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Journal

Human Ecology, 2(2)

ISSN

0300-7839

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Publication Date

1974-04-01

DOI

10.1007/BF01558115

Human Ecology, Vol. 2, No. 2, 1974

Dung as an Essential Resource in a Highland Peruvian Community

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Received April 21, 1973; revised October 2, 1973

The present paper examines the use of dung for two essential human resources, fuel and fertilizer, in a highland community of southern Peru. The limited energy availability and the poor soils of the region, primarily the result of high-altitude climate and topography, necessitate this practice. Alternatives to dung use are costly or unavailable. Grazing herbivores transform the widely dispersed puna *grasses into a compact and easily gathered source of energy and nutrients. Native choice among available dungs corresponds to their qualities: sheep dung, richest in nutrients, is applied as fertilizer; llama and cattle dungs, each with a high caloric value, are burned as fuels. Dung use is interpreted as an energetically efficient response to the highland environment and as central to the subsistence pattern in the area.*

INTRODUCTION

Rugged topography and harsh climate present a formidable challenge to human populations inhabiting high-altitude mountainous environments. The Quechua and Aymara, residents of the Altiplano region of the Andes Mountains, are an instructive example of a successful response to such a challenge. The *Altiplano* consists of a series of intermontane valleys and plateaus, lying at elevations above 3700 m and extending from southern Peru southward into

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This work was supported by the Cornell University Latin American Studies Program, the State University of New York at Binghamton, The Pennsylvania State University, and the Wenner-Gren Foundation. Mr. Winterhalder received support from the National Science Foundation, and Mr. Larsen from the Ford Foundation.

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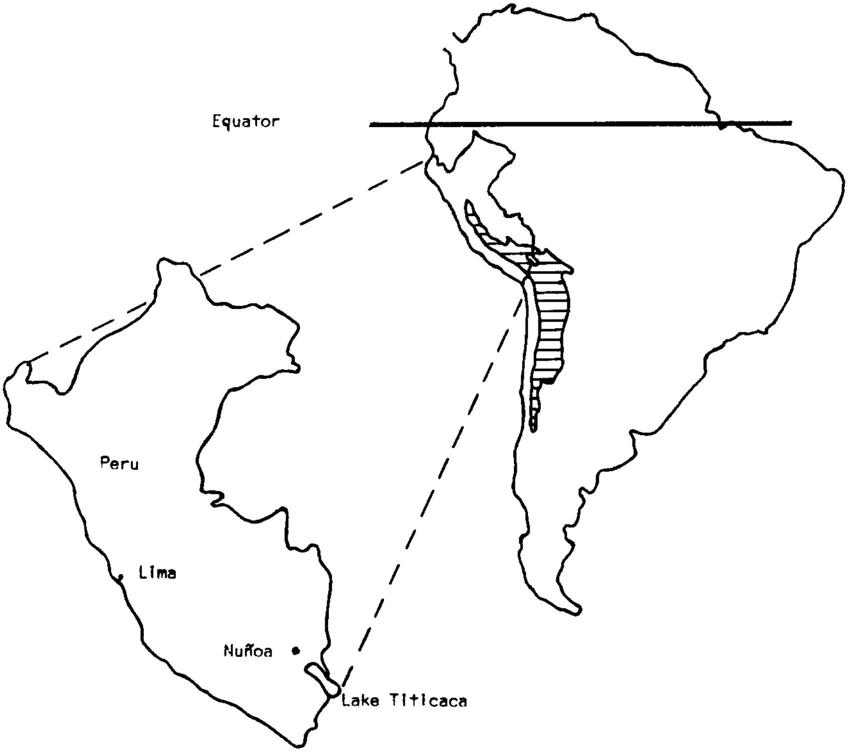

Fig. 1. Hatched area represents the Andean *Altiplano;* the study was done in and around the town of Nuñoa in southern Peru. Maps redrawn from *Hammond's Comparative World Atlas* (n.d.).

eastern Bolivia and northern Chile and Argentina (Fig. 1). At altitudes characteristic of the *Altiplano,* oxygen tension is 40% or more below that at sea level, temperatures are low, frost and snow are frequent, and precipitation is variable and seasonally limited. Because of climatic and other factors, plant life is confined to slow-growing grasses and herbs and an occasional pocket of low trees.

Despite the rigors of this environment, human populations have successfully adapted to the *Altiplano.* Over 10 million people currently live in the region, and it is estimated that shortly before the Spanish conquest 40% of the hemisphere's inhabitants lived in this area (Baker, 1969). Archeological evidence indicates seasonal population of the *Altiplano* by 10,500 B.P. by groups practicing transhumant hunting and gathering (Lynch, 1967; Lynch and Kennedy, 1970). The predominant subsistence activity of highland peoples since about 500 A.D. has been pastoralism of native camelids and cultivation of locally domesticated crops including the potato and the Andean cereals (Lanning, 1967). This system continues today in isolated rural areas, augmented by sheep and cattle introduced after the conquest.

Intensive research on biocultural adaptations of *Altiplano* groups began in the early 1960s. Studies conducted by Baker and colleagues focused on adjustments to hypoxia (low partial pressure of oxygen) and cold (Baker, 1969), stresses which are density independent. Thomas (1973) carried the work further with recognition that low energy availability, a density-dependent factor, is an additional highland stress. While Thomas's work provides a broad picture of energy flow through a high Andean community, the role of specific resources on maintenance of this flow, and on stress amelioration, has not been extensively examined.

This paper continues ecological analysis of a human population living on the *Altiplano* by considering the use of dung for fuel and fertilizer. We will indicate, using the concepts of energy flow and nutrient cycling (Odum, 1971) and environmental adaptation (Baken, 1962), the importance of efficient use of animal excrement in the adaptation of highland peoples.

CLIMATE AND ADAPTATION ON THE *ALTIPLANO*

Low energy availability on the *Altiplano* is primarily the result of the climatic character of the region. In contrast to high-latitude areas where warm and cold weather alternate seasonally, mean monthly temperatures of tropical high mountains vary only several degrees within a year. Day to night temperature changes, however, are consistently great, and it is this diurnal rhythm to which high-altitude plants and animals must adapt (Troll, 1968). In the dry season, intense solar insolation warms the area to a midafternoon peak, and low atmospheric density and sparse cloud cover accentuate loss of heat at night. The diurnal temperature range is less pronounced during the cloudy, wet season. In southern Peru, daily temperature ranges are on the order of 17°C, and the mean monthly variation is about 2°C (Fig. 2). Night frosts are frequent and can occur any month of the year (Fig. 3).

The wet season in the southern Peruvian highlands occurs during the months of October through March, with precipitation often falling as snow or hail (Fig. 4). During these months, there is a warm, moist air mass above the Amazon Basin. Strong weatherfront activity along the eastern escarpment of the Andes pushes the moist air over the eastern ranges (*Cordillera Oriental*) onto the *Altiplano*. The remainder of the year has little or no precipitation. Poor soil composition and atmospheric conditions, which abet runoff and evaporation of the water, respectively, increase the general dryness of the area. Rivers on the *Altiplano* flow year round, fed by glaciers and snow pack, but they have eroded channels below the level of the pampas and hence provide little moisture to the majority of the region. In addition, weather patterns in local valleys of the highlands can be highly variable from year to year (Thomas, 1973).

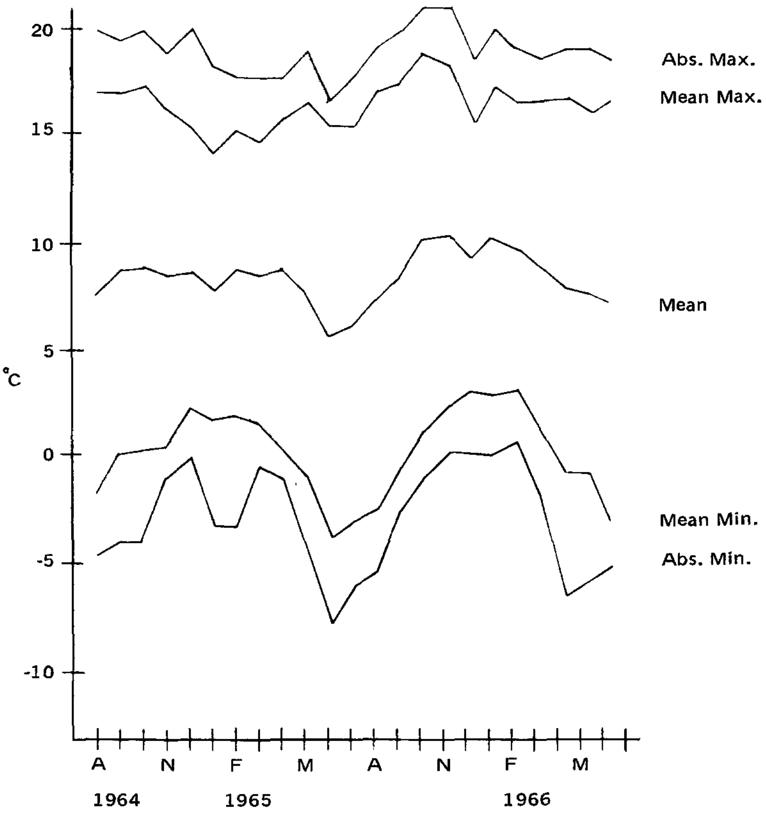

Fig. 2. Summary of daily temperature data for Nuñoa for the period August 1964 to May 1966. Mean annual temperature was 8°C. Data from Baker (1968).

The combination of seasonal desiccation and low and rapidly changing temperatures in the highlands retards decomposition of organic matter (Cabrerra, 1968). This slows nutrient cycling and the formation of soils. Geological features such as solifluction further inhibit soil development (Troll, 1968). Primary productivity on the *Altiplano* is consequently limited to grasses, herbs, and a few trees, and is dispersed in a thin layer over wide regions. We are aware of no net primary productivity measurements for *Altiplano* grasslands, the *punas,* but it is known that productivity decreases along decreasing temperature and moisture gradients (Whittaker, 1970). This fact, and studies from other alpine environments (Bliss, 1966), reinforces our impression that productivity on the *Altiplano* is low. Growth of plants in the region is slow and mature size is reduced (Troll, 1968).

Adaptation by human groups to the highlands, however, implies that the local population has obtained a flow of energy and nutrients from this ecosystem in a manner efficient enough to permit reproductive continuity. Adaptation also implies effective counteraction of environmental stresses, such as cold and hypoxia. Efficiency, the ratio of energy available from a flow to the energy expended creating the flow, is one measure of adaptiveness of subsistence activities. Presumably, in an energetically limited environment with alternative responses to energy flow available, the more efficient response, or activity, is the more adaptive.

Two aspects of adaptation to low energy availability on the *Altiplano* are pertinent to this paper: (1) the flow of energy and nutrients generated by crops requires maintenance of a soil base sufficiently fertile for the cultigens grown, and (2) a fuel source is required to cook and to provide protection against cold stress. Published reports (Mishkin, 1946) and observation led us to believe that

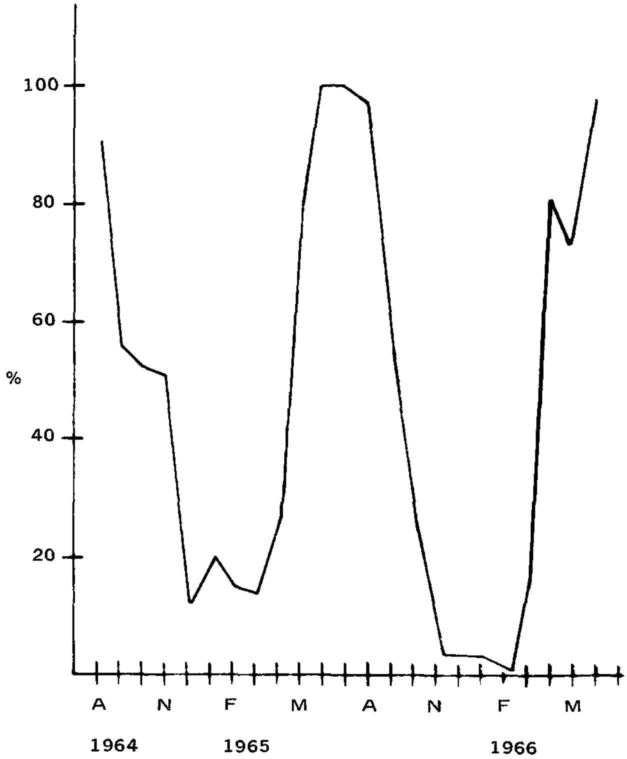

Fig. 3. Percent incidence of days with temperatures below freezing for the period August 1964 to May 1966. Data from Baker (1968).

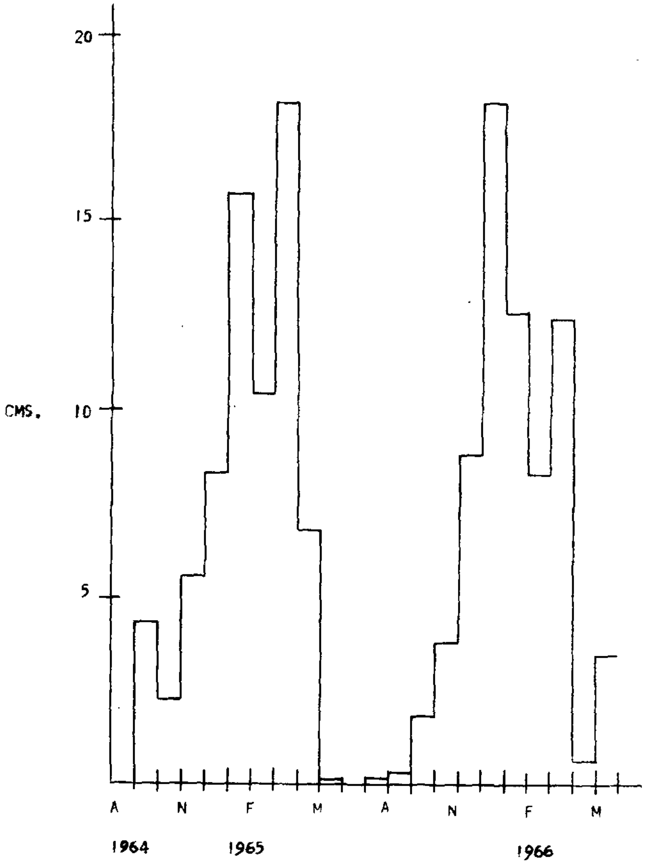

Fig. 4. Summary of monthly rainfall data for Nuñoa for the period August 1964 to May 1966. Mean annual rainfall was 76 cm. Data from Baker (1968).

dung is a critical resource in both situations, as a manure to supplement poor soils and as a fuel for cooking and heating. Alternatives to dung use are apparently not available to most rural highland populations in southern Peru.

THE STUDY COMMUNITY, NUÑOA

The study took place in and around the town of Nuñoa, Department of Puno, Peru. Nuñoa is located about 50 km NNW of Lake Titicaca (14°28′ South Latitude; 70°39′ West Longitude), at an altitude of 4050 m (Fig. 1). Situated in a flat valley along the Nuñoa River, the town is surrounded by the rugged foothills of the *Cordillera Oriental.* Population statistics for the district immediately surrounding Nuñoa show a density of 4.8 persons/km^2 (Baker, 1969). Because of its geographic location, the economy of Nuñoa is little affected by the national Peruvian economy. This is especially true of the rural areas, where many features of family subsistence practice antedate Spanish contact.

FIELD METHODS

Field research involved three steps: (1) identification of alternative fuel and fertilizer resources, (2) observation, aided by questionnaires, of resource use, and (3) experimental work to supplement and clarify certain aspects of the descriptive data. Six possible fuel sources were identified (llama, alpaca, cattle, and sheep dung, and wood and kerosene) and four potential fertilizers (the four dung types). We then questioned 15 rural families about resource preferences, asking how and in what quantities the possible fuels and manures were used, and how they were obtained. Families living on *haciendas* or communities surrounding Nuñoa and practicing more traditional agriculture and herding were chosen for this study.

Differences in the cooking and heating qualities of the various fuels were measured in a native kitchen, and time-motion studies of persons collecting these resources were made. Together with previously published energy expenditure data for Nuñoa adults engaged in various activities (Thomas, 1973), the time-motion studies permitted calculation of the energetic costs of obtaining each fuel.

An estimate of production of dung by llamas was obtained by weighing observed daytime defecations and adding this to an early morning collection obtained by sweeping the night corral. Eight adult animals (seven males and one female) were observed for two 24-hr periods, and the results averaged. Observations were made during the dry season. Samples of the dungs and wood were returned to the United States for calorimetric determination, and in the case of dungs for content of essential soil elements.

RESULTS

Dung is gathered from corrals where the animals are kept overnight, and is used on the soil prior to planting of potatoes (*Solanum tuberosum*). A second-year crop of *quinoa* (*Chenopodium quinoa*) or *cañihua* (*Chenopodium pallidicaule*) is planted without dung, followed by 2-7 years of fallow. Animals graze and defecate on the fallow plots. Application of dung to potatoes is variable, but from reports and measurements we estimate an average of about 900 kg/500 m^2. Of the 15 rural families questioned in the Nuñoa area, 14 indicated preference

Table I. Results of Soil Surveys for the Nuñoa Valley (Nuñoa Series) and for the Lower Hillsides of the Valley (Ayabacas Series)[a]

	Valley (Nuñoa series)		Lower hillside (Ayabacas series)		
	Horizon A1	Horizon A1	Horizon A	Horizon B	Horizon C
Depth (cm)	0-20	0-25	0-30	30-55	55-70
*p*H	4.9	5.3	7.9	7.9	8.0
Phosphorus (kg/ha)	6.9	16.0	60.0	156.0	60.0
Exchangeable cations					
K (g/kg)	0.14	0.58	0.18	0.21	0.24
Mg (g/kg)	0.14	0.12	0.13	0.07	0.11
Ca (g/kg)	0.98	0.54	3.72	3.82	4.50
Cation exchange capacity	6.70	6.40	20.24	20.80	24.80
Organic material (%)	3.78	2.07	2.31	0.89	0.76
Nitrogen (% total)	0.179	0.136	0.089	0.039	0.034

[a] Institute Nacional de Planificación (1965).

for sheep dung for use as manure; one person preferred cattle dung. When asked why sheep dung was preferred, people generally said that it was better or that llama or cow dung caused worms. Many people gave no definite reason for their choice.

Table I presents results of a soil survey for the Nuñoa Valley taken by the Instituto Nacional de Planificacion, Peru (1965). The Nuñoa series corresponds to the valley floor, and the Ayabaca series to the mature lower slopes surrounding the valley. Both areas are used for agriculture. With regard to agricultural use

Table II. Comparison of Two Nuñoa Soils, Each With and Without a Standard Application of Sheep Dung, and Dung as Applied to the Field[a]

	Valley (Nuñoa series)		Lower hillside (Ayabacas series)		Dung
	Without dung	With dung	Without dung	With dung	
*p*H	5.1	6.8	5.1	6.3	7.5
Phosphorus (kg/ha)	132.0	356.0	63.0	285.0	596.0
Exchangeable cations					
K (g/kg)	0.101	0.998	0.234	0.998	11.300
Mg (g/kg)	0.108	0.370	0.252	0.410	2.520
Ca (g/kg)	0.70	1.70	1.04	1.64	7.80
Cation exchange capacity	12.7	15.2	18.0	17.3	89.0
Nitrogen (ppm)	37.0	146.0	44.0	172.0	262.0
Use	Fallow	Potatoes	Fallow	Potatoes	

[a] Cooperative Extension Service of The Pennsylvania State University.

Table III. Analysis of Dung Samples Obtained in Nuñoa and Nutrient Content of Manures as Reported in the Literature for U.S. Animals[a]

	N	Ca	Mg	K	P
Cattle (Nuñoa)	1.62	1.70	0.30	0.47	0.29
Llama (Nuñoa)	1.60	1.46	0.36	0.79	0.29
Sheep (Nuñoa)	1.82	2.30	0.48	1.06	0.28
Cattle[b]	3.2	0.5	0.4	2.0	0.9
Sheep[b]	4.7	1.9	0.6	3.3	0.7
Cattle[c]	1.8	–	–	0.9	0.9
Sheep[c]	2.6	–	–	1.6	1.3

[a] All values have been converted to percentage composition of dry material. Analysis of Nuñoa samples was done by the Cornell University Agronomy Department.

[b] Benne *et al.* (1961).

[c] Smith (1952).

of the land, the survey singles out deficiencies of nitrogen, phosphorus, and organic matter. In addition, the shallow Nuñoa series is subject to excess drainage; in the Ayabacas series this problem is complicated by pluvial erosion.

Analysis of soil samples taken in 1968 is given in Table II. Two examples are provided; one represents a valley site and one hillside site. In each case, one sample was taken from the fallow field, prior to application of dung and planting of potatoes, and one from the same field after fertilization and planting. The fifth column of this table reports data on the sheep dung as applied. Table III gives results of element analysis of different dung types obtained in Nuñoa and similar information for U.S. animals. And, finally, Table IV provides estimates of dung production of adult cattle, sheep, and llamas. We were unable to determine dung production of adult sheep and cattle in Nuñoa, and have substituted data from U.S. animals. To compensate for the smaller size of highland animals, calculations in this paper are based on the lowest production values given.

When considering dung as a fuel, 12 of the rural Quechua families questioned favored cattle dung, one favored llama dung, and three favored wood

Table IV. Dung Production of Major Animals Utilized in the Nuñoa Area[a]

Source	Cattle	Sheep	Llamas
Anderson (1972)	4.65 (4.31-5.17)	0.25	–
Miner (1971)	4.01	0.29	–
Present study	–	–	1.0

[a] All values are in kg dry matter (animal) day. Anderson and Miner values are for U.S. animals.

Table V. Energetic Values and other Characteristics of Potential Nuñoa Fuels[a]

Type	Heat value (kcal/kg)	Collection cost (kcal/kg)	Energetic efficiency	Characteristics
Cattle	3,787[b]	From field[c]: 10 From corral[c]: 5	378.7 757.4	Cattle dung is easy to gather, kindle, and burn. Available in corrals and fields near the homesite. Less frequent in higher areas where cattle are less plentiful.
Llama	3,904[b]	From field[c]: 10 From corral[c]: 5	390.4 780.8	Llama dung produces an even, hot fire that is difficult to maintain. Little smoke. Available around all homesites.
Sheep	3,547[b]	–	–	Sheep dung produces an acrid smoke and is not used as a fuel. Available around all homesites.
Wood	4,104[b]	9.1	451.9	Wood is a good but rarely used fuel. The limited stands of highland trees are far from most households.
Grass	3,809[b]	–	–	Grass is used to kindle fires, but poor burning qualities and bulk make it unacceptable as as cooking fuel.
Kerosene[d]	10,926	2500	4.37	Kerosene can be purchased for cash; a stove (Primus) is also required. This fuel must be obtained at locations far from homesites.

[a] Efficiencies (except for kerosene) were calculated as calories of heat obtained from the fuel for each calorie spent collecting it. Caloric determinations were done by the University of Wisconsin, Department of Poultry Science.

[b] Caloric values are based on a 10% moisture content.

[c] Cost of collection of dungs and wood from fields based on a 5-km radius and from corrals on a 200-m radius.

[d] Cost and efficiency of kerosene obtained as follows: A kilogram of kerosene costs S/4, which is equivalent in price to 2500 calories of flour. Efficiency is equivalent to calories of heat (kerosene) gained at the expense of each calorie of flour.

from the *queñua* tree (*Polylepis tomentella*). Many families reported they did not use one dung exclusively, but mixed cattle dung and llama dung. None of the families used sheep dung as a fuel.

Those families preferring cattle dung cited three reasons for their choice: (1) cattle dung is the easiest of the fuels to collect, primarily because of its size, (2) a cattle dung fire is easy to kindle and maintain, and (3) it produces a hot fire with a minimum of smoke. Camelid dungs, those of the llama and alpaca, produce an intense fire with little smoke, but the fire is difficult to maintain. When asked why sheep dung was not used as a fuel, the Quechua replied that it produced an acrid smoke and that they preferred to use sheep excrement for manure. The same families suggested that wood use was restricted because of adequate quantities of dung near their homes and because wood collection required greater time and effort.

Energetic values and other characteristics of potential Nuñoa fuel resources are given in Table V. The cost per kilogram of obtaining the dungs and wood has been calculated from time-motion studies of adults gathering fuels and is an average value for all aspects of the procedure. In the case of kerosene, we have converted the cash cost into an energetic equivalent based on calories available from flour purchased for the same sum of money. This is a realistic procedure for a society which has limited food energy available (Baker, 1969) and which relies on trade and cash purchase to obtain high-energy foods (Thomas, 1973). Energetic efficiency is calculated as calories returned for each calorie invested.

Fire characteristics of dung and wood fuels were observed in two thermal studies conducted in a typical Quechua cooking house. Cooking was done over a native oven, or *fogon,* in one case with a mixture of cattle and camelid dungs and in the other with wood only. Both types of fire heated water to a similar temperature in a given time (75°C after 90 min, and both warmed the room to about 35°C (1 ft from the oven). The dung fire required 15.4 kg of material and the wood fire 11 kg over a 3-hr period.

DISCUSSION

The high variability of soil elements noted in Table I and the samples of Table II (without dung) is expected. Microclimatic differentiation is common on the *Altiplano,* and soils can differ abruptly over short distances. High variability of domesticated plants (Simmonds, 1965; Ungent, 1970) reflects this diversity, as do patterns of Pre-Columbian subsistence on the *Altiplano* (Murra, 1968). Soil survey results, however, indicate that consistent deficiencies of nitrogen, phosphorus, and organic matter exist in the Nuñoa area. Water erosion and poor water retention are also characteristic of Nuñoa area soils. These are the salient features of this discussion.

Considering soil nutrients, nitrogen and phosphorus are crucial to both soil series. They represent 1.82% and 0.28% dry weight composition, respectively, of Nuñoa sheep dung (Table III). These elements, along with potassium, are primary inorganic nutrients in manures (Miner, 1971). The increase in soil fertility with an application of dung is evident by comparing the soil samples with and without dung in Table II. Nitrogen, phosphorus, and other elements increase substantially when dung is applied to the soil. Dung is placed directly on the furrow where the potato is planted, concentrating the nutrients in the immediate vicinity of the roots. Without application of dung, fallow fields are not sufficiently fertile to grow potatoes (Thomas, 1973).

While manure is a source of nutrients, generally its main function is improvement of physical aspects of the soil. Manures improve aeration and soil moisture relationships and provide organic matter, which is the center of biological activity in the soil (Smith, 1952). By aiding soil aggregation, manures increase water-holding capacity of soils and reduce loss to wind and water erosion (Klausner *et al.*, 1971; Miner, 1971). These are benefits of obvious importance to Nuñoa soils, which are deficient in organic matter, retain water poorly, and erode easily. A standard application of dung to a plot of land increases organic matter in the upper 16 cm by 31%.

Although the people of Nuñoa did not give us explicit reasons for use of sheep dung in preference to llama or cattle dung, their choice is apparently a good one. Table III shows sheep dung to be somewhat superior in nitrogen content, and it has higher concentrations of magnesium, calcium, and potassium. Phosphorus content is similar in all three dungs. These relationships hold true for both Nuñoa animals and U.S. animals: Comparing sheep and cattle manures, Smith (1952) points out that sheep manure is more concentrated, which results in more rapid bacterial changes and formation of humus. Sheep and llama dungs are both in the form of small pellets and are thus easier to use than would be cattle dung. We were unable to evaluate the claims that cattle and llama dungs cause worms in the potatoes, but, all things considered, sheep dung appears preferable.

For fuel resources, the rural Quechua of southern Peru have adapted to an energy-poor environment through efficient use of available forms of natural energy. This includes the use of dung which would otherwise be lost to the decomposer portion of the nutrient cycle. An early morning and late evening cooking fire provides hot food and ambient heat during the two periods of the day most likely to induce cold stress (Larsen, 1973). Similar utilization of animal dung has been documented in India (Odend'hal, 1972), southern Iraq (Maxwell, 1957), and reported generally for the highlands (Mishkin, 1946).

Eighty-seven percent of the Quechua families interviewed used animal dung rather than wood or kerosene as a cooking fuel. This situation, for the majority of rural people, arises out of necessity. The cost of kerosene, and hence its low efficiency, prohibits use of this fuel among families engaged in subsistence agriculture. Wood is an economical alternative available to a few families. However, the very limited and slow-growing stands of queñua are a rapidly exhaustible resource; consequently, they are not heavily exploited. Availability at limited expense, coupled with acceptable fire characteristics, makes dung the preferred fuel.

While most families interviewed preferred cattle dung, a typical fire contains both cattle and camelid dungs, kindled with a handful of grass. According to energy values obtained by burning the fuels in a bomb calorimeter, the Quechua have chosen the higher-energy dungs for fuels (Table V). Camelid dung contains 3% more potential energy than does cattle dung, and 10% more than sheep dung. A fire of cattle and camelid dungs provides only 7% fewer kilocalories than a comparable amount of wood.

Comparison of the thermal and cooking characteristics of wood and dung supports the determined energy values. The dung fire required 28% by weight more fuel than did the wood fire, but produced comparable temperatures over the fire, and identical food temperatures. The energy costs of wood and dung collection are similar when calculated in kcal/min. Both activities require between 4.76 and 4.90 kcal/min, values which fall in the moderate to heavy work range for both males and females (Thomas, 1973). Wood collection generally involved more time, and greater effort at times, than dung collection.

The high efficiency of dung and wood fuels relative to kerosene reflects the natural availability of these fuels. Fuels collected from corrals have a higher efficiency because animals are supplying the energy to transport the fuel to a convenient gathering place. With the restrictive aspects of the two superior fuels, wood and kerosene, the Quechua have chosen to rely on animal dung. Their judicious selection of available dungs and their mastery of dung fire construction make these fuels a satisfactory substitute for wood.

A final question concerns the number of animals and pasture a family must have access to, or maintain, in order to obtain the required manure for its crops and fuel for cooking fires. Table V gives dung production of sheep as 0.25-0.29 kg/animal/day, of which we estimate 40% falls in the corral, where it is easily gathered. Based on a full year's accumulation, and a 900 kg/500 m^2 application, we estimate, using the conservative value, that a minimum of 25 adult animals are needed. Loss of manure, leaching, and volatilization of nutrients throughout the accumulation period would increase the number of animals required under normal circumstances.

A typical day's fuel supply of about 30 kg, again using the 40% of production obtained from corrals, and Miner's value for cattle production (Table IV), requires access to either 19 cattle or 75 llamas, or a mixture of the two—for instance, 10 cattle and 38 llamas. These estimates are considered average because gathering is done daily, reducing loss, and can always be supplemented by dung from the fields. The tendency of camelids to defecate in common piles facilitates this latter practice.

In both cases, for manure and for fuel, the rural Quechua family must have access to considerable numbers of animals to meet resource needs. In the Nuñoa area, families generally own about 100 animals (40 sheep and 60 camelids), and herd another 100, including some cattle, for a hacienda. Those with whom we talked indicated that the supply of dung was adequate, although the preferred cattle dung was not always available.

We have calculated that about 134 ha of grazing land will support the animals (25 sheep, 10 cattle, 38 llamas) to provide sufficient dung for a family. For manure alone, 250 m^2 of *puna* is needed to provide fertilizer for 1 m^2 of potato field. These figures are description of current practice and should not be interpreted as statements of carrying capacity.

Dung Within the Nuñoa Subsistence System

Adaptations of plants and animals other than man to the highland environment are many, but one is especially pertinent to the theme of this paper. Sheep, cattle, and camelids are ruminants, animals which support in their first stomach an enormous population of microorganisms capable of enzymatically converting cellulose into carbohydrates and organic acids, which the ruminant can then use as energy sources (Miner, 1971). This adaptation allows these animals to live on

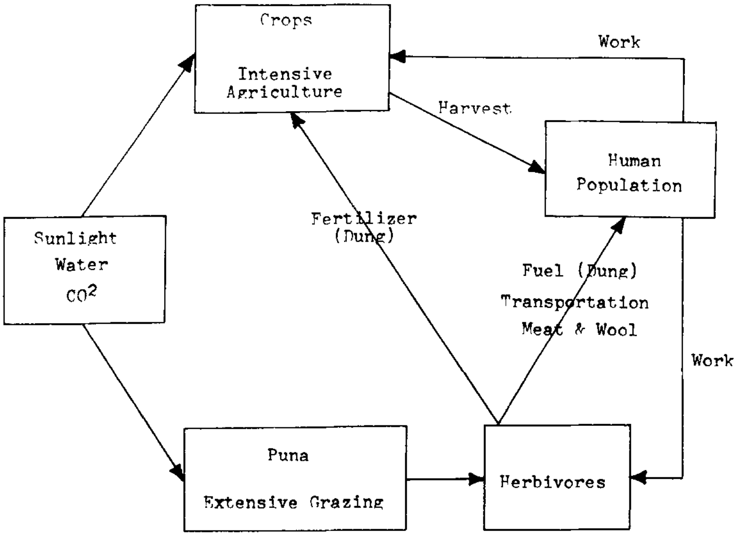

Fig. 5. A simplified diagram of the subsistence system for Nuñoa. An explanation is provided in the text.

the sparse and seasonally dry *puna* vegetation, effectively digesting what would otherwise be a poor source of food (Gilmore, 1950). Hafez *et al.* (1969) point out a further value of ruminant digestion: "grazing permits the animal to gather a maximum amount of feed with a minimum amount of exposure in an open field situation; rumination permits the animal to finish eating the gathered food at its leisure, perhaps in a less vulnerable environment." This advantage could be quite important in the inclement *Altiplano* environment.

Our interpretation of the role of dung in the highland subsistence pattern is summarized in Fig. 5. In simple terms, this diagram points out that sunlight, water, and carbon dioxide provide conditions for two categories of producers: the natural vegetation and crops. Humans invest work in the crops and harvest the results directly. Work is also invested in the domesticated herbivores, allowing indirect harvesting of the *puna*. Herbivores can be used for their wool, dung, meat, and organs, and in the case of llamas, for transportation.

Dung is a crucial connection between the extensive natural ecosystem and the intensive agriculture of the human population within that system. The grazing animals channel a widely dispersed and low-rate primary productivity into the human population, concentrating and reconstituting the energy and nutrients into forms usable as fuel or fertilizer. The *puna* grasses on which the animals graze are useless for either of these purposes, and alternatives such as wood, kerosene, and commercial fertilizer are unavailable or prohibitively costly. By producing manure, the animals and their attendant rumen organisms are acting in the functional role of decomposers, with some of the dung diverted from the decomposer cycle for use as fuel.

ACKNOWLEDGMENTS

We would like to acknowledge the assistance of Michael Little, Victor Barreda, Jorge Huayhuaca, Stephen McGarvey, James Larrick, and Nicole and Darna Dufour, and the patient cooperation of the people of Nuñoa.

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