in Table 15. Chemical weed control is the greatest expense. The price of imported commodities is high in Bolivia and it is impossible to place bulk orders for fertilizers and pesticides. Low usage and subsequent lack of demand maintain prices at levels unaffordable by small farmers and this problem is exacerbated by lack of credit sources.

The small farmer in general receives a minimal price for his coffee. This is attributed to 3 reasons (1) poor quality caused by primitive processing (fermenting), (2) lack of organization on the farmers' part, and (3) an exploitation by coffee buyers.

A fair price must be obtainable to sustain higher level cultural technologies. The experimental export of the San Francisco Xavier Cooperative's coffee by Buitrago (1979) showed a good price can be gotten for good quality coffee.

Cost and returns are summarized in Table 16. Gains are calculated based on a farm price of $b 1500 per quintal. This amounted in 1981, to $US 60 per quintal of parchment coffee. Net returns even at this low price are substantially above current ones for coffee in Bolivia.

Table 15. Summary of production costs per hectare in Bolivian pesos ($b)[+] for sun grown coffee 1980-1981

Input	Treatment‡				
	Control	Hand weed	Paraquat	Glyphosate I	Glyphosate II
	($b/ha)				
Weed Control	1,140	6,780	960	300	489
Fertilization	1,020	1,020	1,020	1,020	1,020
Harvest	2,100	4,920	4,740	5,460	6,120
Fertilizers	5,300	5,300	5,300	5,300	5,300
Herbicides	---	---	4,500	9,900	16,500
Total	9,560	18,020	16,520	21,980	29,420

[+] Exchange rate $b 25.00 : US$ 1.00.

‡ Control was machete-slashed, hand weeding was handhoeing, herbicides were applied using a hand-pumped CP3 backpack sprayer. Glyphosate I treatment was applied in months of February, June, and October. All other treatments were applied in months of February, April, June, August, and October.

Table 16. Summary of expenses and returns for 1 quintal of sun-grown parchment coffee by weed control treatment during the 1980-1981 growing season.+

Activity	Treatment ‡				
	Control	Hand weed	Paraquat	Glyphosate I	Glyphosate II
	($US)				
Weed Control					
Labor	3.80	9.80	1.40	0.40	0.60
Materials	----	----	6.70	12.90	19.20
Fertilization					
Labor	3.40	1.50	1.50	1.30	1.20
Materials	17.80	7.70	7.90	6.90	6.20
Harvest					
Labor	7.10	7.10	7.10	7.10	7.10
Total	32.18	26.10	21.80	28.60	34.30
Returns/qq	60.00	60.00	60.00	60.00	60.00
Net return/qq	27.80	33.90	35.20	31.40	25.70
Net return/ha	331.00	936.00	941.20	968.70	882.20

+Does not include cost of depulping, fermentation, washing, and drying.

‡Control was machete-slashed, hand weeding was handhoeing, herbicides were applied using a hand-pumped CP3 backpack sprayer. Glyphosate I treatment was applied in months of February, June, and October. All other treatments were applied in months of February, April, June, August, and October.

Legume Cover Crops

Strategy

The success obtained in these weed control experiments demonstrate sun-grown coffee could be a viable agricultural enterprise in the Yungas if chemical inputs, i.e fertilizer and herbicide, could be obtained at reasonable cost to the farmer and, more important, the farmer could obtain a fair market price for his coffee. The cooperative at Carmen Pampa could play an important role in acquiring needed agricultural products and equipment for members' use. The farmers would depend upon the cooperative to obtain a fair price for the coffee. It was pointed out in discussions with cooperative officials, having sufficient funds to make a first payment for coffee brought in for processing was a real constraint. It has been estimated that at least five hundred 60 kg bags of export coffee would be necessary to make direct exportation of coffee by the cooperative a viable consideration (Hanrahan _et al._, 1980).

A study was planned to help reduce production costs that would incorporate legume cover crops into the cultural scheme. Legume cover crops would reduce weed control costs and possibly add nitrogen to the soil supplementing chemical fertilization.

Economic Considerations

No significant differences were found among the 3 treatments with respect to coffee production. Production was low on all plots.. Reduced production costs would, however, favor the legume cover crop, *Stylosanthes guianensis*, as an alternative.

The single harvest made of *Stylosanthes* dry matter production indicated that approximately 4.5 mt/ha could be grown annually. Results of chemical analyses of oven-dried *Stylosanthes* showed approximately 120 kg N/year/ha would be fixed and eventually become mineralized in the soil around the coffee trees if the 2.65% nitrogen content is used as an average value. Volatilization, leaching, and non-coffee utilization over time would influence the amount of N that would be available for use by the coffee plants.

An alternative strategy would be to use the legume cover crop for animal feed. Dairy cattle, while not great in number, are found in the area and seem to be successfully grazed along roadsides and fallow fields. They are not damaging to coffee trees if adequate pasture is available.

Grain Legume Intercrops

Strategy

Establishment or recuperation of a coffee planting in full sun is a non productive time. It was decided to try to intercrop with annual grain legumes. Objectives were (1) to utilize available space between plants to obtain agricultural production that could be consumed or sold and

(2) to evaluate the economic and physiological benefits or constraints of such a system.

Consumption of vegetable proteins contained in the grain legumes would help supplement dietary protein that is lacking in the rural poor peoples' diet in the Yungas.

Intercrops

Five annual grain legumes were selected for incorporation into the study. They were peanut, soybean, lima bean, pigeonpea, and cowpea. Peanut and soybean are known in the Yungas. The remaining 3 crops were introduced.

Comparisons of grain legume intercrop yields with monoculture yields is given in Table 17. In all cases the crop grown a monoculture yielded higher than when grown as an intercrop. The reason for this is obvious since plant populations were greater in the monoculture plots. Relative yield totals (RYT) show when the yields for both coffee and the legume are consider, the intercrop plots had higher yields. The gross income equivalent ratios indicate that the farmer can actually earn the same or a greater income with all grain legumes with the exception of pigeonpea. Care should be exercised in making strong assumptions about the viability of the cropping strategies because of the tremendous variability of among the different experimental plots. It is important to consider the benefits of growing legumes in regard to possible

Table 17. Yield, variation, relative yield totals (RYT) and gross income equivalent ratio (IER) of coffee intercropped grain legumes.

Crop	Intercropped				Mono-Culture		RYT	IER
	Legume		Coffee					
	kg/ha	CV(%)	kg/ha	CV(%)	kg/ha	CV(%)		
Coffee	---	---	---	---	11	88	---	---
Lima bean	330	90	11	72	720	38	1.46	1.00
Cowpea	90	78	12	67	310	21	1.39	1.09
Soybean	330	66	13	76	1060	47	1.49	1.18
Peanut	310	79	12	73	540	64	1.67	1.09
Pigeonpea	570	90	9	94	640	64	1.71	0.82

vegetable protein and food energy (Table 18). Considering the need to supplement the diet of the rural peasant, the grain legumes grown in the study can produce considerable amounts of nutrients for the farmer family.

Pigeonpea and soybean produced the most protein as an intercrop and peanut and pigeonpea produced the most food energy because of their oil content.

Estimated gross incomes from the various treatments are compared in Table 19. Incomes do not include coffee since production was minimal. Pigeonpea and peanut were the best. Lima bean production was respectable but soybean and cowpea produced the least with respect to gross income. Yields observed for the grain legumes grown as a monoculture were much higher demonstrating the possibility of being a viable enterprise in the Yungas.

Soil Analyses

Comparisons of soil nitrogen, organic matter, and pH before and after growing the cover crop and grain legumes are shown in Tables 20 and 21. All 3 chemical characteristic were increased after one year. The same trends were noted in the handweeding and chemical weed control treatments also. These differences were not significant a the .05 level, however.

Double-acid extractable macro-elements P, K, Ca, and Mg before the treatments were applied and after 1 year are summarized in Tables 22 and 23. These soil nutrients

Table 18. Food, protein, and food energy produced per ha. by various grain legumes.

Grain Legume	Food		Protein[+]		Calories[+]	
	Mono-culture	Coffee inter-cropped	Mono-culture	Coffee inter-cropped	Mono-culture	Coffee inter-cropped
	(kg/ha)				(kcal/ha)	
Black bean	2085	---	465	---	707	---
Peanut	535	308	138	79	294	169
Soybean	1057	330	352	110	435	136
Cowpea	308	91	70	21	106	31
Pigeonpea	642	573	131	117	220	196
Lima bean	718	332	146	68	248	115

[+] Denotes calculated value using food composition tables (Watt and Merrill, 1975).

Table 19. Estimated gross income from grain legume intercropping and monoculture production per ha.

Grain legume	Price	Gross income	
		Monoculture	Intercropped
	($b/kg)	-----($b/ha)------	
Bean	16.80	35,028	----
Peanut	24.50	13,108	7,546
Soybean	7.20	7,610	2,376
Cowpea[+]	(16.10)	4,959	1,465
Pigeonpea[+]	(16.10)	10,336	9,225
Lima bean[+]	(16.10)	11,560	5,345

[+] Estimated price ($b/kg).
Source: Ministry of Agriculture, 1981.

Table 20. Soil nitrogen, organic matter, and pH in soil before legume intercropping and weed control.

Treatment	Soil depth	Soil			
		N	OM	pH (H_2O)	pH (KCl)
	(cm)	-------%--------			
Handweed	0-20	0.41	8.20	3.7	3.7
Herbicide	0-20	0.41	7.50	3.7	3.7
Stylosanthes	0-20	0.31	5.06	3.9	3.8
Control	0-20	0.36	6.71	4.0	3.6
Control	20-40	0.30	4.85	3.9	3.5
Lima bean	0-20	0.33	5.69	3.9	3.6
Lima bean	20-40	0.23	3.34	3.8	3.7
Cowpea	0-20	0.35	6.14	3.9	3.6
Cowpea	20-40	0.29	4.58	3.9	3.7
Soybean	0-20	0.34	6.51	3.8	3.6
Soybean	20-40	0.25	4.72	3.9	3.7
Peanut	0-20	0.34	6.06	3.9	3.7
Peanut	20-40	0.28	4.18	3.9	3.7
Pigeonpea	0-20	0.33	6.05	4.2	3.7
Pigeonpea	20-40	0.23	3.10	4.2	3.7
Shade	0-20	0.45	7.85	3.9	3.7
Shade	20-40	0.33	5.60	4.1	3.8

Table 21. Soil nitrogen, organic matter, and pH in soil after legume intercropping and weed control.

Treatment	Soil depth	Soil			
		N	OM	pH (H_2O)	pH (KCl)
	(cm)	-------%--------			
Handweed	0-20	0.45	8.96	4.1	3.6
Herbicide	0-20	0.42	9.51	4.2	3.6
Stylosanthes	0-20	0.40	7.33	4.5	3.8
Control	0-20	0.36	6.17	3.9	3.6
Control	20-40	0.25	4.39	4.3	3.7
Lima bean	0-20	0.31	5.44	3.9	3.5
Lima bean	20-40	0.28	3.89	4.2	3.6
Cowpea	0-20	0.34	6.30	3.9	3.5
Cowpea	20-40	0.28	4.80	4.1	3.7
Soybean	0-20	0.34	6.30	3.8	3.8
Soybean	20-40	0.30	5.14	4.0	3.6
Peanut	0-20	0.37	6.59	4.0	3.5
Peanut	20-40	0.32	5.34	4.2	3.6
Pigeonpea	0-20	0.37	6.23	4.2	3.6
Pigeonpea	20-40	0.26	4.43	4.3	3.6
Shade	0-20	0.42	7.59	4.5	3.8
Shade	20-40	0.28	5.60	4.5	3.8

demonstrate a decreasing trend in almost all cases. This same trend is not as evident for the micro-elements (Tables 24 and 25).

Since the changes were not significant (0.5 level), the data do not necesarily imply a loss of fertility.

Coffee Foliar Analyses

Comparisons of macro- and micronutrient levels in coffee plants from the intercropped, weed-controled, and control plots are summarized in Tables 26 and 27. Differences between treatments were not significant at the 0.5 level. It is important that the coffee trees not be stressed appreciably in the intercropping strategy. The data suggest stress is minimal both from the standpoint of foliar nutrient levels and coffee production during the intercropping period.

Table 22. Double-acid extractable macro-nutrients in soil before legume intercropping and weed control

Treatment	Soil depth	Soil			
		P	K	Ca	Mg
	(cm)	ppm			
Handweed	0-20	1.9	58	124	26
Herbicide	0-20	2.1	62	168	32
Stylosanthes	0-20	1.4	56	229	49
Control	0-20	3.7	91	143	29
Control	20-40	2.4	65	173	24
Lima bean	0-20	2.5	86	186	41
Lima bean	20-40	1.3	48	113	26
Cowpea	0-20	2.9	74	146	35
Cowpea	20-40	1.8	53	94	24
Soybean	0-20	4.2	91	238	51
Soybean	20-40	1.5	49	84	18
Peanut	0-20	2.7	70	199	40
Peanut	20-40	1.7	44	121	28
Pigeonpea	0-20	2.4	69	197	46
Pigeonpea	20-40	1.3	45	89	19
Shade	0-20	4.4	93	743	159
Shade	20-40	1.1	43	445	99

Table 23. Double-acid extractable macro-nutrients in soil after legume intercropping and weed control.

Treatment	Soil depth	Soil			
		P	K	Ca	Mg
	(cm)	ppm			
Handweed	0-20	0.8	36	98	19
Herbicide	0-20	0.8	60	131	31
Stylosanthes	0-20	0.9	46	454	69
Control	0-20	1.4	39	67	16
Control	20-40	1.0	26	41	11
Lima bean	0-20	2.0	44	116	23
Lima bean	20-40	0.9	33	88	18
Cowpea	0-20	1.8	57	95	21
Cowpea	20-40	1.1	40	88	20
Soybean	0-20	1.6	44	58	14
Soybean	20-40	1.0	26	56	14
Peanut	0-20	1.6	52	264	50
Peanut	20-40	1.1	37	169	34
Pigeonpea	0-20	1.2	47	104	24
Pigeonpea	20-40	0.7	43	76	18
Shade	0-20	1.1	74	711	158
Shade	20-40	0.9	51	410	106

Table 24. Double-acid extractable micro-nutrients in soil before legume intercropping and weed control.

Treatment	Soil depth	Soil Cu	Soil Zn	Soil Mn	Soil Fe
	(cm)	ppm			
Handweed	0-20	0.37	1.03	38	20
Herbicide	0-20	0.37	1.30	53	18
Stylosanthes	0-20	0.98	0.75	42	20
Control	0-20	0.36	1.67	51	30
Control	20-40	0.34	1.10	35	28
Lima bean	0-20	0.32	1.41	35	34
Lima bean	20-40	0.44	0.68	15	46
Cowpea	0-20	0.39	1.41	42	31
Cowpea	20-40	0.47	0.92	24	30
Soybean	0-20	0.41	2.18	55	32
Soybean	20-40	0.39	1.08	19	38
Peanut	0-20	0.32	1.51	26	30
Peanut	20-40	0.47	0.93	27	30
Pigeonpea	0-20	0.41	1.71	45	30
Pigeonpea	20-40	0.51	0.71	55	35
Shade	0-20	0.32	3.97	82	18
Shade	20-40	0.36	1.38	31	14

Table 25. Double-acid extractable micro-nutrients in soil after legume intercropping and weed control.

Treatment	Soil depth	Soil			
		Cu	Zn	Mn	Fe
	(cm)	ppm			
Handweed	0-20	0.39	1.12	27	20
Herbicide	0-20	0.44	1.31	36	24
Stylosanthes	0-20	0.61	1.38	39	23
Control	0-20	0.43	0.99	22	31
Control	20-40	0.46	0.65	12	36
Lima bean	0-20	0.47	0.92	20	46
Lima bean	20-40	0.48	0.72	11	51
Cowpea	0-20	0.64	1.14	32	39
Cowpea	20-40	0.53	0.93	24	34
Soybean	0-20	0.46	0.90	26	39
Soybean	20-40	0.40	0.90	18	37
Peanut	0-20	0.57	1.91	36	36
Peanut	20-40	0.41	1.29	27	37
Pigeonpea	0-20	0.55	1.21	17	37
Pigeonpea	20-40	0.45	0.77	12	47
Shade	0-20	0.37	3.98	46	17
Shade	20-40	0.45	2.28	28	46

Table 26. Foliar nitrogen, phosphorus, potassium, calcium, and magnesium levels in coffee before and after legume intercropping and weed control (1 year).

Treatment	Before treatment					After treatment				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg
	%					%				
Handweed	---	---	---	---	---	3.3	0.13	1.0	0.75	0.4
Herbicide	---	---	---	---	---	3.0	0.13	1.3	0.49	0.2
Stylosanthes	---	---	---	---	---	3.0	0.18	1.2	0.60	0.4
Control	3.3	0.16	1.5	0.80	0.4	3.0	0.15	1.4	0.46	0.2
Lima bean	3.5	0.13	1.6	0.60	0.3	3.4	0.15	1.5	0.55	0.3
Cowpea	3.8	0.16	1.4	0.76	0.4	3.4	0.15	1.5	0.49	0.2
Soybean	3.6	0.20	1.5	0.67	0.4	3.2	0.15	1.6	0.50	0.2
Peanut	3.4	0.16	1.3	0.70	0.4	3.1	0.15	1.7	0.53	0.3
Pigeonpea	3.4	0.15	2.0	1.01	0.4	3.4	0.15	2.3	0.57	0.3
Shade	3.8	0.18	2.3	1.35	0.5	2.6	0.14	1.8	0.63	0.4

Table 27. Foliar iron, manganese, copper, zinc, and aluminum levels in coffee before and after legume intercropping and weed control (1 year).

Treatment	Before treatment					After treatment				
	Fe	Mn	Cu	Zn	Al	Fe	Mn	Cu	Zn	Al
	ppm					ppm				
Handweed	---	---	---	---	---	63	283	13	9	66
Herbicide	---	---	---	---	---	73	286	12	8	67
Stylosanthes	---	---	---	---	---	65	179	15	17	60
Control	86	491	16	10	66	68	449	15	8	62
Lima bean	83	317	17	10	77	114	332	16	9	117
Cowpea	146	560	20	41	77	83	487	15	8	71
Soybean	130	398	19	10	89	94	366	16	9	79
Peanut	111	358	25	12	71	86	421	15	9	65
Pigeonpea	291	174	20	20	143	99	502	13	8	60
Shade	147	85	22	14	119	77	64	11	10	52

SUMMARY AND CONCLUSIONS

Sun-grown coffee can be grown in the Yungas of Bolivia. Weed control is an important cultural practice. Yields that justify higher technological inputs can be obtained. Chemical weed control can reduce labor requirements substantially and may be necessary if coffee production increases cause a labor shortage during weeding time.

Cover crops can be used to reduce weed competition without significantly reducing coffee yields. They may serve a supplementary role in nitrogen fertilization.

Grain legumes may be grown in association with coffee trees during non producing years, establishment, or cultural pruning. Peanut and pigeonpea yielded more than cowpea, lima bean, or soybean when grown either as an intercrop with coffee or as a monoculture. Coffee production, although low, was not significantly reduced by the intercropping of grain legumes. Black bean yielded extremely well as a monoculture and may be adapatable to intercropping. No apparent damage was done to the trees when foliar nutrient levels were compared before and after intercropping and additional income could be generated for the farmer. The farmer may consume the production at home and thus supplement his protein deficient diet.

The prime constraint to sun-grown coffee is the price received by the producer. The farmer cannot obtain sufficient income to justify his increased production costs without a good marketing system. Although intercropping can supplement his income with grain legume intercrops, it is probably not sufficient to justify sun-grown coffee culture.

Another difficulty in addition to low prices exists in obtaining credit and agronomic inputs. This could be resolved with a viable cooperative organization that could purchase wholesale and sell at reduced retail prices. The cooperative also could assist in processing and marketing the coffee in addition to helping the farmer obtain his agricultural inputs. It is estimated the cooperative would require sufficient operating capital to purchase at least 500 bags (60 kg) of dried, exportable coffee to make direct exportation of coffee a viable operation.

Initial results suggest further research in intercropping sun-grown coffee in the Bolivian Yungas. For the enterprise to be viable, the farmer must increase his level of technification. This new technology will enable the Bolivian coffee producer to continue to grow coffee inspite of the threat of the coffee rust disease. Current cultural practices will not effectively combate this disease.

Research direction should concentrate on high yielding, rust resistant coffee varities. Proper spacings and other required cultural practices could be the only alternative if coffee is to continue as a major cash crop in the Yungas.

While higher technology levels require more inputs, research should be aimed at reducing these costs whenever possible. Native covers should be more thoroughly studied. Appropriate technology should be extended to the farmers on a timely basis and marketing infrastructure and credit facilities should be priorities in development schemes in the valleys of Bolivia.

APPENDIX

Nutritional Status in the Yungas

Sampling surveys have demonstrated malnutrition affects 40 to 50% of pre-school age children nation-wide. Results of surveys conducted in selected urban and rural communities during the period 1965-1974, are summarized in Table 28. Seven average sized, rural communities located in higher elevation areas (Tarija an exception) were sampled during 1965-1968 and 2,508 pre-school children (ages 1-5 years) were examined. According to the Gomez' Classification system of protein-calorie malnutrition (Gomez *et al.*, 1955), 43.3% of the children examined were considered malnourished. Of the total, 32.6% were classified First Degree (least serious), 9.4% as Second Degree, and 1.3% as Third Degree (most serious). Studies made in La Paz, Bolivia's largest city, with pre-school age children (ages 1-6 years) during the years 1972-1973, demonstrated even a higher percentage of malnutrition (42-52%) with higher percentages of the total sample classified in the more serious Second and Third Degree categories. Studies made in the tropical area of Bolivia, Santa Cruz, indicate less malnutrition overall and lower Third Degree malnutrition in children 0 to 5 years of age. Economic conditions and food availability are considered better in this area (USAID/Bolivia, 1978).

Table 28. Nutritional status of Bolivian children (1965-1974).

Year	Location	Ages	Sample size	Percent mal-nourished	Gomez Class+ I	II	III
				-----------	-------%-------		-------
1965	Tejar and Alto La Paz	1-5	702	41	28.0	12.0	0.4
1967	Santiago de Llallagua (LP)	1-5	176	47	42.0	4.0	1.0
1967	Three Rural Areas (La Paz)	1-5	1,338	44	32.7	9.6	1.6
1968	Tarabuco (Chuquisaca)	1-5	138	39	32.0	4.0	3.0
1968	Concepcion (Tarija)	1-5	154	48	41.0	6.0	1.0
1972	La Paz	0-6	2,777	42	26.0	10.5	5.5
1973	La Paz	0-6	4,810	52	30.4	16.3	5.3
1974	Mineros (Santa Cruz)	0-6	496	31	22.5	7.4	0.8
1974	Santa Cruz	0-6	354	28	24.6	2.8	0.6

+ The Gomez classification of malnutrition considers Class I to be less severe, Class II more severe, and Class III most severe.

Sources: Ministry of Public Health, Division of Nutrition, Unpublished Data, 1974.
Gomez *et al.*, 1955.

Recent information has not been published concerning the health and nutritional status of children in the Yungas. However, a major epidemiological study was conducted in 1964 by the Research Institute for the Study of Man (RISM) and the Peace Corps (Omran et al., 1967).

Six communities were selected for study nation-wide to develop plans for future programing direction in health promotion and disease prevention projects. Coroico and environs were selected as one of the representative areas for the study. The final report of this study compared Bolivian children with a sample population of children from Boston, Massachusetts, to evaluate the nutritional status of the Bolivian children.

Both the total sample and the Coroico subsample of children between the ages of 2 and 18 years were determined to be below the standards for height and weight as defined by the Boston sample of children of the same age.

Gomez et al. (1955) found children to develop within certain weight ranges during infancy. The comparisons made between the Bolivian and Boston children are most meaningful during the first 5 years of life.

Comparisons were made for Ponderal Index (PI) as a function of age. The Ponderal Index is a measure of body bulk and considered to be an unbiased measure of weight differences between age groups by removing the effect of height differences from the comparisons. PI values, while unstable during early years, tend to stabilize and vary little in later years. The higher the value, the leaner the person; and conversely the lower the value, the bulkier.

Bolivian and Boston girls show a lower index than boys after age 12. Sex difference is more pronounced in the Bolivian samples than the Boston sample. Bolivian boys are also shown to be bulkier than Boston boys. The study speculated that this was due to the high starch diet of the Bolivian children. Also, constitutional differences in body build were mentioned, suggesting that comparison among other Andean groups would be useful.

Blood samples were drawn from 2,530 persons (1,347 males and 1,183 females) of all ages for determination of hemoglobin concentration and hematocrit values in addition to the above measurements. Males showed the expected higher values for hemoglobin and hematocrit in all communities except in Reyes, where both men and women had equally low values. Comparisons are difficult between areas of the study due to the confounding of factors such as altitude and parasitic infection. This is evident in the Coroico values when the town sample is compared with values from the rural environs. Blood sample values were lower in the rural areas and parasitic infection rates were also higher. The study concluded overall the low values for hemoglobin concentration suggest a degree of malnutrition in all communities.

Food commonly used by both the urban and rural populations in Bolivia is listed in Table 29. A Yungas farmer's breakfast generally is composed of sugar sweetened coffee and boiled plantain or cassava. The noon meal, referred to as Sufrehambre del medio dia, contains a piece of dried beef jerky (charque) or the more prevalent dried fish Isppi and cold boiled cocoyam, taro, or cassava. The evening meal consists of soup prepared with varying combinations of quinoa, rice, maize, peanut, pea, broad bean, turnip, cocoyam, taro, or plantain. Some of these ingredients may be home grown.

Deep fat fried pork (chicharron) and chicken are usually reserved for fiestas but home grown guinea pigs (quis or conejos) may be eaten 2 or 3 times a month.

Infants are breast fed until they are replaced by a younger sibling. This is usually after one year. If mother's milk is not available or if weaned, the child is bottle fed canned milk if the household economic situation allows the purchase of the milk. Breast milk is considered superior to canned milk. After one year, children are introduced to sugar sweetened coffee as a beverage. Ripe bananas are not considered nutritious. They are thought to cause anemia and children are generally discouraged from eating them (Mamani, 1981).

Table 29. Typical Bolivian foods.

Food	Scientific name
Grains	
Rice	*Oryza sativa* L.
Wheat	*Triticum aestivum* L.
Maize (white)	*Zea mays* L.
(yellow)	*Zea mays* L.
Quinoa	*Chenopodium quinoa* W. L.
Legumes/Pulses	
Broadbean	*Vicia faba* L.
Lentil	*Lens culinaris* Medic.
Pea (dried)	*Pisum sativum* L.
(toasted)	*Pisum sativum* L.
Bean	*Phaseolus vulgaris* L.
Peanut	*Arachis hypogaea* L.
Roots and tubers	
Potato	*Solanum tuberosum* L.
Cassava	*Manihot esculenta* Crantz
Arracacha	*Arracacia xanthorriza* D.C.
Cocoyam	*Xanthosoma sagittifolium* Schott
Taro	*Colocasia esculenta* Schott
Miscellaneous	
Eggs	(chicken)
Isppi+	(fish)
Plantain (green)	*Musa* spp. L.
-(ripe)	*Musa* spp. L.
Chuno (potato)	*Solanum tuberosum* L.

+ Isppi- (Aymara word) small fresh water fish eaten dried, boiled, or fried.

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BIOGRAPHICAL SKETCH

Lawrence J. Janicki was born in Sewickley, Pennsylvania, on April 30, 1947. He studied chemistry at Saint Vincent College, Latrobe, Pennsylvania, from 1965 to 1967. In June 1967, he entered the Joint Peace Corps/College Degree Program at the State University College at Brockort, New York. He graduated with a B.A. in chemistry in August 1968.

He served as a Peace Corps Volunteer in the Dominican Republic from September 1968 to August 1971. While a Peace Corps Volunteer, he worked as a science teacher trainer and during his last year he taught science at El Instituto Superior de Agricultura, an agricultural school in Santiago de los Caballeros, Dominican Republic.

He entered the University of Florida in September 1971, and received a M. S. in food science and human nutrition in August 1973.

After working for the United States Department of Agriculture at the National Peanut Research Laboratory in Dawson, Georgia, for two year, he returned to the University of Florida in 1975, to begin studies leading to a Ph. D. in agronomy.

His studies were postponed for a time when he accepted employment on the University of Florida/State Department

Contract in Bolivia. During his service in Bolivia, 1976 to 1980, he worked as an Assistant Research Scientist in the Yungas area of Bolivia. In 1978, he assumed the position of Chief of Party until March of 1980.

He reentered the Graduate School of the University of Florida in August 1980 and returned to Bolivia in October under financing of a Title XII Strengthening Grant to finish field research related to this dissertation.

He married Ms. Karen McDeavitt in August 1982. They have one daughter, Michelle.

He expects to received the degree of Doctor of Philosophy in December, 1982.

He has accepted a position with the University of Florida/USAID Contract in Malawi, Africa. He expects to join the team in January 1983.

I certify that I have read this study and that in my opinion is conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Professor of Agronomy

I certify that I have read this study and that in my opinion is conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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