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Terracing and Irrigation in the Peruvian Highlands[1]

by David Guillet

Agricultural terraces in the Colca Valley of southern Peru facilitate the irrigation necessary for agriculture in this semiarid environment. Terrace expansion and contraction, in turn, are closely related to the availability of water. In the short term, households abandon terraces because of constraints in the system of water distribution. In the longer term, periodic droughts trigger water conservation practices which curtail expansion and lead to terrace abandonment. During periods of relative water abundance, constraints are relaxed, allowing new terraces to be constructed and abandoned ones rebuilt. Cyclical patterns of terrace contraction and expansion suggest that repeated observations of land use over time are necessary for an understanding of agricultural intensification and deintensification in the Central Andes.

DAVID GUILLET is Associate Professor of Anthropology at the Catholic University of America (Washington, D.C. 20064, U.S.A.). Born in 1943, he was educated at Loyola University (B.A., 1965) and at the University of Texas (Ph.D., 1974). He has published *Agrarian Reform and Peasant Economy in Southern Peru* (Columbia: University of Missouri Press, 1979), "Toward a Cultural Ecology of Mountains: The Andes and the Himalayas Compared" (CURRENT ANTHROPOLOGY 24:561–74), and "Reciprocal Labor and Peripheral Capitalism in the Central Andes" (*Ethnology* 19:151–67). The present paper was submitted in final form 24 XI 86.

Aboriginal agrarian systems in the New World have been the object of increasing attention in the last two decades. Scholars are now engaged in intensive archaeological, ethnological, geographical, and ethnohistorical research on a variety of ancient land use systems in the highlands and lowlands of Central and South America (Ravines 1978, Donkin 1979, Lechtman and Soldi 1981, Denevan, Mathewson, and Knapp 1987). Work of this kind promises clarification of a number of important questions concerning land use and agricultural intensification and deintensification that have surfaced during the same period. This paper presents the results of an investigation of an aboriginal terrace system in highland Peru focusing on the relation between terracing and irrigation.

In *Agricultural Terracing in the Aboriginal New World*, Donkin (1979), drawing from archaeological reports and the observations of travelers, documented large-scale aboriginal terrace systems in a number of locations in the Americas. One especially significant area was the Central Andes. During Inca times large expanses of land were farmed using terracing to overcome the difficulties in cultivating slopes. The ubiquity of the Andean terraces was noted by the early Spanish chroniclers, who marveled at the genius of Inca engineers.[2] It is generally accepted that terraces were being built long before the advent of the Incas, and there is good reason to believe that they date to as early as the pre–Early Intermediate Period, ca. 500 B.C. (Donkin 1979:17). The perfection of terracing and its widespread expansion occurred, however, under the Incas in conjunction with the increased cultivation of maize, a crop with ceremonial significance which could be easily preserved, stored, and transported (Murra 1960).

After the conquest of the Inca Empire by the Spanish in 1532, native agrarian systems collapsed, and agricultural production dropped precipitously. Only recently, with the aid of aerial and LANDSAT photography, have quantitative estimates of the scope of terrace abandonment been made. Masson (1984) gives a figure of approximately 1,000,000 hectares of terraced land in Peru, only a small portion of which is currently in use. On the western slope of the Peruvian Andes, 40 of the 54 coastal river valleys contain approximately 300,000 hectares of terraced land. The Rimac Valley has an estimated 6,382 hectares of terraced land: of those, 1,213 hectares are in use, another 1,046 are in good repair, and 3,523 are abandoned. Wright (1963:13) estimates that 80% of the terraces in northern Chile are abandoned. Denevan and Hartwig (1986), using 1:17,000-scale aerial photographs, calculated that 61% of the terraced fields in ten districts between Chivay and Cabanaconde in the Colca Valley are abandoned.

Rejecting the idea that terraces were constructed primarily to check soil erosion, Donkin (1979:34) argued that terracing was designed to overcome the major disadvantages of slopes for farming in areas with a marked dry

1. This article reports on research conducted with the assistance of a research leave from the University of Missouri–Kansas City and the Title XII Collaborative Research Support Program under Grant No. AID/DSAN/12 XII-D-0049 in collaboration with the Instituto Nacional de Investigaciones Agro-Pecuarias and the Universidad de San Agustín, Peru. Additional support was provided by the University of Missouri–Columbia. The Center for Latin American Studies of the University of Florida supplied travel funds for use of the Latin American Library there. An earlier version was presented before the departments of anthropology of the universities of South Carolina and Missouri–Columbia and the Latin American studies centers of the universities of Florida and Texas. Helpful comments on earlier drafts came from William Denevan, Robin Donkin, Ricardo Godoy, Michael Malpass, Luis Masson, William P. Mitchell, Michael Moseley, and Bruce Winterhalder.

2. See Donkin (1979:20–21) for a summary of early references to agricultural terraces in the Central Andes.

season—thin soils and inadequate soil moisture. He suggested, further, that the relationship between terracing and irrigation can help to explain the process of terrace expansion and contraction (p. 132):

> Irrigation and terracing rested upon similar skills and experience. Terracing not merely stabilized existing cultivation, it also served to extend agriculture into climatically marginal areas, and this was particularly the case where terracing and irrigation were combined. Consequently any significant reduction in water supply, for whatever reason, was likely to be followed by a comparable reduction in the cultivated area.

An examination of a hypothesized relation between terracing and irrigation should touch on two issues. First, temporal trends in the water available for irrigation must be determined. The quantity of water that can be extracted from the environment depends, of course, on such variables as the rate of retreat of glaciers and rainfall. Trends and variations in environmentally determined levels of moisture over the short and the longer term must be isolated and examined in relation to fluctuations in the area of terraces under cultivation.

Second, the relationship of the social management of water to terrace contraction and expansion must be analyzed. Water management involves the creation of social institutions to transport water from its source to cultivators, to establish a set of principles governing water allocation, and to distribute water according to those principles. The amount that a cultivator receives from the irrigation system depends on the nature of these institutions. In the Central Andes, the management of water has tended to reside in local sociopolitical units. During the period of Inca hegemony, the state limited its control over water and land to the distribution of land and canals to *ayllus, panacas,*[3] and nobles. It exercised its interests in water by creating an official irrigation calendar and manipulating the symbols of water. Within the ayllu or on the noble's lands, land and water rights were regulated by panaca and ayllu authorities rather than by the state bureaucracy. Even in the Inca capital, there was local administration of each canal (Sherbondy 1982:98). The principle of local autonomy in water management in highland communities continued under colonial and republican administrations. Local systems remain confined to a community or adjacent communities today. While individual households maintain branch canals, the main canal is the responsibility of farmers acting jointly. Canal maintenance is usually accompanied by ritual.[4]

3. The ayllu is a kinship and local corporate group. The panaca is a royal ayllu whose head and founder was one of the ten official Inca kings (Sherbondy 1982:18–22).
4. Ethnographic reports on irrigation in the Peruvian highlands include Adams (1959) and Mitchell (1976); an account of irrigation ritual can be found in Isbell (1977).

Terracing in a Colca Valley Village

One of the most interesting places to look at the relationship between terracing and irrigation in the Andes is the Colca Valley in the highlands of the Peruvian Department of Arequipa. The Colca Valley lies on the arid, western side of the western branch of the Andean cordillera. The physiognomy of the area is a complex of high plateaus and well-graded moderate slopes created by uplift and glacial erosion and cut by deep canyons with steep sides and narrow floors. The floor of the valley consists of a deep layer of alluvial fill deposited during the Quaternary period and an inner valley now being cut by the Colca River. Villages tend to be located at the base of the slopes rising from the alluvial fill and to overlook the inner valley. A spectacular set of photographs of the Colca Valley taken during the Shippee-Johnson expedition in 1928–30 (Johnson 1930:23–30, figs. 23–28) documented large expanses of finely constructed terraces—both abandoned and cultivated—clinging to the sides of the lower and middle slopes of the valley (see, for example, Donkin 1979:100, fig. 3.53). Archaeological research has suggested that the upper terraces were built during the Middle Horizon, used during the Inca Period, and abandoned during the Colonial Period. The lower terraces, in contrast, were built and cultivated during the Inca Period and have been in use ever since (Malpass n.d.)

The main population concentrations occur in the middle section of the valley, from Chivay to Cabanaconde. They are survivals of a prehistoric Collaguas polity, conquered by the Inca under Mayta Capac and then Hispanicized as a result of the Spanish conquest (Málaga Medina 1977). As in most Andean valleys, both continuity and change are evident. On the one hand, village location and boundaries have remained relatively unaltered since the resettlements (*reducciones*) of the late 16th century. Early documents describe an agro-pastoral adaptation based on irrigated terraces and camelid herding (Ulloa Mogollón 1965[1586]). Maize, quinoa, and barley were produced on the terraced slopes and llamas and alpacas raised on the higher slopes and pampas. This basic adaptation has continued relatively stable in spite of some shifts in crops and animals. On the other hand, the demographic patterns of native Colca Valley populations have been significantly altered: there was a dramatic decline immediately after contact followed by a slow rise beginning in the middle of the 18th century and a sharp increase in this century. Cook (1982:81–88) has estimated that the preconquest native population was approximately twice that of today. The demographic pattern in the Colca Valley is thus quite similar to that found throughout the Central Andes (Cook 1982).

Lari is one of several villages on the north side of the Colca Valley. It is connected by an unpaved all-weather road from Chivay, the capital of Caylloma province and the transportation hub of the Colca Valley, to a mine at Madrigal. The population consists of predominantly Quechua-speaking farmers who depend directly or indirectly on cultivation of the terraced pampas and slopes surrounding their village. Aside from mine work for a few and occupations such as weaving, the village is oriented toward the production of foodstuffs for consumption. While some changes have occurred in the economy, the major shifts have been demographic: Lari's population has grown consistently since the 1940s, with a large spurt in the period between the census years of 1961 and 1972. In 1981, the latest census, 1,156 people were enumerated.[5]

On the contours of sloping land rising from the valley bottom to the ledge on which Lari is located and from there to the slopes behind the village are rock-faced terraces. The expanse of terracing is most apparent during the agricultural season. Especially during the early months, from September to December, when little rain falls, the difference between irrigated and unirrigated land is stark. The current upper limits of agriculture follow a 3,600-m contour separating the green cultivated terraces from the upper, largely barren slopes.

The majority of the abandoned terraces are found above the 3,600-m contour. Another large section is located between cultivated terraces on the east side of the village in an area known as Humaro. Small patches of abandoned terraces are also dispersed seemingly at random throughout the cultivated areas. On the basis of measurements from aerial photographs, Denevan and Hartwig (1986) have calculated 478 hectares out of a total of 1,031 hectares of terraces (46%) abandoned. Overall 34% of fields (1,389 hectares) are abandoned.

Lari's terraces vary considerably in length and less so in width and height. The smallest measures two meters in length and a meter and a half from front to rear. Other terraces are several hundred meters in length and up to three meters in height. Several specialized features are often engineered into terraces. A concrete bath which fills with the warm waters of a thermal spring is built into a section of lower terraces abutting the Colca River below Lari. (Several others are found in similar positions in other villages.) Large rocks set into the terrace face allow one to climb from one terrace to another, and a small circular rock wall or indentation built into the bottom of a terrace face, called *utalla* in Quechua, is used for storage or for sleeping during the harvest, when crops have to be protected against theft.

Information on crops grown on terraced and unterraced land is presented in table 1. The two most important terrace-associated crops are maize and alfalfa. Maize is highly susceptible to frost, and slopes facilitate cold air flow that reduces frost risk. Maize is used in Lari for the preparation of foodstuffs and *chicha*, a fermented maize drink. It is also an important item in the barter for products of the upper grazing zone brought down annually by llama caravans. Alfalfa was first introduced into Lari in 1947 and is now cultivated during the traditional fallow period in maize agriculture. It is an important source of forage and is recognized as having soil-improving qualities.

Crops associated with unterraced plots, located on patches of relatively flat land, include, in order of importance, barley, alfalfa, maize, and broad beans. Barley is an important trade item, along with maize, and a major component of local diets. In spite of the fact that the valley lies within the "normal" limits of tuber cultivation, potatoes have never been an important component of the crop mix. According to informants, there is insufficient humidity to ensure potato yields.

Cultivators take advantage of the warmer temperatures of protected ravines and low terraces by planting eucalyptus (*Eucalyptus globulus*) and an edible fruited cactus, tuna (*Opuntia ficus indica*), on terrace faces and endwalls. They recognize that trees protect terrace faces against collapse and provide useful construction material.

The initial impression gained by the visitor to the Colca Valley is that terraces are part of a relatively stable, unchanging landscape. This impression is supported by the aridity of the valley. Terraces seem to be fossilized relics of an ancient agrarian system which, having resisted environmental disruption, continues to be used by an equally changeless peasantry. The impression of stasis could not, however, be farther from the truth. While their origins are in the past, terraces must be continually maintained. They are under constant threat, paradoxically, in this semiarid environment, from hazards associated with excessive water. Heavy rains from December to March cause soil erosion, weakening of terrace faces and endwalls, landslides, mudslides, and the flooding and subsequent washing away of terraces on the valley bottom.

Damage to a terrace usually begins with poor drainage that allows water to pool on the surface and causes the underlying fill to become waterlogged. A combination of pressure on the face of the terrace and overspill in places where water pools leads to rapid erosion and eventually the collapse of the terrace face. If upper terraces are not maintained, even well-maintained lower ones will be damaged.

The reconstruction of a badly damaged terrace involves technology within the expertise of every farmer in Lari. The technology is similar to the erection of a stone wall during house construction. First, a trench approximately 50 mm in depth is excavated into which a row of large stones is set, shimmed with smaller stones, and packed with earth. On this foundation the terrace face is then constructed by laying successive rows of stones, filling in the spaces with smaller stones, and carefully compacting with soil until the desired height is reached. Once the face is finished, the terrace is filled with soil from which stones and waste have been removed; otherwise, no special attention is given to the fill. The surface is graded flat or finished with a slight decline toward the face. In a variant of this technology,

5. Population figures for Lari from national censuses are: 1876, 237; 1940, 1,014; 1961, 1,318; 1972, 1,239; 1982, 1,156. For a detailed analysis of the population history of the Colca Valley up to the 1970s, see Cook (1982). Out-migration in the last 30 years has tended to counter to some degree the effect of declining neonatal death rates.

TABLE I
Crop Associations with Terraced and Unterraced Plots[a]

Plot Type	Alfalfa N	Alfalfa %	Potato N	Potato %	Maize N	Maize %	Beans N	Beans %	Barley N	Barley %	Wheat N	Wheat %	Total N	Total %
Terrace	70	34.0	4	1.9	99	48.1	15	7.3	14	6.8	4	1.9	206	100
Pampas	60	27.8	3	1.4	36	16.7	22	10.2	88	40.7	7	3.2	216	100

[a]Based on results of a land-use questionnaire administered to 54 household heads; $P < .05$

used for the construction of new terraces on uncultivated slopes, once the face is finished the terrace is allowed to fill with soil washed down by rain from above. (This method is also reported for the neighboring village of Coporaque [Malpass n.d.].)[6] In old terraces, one encounters stone-lined drainage canals, called *colcha,* and spillways. In contemporary terrace construction these refinements are usually ignored, although a feeder canal lined with flat stones is sometimes built into the terrace face. To ensure that the work is successful, a special ritual, known as a *tinka* in Quechua and a *pago a la tierra* in Spanish, is performed.

The best time for work on terraces is during the rainy season, from January to April, when irrigation is finished and there is a lull in agricultural chores. During this period the soil is easier to work because it is moist and rocks can be dug with little effort. Most important, soil is damp and consistent and can be packed into the foundation, walls, and terrace cavity. A well-packed terrace is said by informants to be the mark of good construction. If the construction occurs during the dry season, terrace walls and face cannot be well packed and will collapse at the first irrigation. In any event, the first irrigation of a new terrace must be done with care to prevent water from pooling on the surface, spilling over, and weakening the face.

The labor involved does not have to be highly skilled. There are no terrace-construction specialists. It is arduous, however, and usually the domain of adult men. Generally, it is carried out with household and exchange labor, although if time is short and funds are available, wage labor will be recruited. When informants were asked to estimate the time required to build a new terrace 100 m long, 3 m wide, and 2 m high with two men working full-time, the average of the estimates was a little over 43 days. This contrasts with an estimate of 9 man-days to construct a 100-m-long stone wall approximately 1.5 m high on flat ground. Time would, of course, be reduced if the labor force were expanded. For example, one informant estimated that the work could be completed in 5 days if 8 laborers were used. Time requirements also vary depending on the nature of the soil. Rocky soil is very hard to dig; while it does not provide good fill, it does offer material for wall construction. Sandy and loamy soils are easy to dig and use as fill but lack the rocks necessary for face and endwall construction.

Terraces and Irrigation

In the semiarid environment of the Colca Valley, it is impossible to discuss terrace systems independently of their role in irrigation. Terraces provide a surface for cultivation and, more important, for the flow of water to plots. Without irrigation, the slopes would be virtually uncultivable. Precipitation is simply too low and unreliable for rainfall agriculture. Around 400 mm of rain falls annually in the lower zone and 500 mm in the upper zone. While an occasional rain-fed terrace in the upper reaches of the cultivated zones is encountered, it is most commonly used for the cultivation of forage rather than food.

The water that feeds the irrigation system of Lari comes from the plateaus and snow-capped mountains of the puna. The snowmelts of peaks feed upland lakes and streams. Canals extract water from these sources and bring it down to the cultivated slopes, where it enters a complex system of feeder canals. Below the upper shelf, thermal springs occasionally provide a source of water for irrigating patches of land. About 88% (722.8 hectares) of the cultivated land in Lari (818.3 hectares) is canal-irrigated and about 12% (95.5 hectares) is spring-fed.[7]

6. It is also mentioned by Cook (1916:496) as an occasional method for terrace construction along the Urubamba River. There is another rarely used method in which the terrace face is constructed with large adobe slabs. I saw a new terrace, several hundred meters wide, constructed in this fashion, but informants pointed out that it would erode with the first rainy season.

7. Interestingly, the Colca River is not exploited as a source of water for irrigation. The lift from the level of the river to the communities is several hundred meters. The water is virtually impossi-

WATER TRANSPORT

The transport of water from its source high above the community to a farmer's plot depends on a complex system of main and branch canals and reservoirs. Three main canals—Chaico, Chunta, and Surimana—feed separate nodes of Lari's irrigation system. Water is moved from a main canal to the farmer's plot in two ways: it may be transported directly through feeder canals or stored overnight in a reservoir for distribution to farmers the next day. Reservoirs are usually positioned above the plots which they irrigate, often on marginal, otherwise unusable land. Other locations are low-lying marshy areas which may already be collecting points for underground water.

Open canals and packed-dirt reservoirs are inefficient in a semiarid environment with porous, volcanic soils. Evapotranspiration, filtration, and waste result in considerable water loss. Lari's irrigation system lacks many of the refinements of Inca hydraulic engineering designed to cope with these problems, notably the lining of main and branch canals and reservoirs with stones (Sherbondy 1982:40–41; Niles 1982:168). Once water enters an agricultural terrace, however, water loss is reduced significantly. Terraces augment the water-holding qualities of soil and increase soil depth. A well-maintained terrace minimizes waste by channeling overflow onto lower terraces, keeping drainage rates at an optimum, and preserving topsoil.

WATER DISTRIBUTION

A second dimension of water management is the distribution of water shares to farmers. This is a complex process which rests on an efficient organization of space and time. Once water leaves a main canal and enters the cultivated area, an offtake, called a *toma,* diverts it to an irrigation sector. An irrigation sector consists of a group of contiguous plots within which water obtained from an offtake of a major canal or a spring is distributed. There are 19 of these sectors, varying with respect to soil quality, slope, exposure, and water availability.

Most irrigation sectors have elected water judges, called *regidores.* Regidores were originally officials of the Cabildo de Indios created by the reducción program of the Viceroy of Toledo. Four regidores were elected each January 1, together with other officials, and were given staffs as symbols of authority (Varallanos 1946:48). It is likely that, when this political organization was adapted to the conditions in the Colca Valley, the regidor was assigned the duties of water judge. In sectors which obtain water directly from main canals and indirectly from reservoirs, meetings (called *reginas*) are held once or twice a week to schedule distribution. In certain smaller sectors, no meeting is held; instead the regidor goes from house to house to make the necessary distribution arrangements. In a few very small sectors fed with water from a local spring, farmers work out an irrigation sequence among themselves and no regidor is named.

The *mit'a* is the length of time during which plots within a sector complete an irrigation cycle. Ideally, a mit'a should take no longer than 90 days. In sectors too large to be irrigated in this period, a mit'a can stretch out to as many as 120 days. The longer the mit'a, the greater the threat to crop production due to water scarcity.

IRRIGATION SEQUENCE, WATER FLOW, AND PLOT SHAPE

An important element of the architecture of irrigated terraces is endwalls which enclose vertical groups of terraces. Endwalls are usually continuous and when seen from afar appear to divide terraces into vertical strips. In one sense, landholdings are dispersed throughout the territory of Lari in a pattern common to Andean communities. On inspection, however, terraces are found to be held as vertical strips, one under the other, to facilitate a top-down pattern of irrigation. Attempts are made to keep holdings intact (on sale or inheritance) to accord with water allocation practice. Generally, an individual will own several terraces within a vertical section bounded by endwalls.

The first terraces to be irrigated are the ones closest to the offtake. Water enters the uppermost terrace of a section, usually at a corner but occasionally in the middle of a terrace. The next lower terrace is then irrigated with the overflow, and so on, until the lowest terrace has been irrigated. Depending on the width of the terrace, from one to four scratch canals will be temporarily cut into the terrace surface to distribute water evenly over the surface and across it to the face from which it falls to the base of the next terrace. After one vertical strip is irrigated, the sequence starts again at the top of the next vertical strip. The set of terraces closest to the offtake is called the head (*cabecera*) and the set farthest away the tail (*culata*). For example, irrigation of Huanconasa (fig. 1), a relatively small sector (9.5 hectares) divided among 27 individuals, starts at the northwest corner and proceeds down successive vertical strips until the southeast corner is reached, at which point the cycle starts again.

The location of terraces within a sector is a very important determinant of the relative quantity of water that will be available to them; those closest to the head will be irrigated first and those in the tail last. This becomes very important when a sector has insufficient water and must stretch out the mit'a beyond an ideal 90-day cycle. An extended wait for water may cause an owner to water too late to ensure seed germination or to maintain optimum plant growth. Owners with terraces near the tail in a sector plagued with water problems may forego cultivation or change to a less water-sensitive crop because of the insufficient supply of water.

ble to tap using traditional technology, and the use of motor-driven pumps would be extremely costly. The river has been dammed upstream in an ambitious project to irrigate land in the Majes and Siguas Valleys on the coast. Some communities on the south bank of the river have tapped into the large pipe along the way.

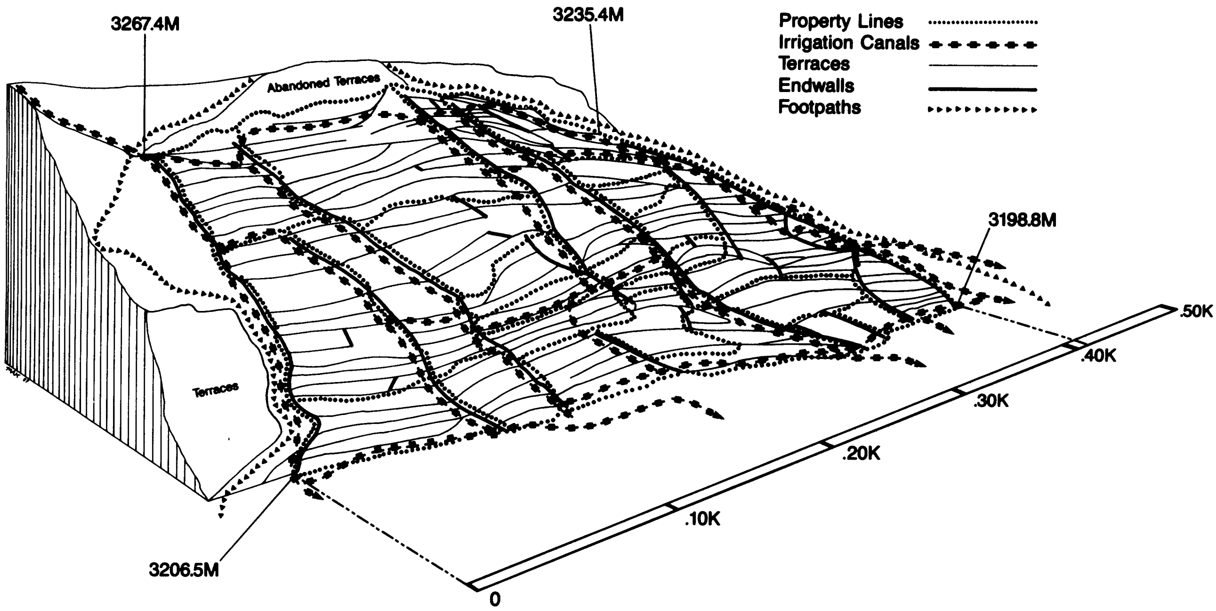

FIG. 1. *The irrigation of the Huanconasa sector.*

WATER CONTROL

One of the key elements of Andean agro-pastoral production is a distinction between privately controlled and communally controlled resources (Guillet 1981). With privately controlled resources, the owner is able to exercise autonomous control over use. The user of community-controlled resources is subject to rules concerning their use. Thus a resource that is individually used may not be individually owned and controlled.

In one sense, farmers in Lari are correct in saying that the community exercises no control over how their land is farmed. There are no direct communal control mechanisms, as in sectorial fallowing regimes found elsewhere in Peru, specifying what crops must be cultivated, in what sequence, and when land must be cultivated and left to fallow. Nonetheless, communal control of water indirectly governs the choice of crop and the area of land which an owner may put to plow. While land is individually owned, communal controls over water indirectly constrain the potential uses of land. In Lari land is alienable, but irrigation water must be obtained through the communal water management system. The need for such access constrains what people do with their land.

Communal control of water was formalized in the 1960s with the creation of a villagewide irrigation association, the *junta de regantes,* to help bring order to the traditional acephalous structure of water allocation. The junta is made up of water judges from each irrigation sector, a president, a secretary, and other minor officials. During the irrigation season, meetings are held every fifteen days. The junta, in turn, is subordinated to state control represented by a water judge (*juez de aguas*) and a water engineer, attached to the Ministry of Agriculture, who resides in Chivay. The state enters into irrigation decision making infrequently, largely to ratify succession to office in the village system, to help in irrigation engineering projects, and to remind the villagers of irrigation law.

Irrigation water is allocated by crop in a specific sequence: early (*mishka*) crops, maize, alfalfa, and barley.[8] A farmer may claim water only if his plot is planted in the crop specified for irrigation in the stage of the mit'a in question. Water obtained for one crop cannot be used to irrigate another; a fine is levied if a crop is irrigated out of sequence. Constraints to be discussed below inhibit the seeding of large amounts of land in one sector. The orientation of the system is toward subsistence agriculture with constraints having the effect of inhibiting specialized market production. There have been some shifts within the crop irrigation sequence, notably toward the incorporation of alfalfa, but by and large the system remains consumption-oriented.

WATER AVAILABILITY AND LAND USE

The success of the irrigation system depends, ultimately, on the absolute amount of water that enters it. Inasmuch as terrace agriculture depends on irrigation, terrace contraction and expansion can be expected to be linked to decline or increase in water availability.

WATER DECLINE AND TERRACE ABANDONMENT

The effect of the withdrawal of water can be seen in two historical cases of land abandonment. The first concerns

8. The sequence may be modified slightly in a particular sector because agronomic conditions make the cultivation of a certain crop unlikely. In the 1983 season, only a small amount of barley was cultivated in Charasuta and Surimana sectors, so it was irrigated along with alfalfa. The occasional plot with potatoes or wheat will be irrigated during the barley period.

Humaro, a large section of terraces on the east side of the village. According to the 1604 *Visita,* or tribute list, for Lari-Hurinsaya, one of the moieties into which the population was divided at the time, Humaro was an important section used primarily for the cultivation of maize. In the 1920s, the water from a high-altitude seep transported to a reservoir to feed Humaro's irrigation system stopped flowing. Terraces were soon thereafter abandoned by their owners, and the land reverted to communal control. It is now being used as a village pasture commons. The second case is Huaylincuna, a ravine behind the village, which used to carry water from a thermal stream to irrigate a small section of terraces at the base of the slopes rising behind the village. During the early 1960s, the stream dried up. Unable to find another source of water or negotiate with neighboring sectors for some of theirs, the landowners were forced to abandon their terraces.

WATER INCREASE AND TERRACE EXPANSION

Improvements in water capture and transport are the main vehicle for increasing the amount of water for irrigation. Over the last 30 years, new sources of water have been tapped, while water loss through filtration has been cut dramatically. Work began about 1960 with the excavation of a canal leading from a high-altitude seep northwest of the village down to Yanahua, an irrigation sector plagued with water scarcity. Two other seeps were subsequently connected to this canal. While the reservoir that the canal filled was not improved, the increase in water capture enabled abandoned terraces in Yanahua to be brought back into use.

By the beginning of the 1980s, projects to improve existing reservoirs or build new ones from scratch had been completed or were under way in five separate locations. With the exception of Yanahua, all of the reservoirs have been improved by lining the bottoms and walls with cement and installing check valves. In 1983, work began on the most recent project, to line Chaico canal with concrete provided by a government agency. These projects have been very successful in improving water transport. The traditional system of open canals and reservoirs allowed virtually unchecked filtration and evapotranspiration. Improvements to the system appear to fit a pattern: first, exploiting previously untapped sources of water in the upper puna, second, rebuilding older reservoirs and constructing new ones, and, third and most recent, lining major canals. As a result of all these efforts, many sections of abandoned terraces have been brought back into use.

TEMPORAL TRENDS IN WATER AVAILABILITY

The amount of water available for irrigation varies from year to year. If there are trends in this variation, then one would expect to find related trends in terrace expansion and contraction. Trends of this kind can be identified over the short and the longer term.

The short-term abandonment of small patches of terraces scattered throughout the cultivated area of the village can be traced to decisions of individual households to suspend cultivation for several possible reasons. One reason is agronomic: allowing plots to lie fallow for a few years to regain fertility. Others stem from household dynamics. In the course of the domestic cycle, demands on resources ebb and flow. As a young household expands, land is acquired and used increasingly intensively to meet the additional demands. As children leave the household and adult members age, pressures decline. Depending on the stage of the household cycle, needs may be met by cultivating only part of the land available to the household. In a related pattern, household members may move away from the village, retaining ownership of their land but abandoning its cultivation. Cyclical migration between Lari and mines in the highlands, Arequipa, other coastal cities, and the plantation zones of the tropics can be traced, in one form or another, to Inca times. Extended stays began to displace temporary migrations from about the 1960s on, as Arequipa and Lima came increasingly to represent final destinations for young men and women from Lari. Retaining land in the village has been a form of insurance for out-migrants in view of the risks of taking up residence in distant towns and cities. Paradoxically, while some land might be expected to be sharecropped by the nonresident landowner under these circumstances, out-migrants often prefer to leave land uncultivated than to cultivate it indirectly: under Peruvian law, if land is sharecropped for more than five consecutive years the tenant can claim rights of ownership.

Lastly, short-term abandonment can occur because of inefficiencies in water distribution. Regidores ideally distribute water to users in a sector according to the location of each plot and the crop irrigation sequence. In practice, there are numerous deviations from this ideal scheme. In most cases, they are episodic: a regidor may mistakenly assign a morning's worth of water to two individuals or a farmer may fail to claim water when his turn comes. More systematic deviations occur when a regidor regularly favors particular users. Favoritism and denial of water to legitimate claimants are very frequent complaints lodged against regidores. The only recourse is an attempt to have the regidor removed, a course of action that is successful only when a vociferous coalition of unheeded users can be assembled.

A longer-term trend refers to stretches of several years of below- or above-average rainfall. The longest recorded series of rainfall data for the Colca Valley comes from a weather station at Yanque, where measurements began in 1951 (fig. 2). Rainfall is highly seasonal, beginning slowly in August, picking up during September and October, and increasing dramatically during November. After March, it declines sharply; the months from May to August are extremely dry. Almost all of the annual rainfall comes in the five months from November through March (Oficina Nacional de Evaluación de Recursos Naturales 1973:44). The rainfall data from Yanque indicate year-to-year unpredictability with occasional stretches of years of extremely low rainfall. According to

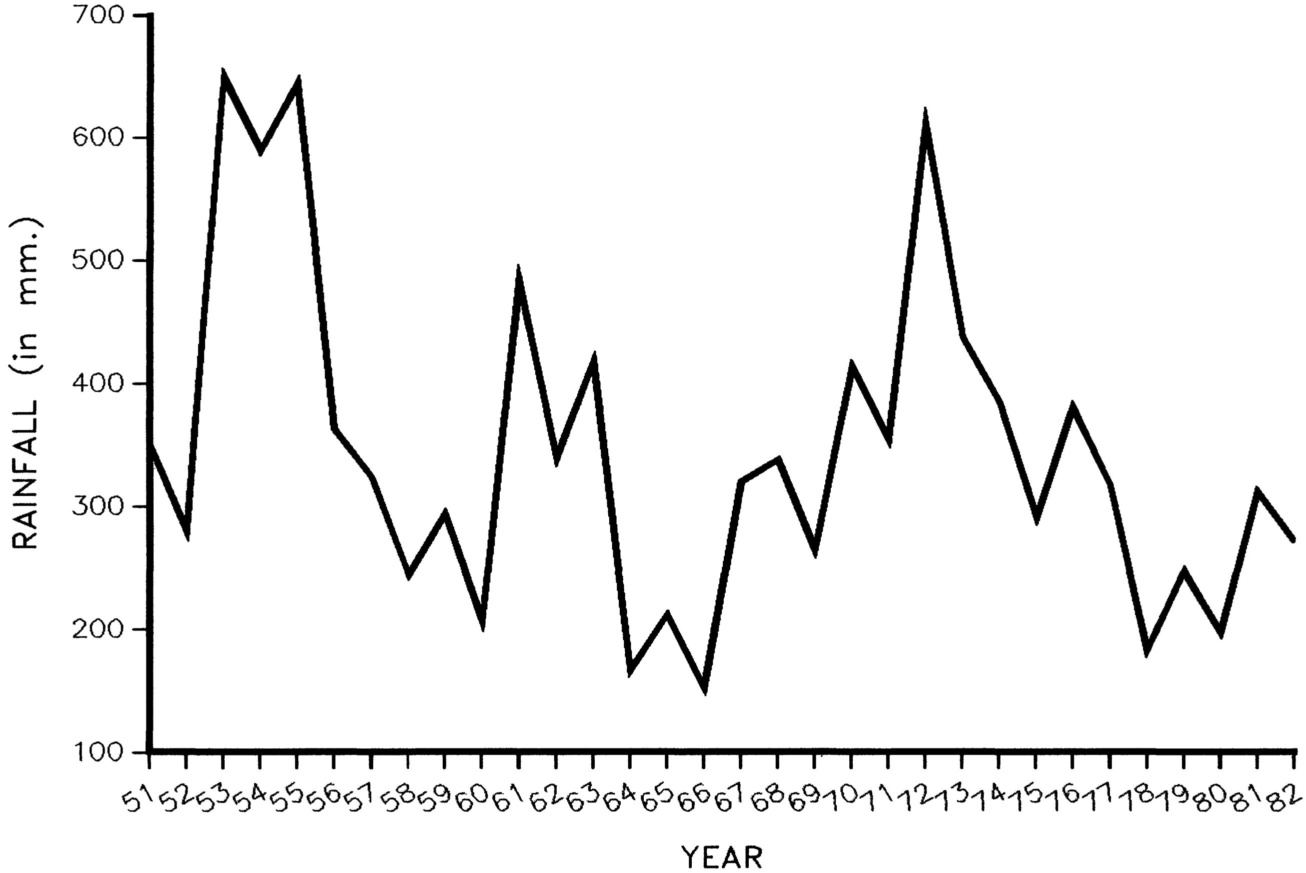

FIG. 2. *Yanque rainfall, November through March, 1951–82.*

Caviedes (1982, 1984), unusually wet years in arid northern and central coastal Peru, El Niño events, are often coupled with below-average precipitation in the southern highlands and the altiplano of Peru and the altiplano of Bolivia. The pattern was particularly evident in El Niño 1982–84 and the contemporaneous drought in the southern highlands. The 1982–84 drought was one of the most severe in recent memory (Claverías and Manrique 1983, Caviedes 1984). Agricultural production in Arequipa Department declined 29%, and estimates of die-off in the alpaca population of Caylloma ranged as high as 50%. The highlands of the department were dramatically affected, as is evident from the reports of mothers' bringing children showing symptoms of malnutrition to hospitals in Arequipa. Over 400 metric tons of donated foodstuffs were dispatched to the stricken zones.[9]

The response of the village to water scarcity in this period indicates that measures taken during drought years to limit the total access of individuals to water can lead to terrace abandonment. As water became increasingly scarce, it became obvious that in many sectors regidores would be unable to supply water for all claimants if the needs of the *mayoristas,* those who possessed more than five *yuntadas*[10] of land in a sector, were met. This problem was brought by the regidores to meetings of the junta de regantes. In the discussions that followed, it was agreed that limits would be set on the amount of water a landowner could receive in a sector. Set early in the 1983–84 season at the amount sufficient to irrigate two yuntadas, the limit was later changed to one yuntada when the plight of Chaico sector, with the largest number of users and little water, became apparent. The effect of this measure was to force mayoristas to abandon much of their land in sectors in which it was concentrated. According to informants, the practice of placing upper limits on water access by sector is consistent with the principle that every farmer is entitled to a minimum quantity of water suitable for subsistence production. It is a principle which is invoked during years of extreme water scarcity.

In years of above-normal rainfall, land use is allowed to expand. This can be observed in Lari in the conversion over the last 30 years of communally controlled, uncultivated land with no water rights into private plots with water rights used for house sites and agricultural plots. In these cases, new plots were placed last in the irriga-

9. The effects of the drought were the subject of a series of articles in *El Pueblo* (Arequipa), in particular, September 16, 1983, November 22, 1983, November 27, 1983, and March 17, 1984.

10. A yuntada is a local measure which corresponds to the amount of land which a team of oxen (*yunta*) can plow in a day.

TABLE 2
Conversion of Communal Land to Private Use, 1966–82

Year	Number of Conversions
1967	1
1970	3
1971	1
1972	2
1973	5
1974	3
1978	4
1980	1

SOURCE: Minutes of the District Council, Lari (Libro de Actas, Consejo de Lari).

tion sequence. In table 2, conversions recorded in the minutes of district council meetings from April 1966 (the earliest available data) to May 1984 are presented. The last recorded conversion was September 26, 1981, with an entry that no more communal lands remained in Lari or outside. While the number of cases does not allow for statistical analysis, the majority occurred during the years 1970 to 1974, a period which coincides with a series of wet years in the valley.[11]

CONCLUSIONS

The agricultural terraces of Lari are a key element in a successful agro-pastoral adaptation to the slopes of this otherwise inhospitable valley. Their contribution is due in large measure to their role in facilitating irrigation. Terraces do improve the microenvironment for growing crops and defend slopes against soil erosion. However, this valley, like others on the western slope of the Andean cordillera, receives insufficient rainfall to support stable and productive agriculture, and the irrigation facilitated by terraces is essential.

Where moisture is in short supply and terracing is instrumental in bringing supplemental water to fields, a relationship between water availability and terrace contraction and expansion may be expected. In Lari loss of water leads directly to terrace abandonment and the discovery of a new source or the improvement of an existing source to the construction of new and the rejuvenation of abandoned terraces. Short-term abandonment of patches of terraces is due to a household's inability to establish a claim to water in a sector or its stage in the domestic cycle and its fallowing practices. In the longer term, periodic droughts trigger water conservation practices which can curtail land expansion and lead to terrace abandonment. During periods of relative water abundance constraints are relaxed, allowing new terraces to be constructed and abandoned ones rebuilt. The cyclical patterns of terrace contraction and expansion suggest that an understanding of agricultural intensification and deintensification in the Andes requires repeated observations of land use over time.

Longer-term trends in water availability and their association with terrace contraction and expansion have not been directly examined in this study, but the evidence presented suggests that they may have a role in explaining the abandonment of agrarian systems in the Central Andes following the conquest. A common theme in discussions of Andean environmental history is that there has been a trend of increasing aridity during the last 2,000 to 2,500 years (Antúñez de Mayolo 1981). A reduction in rainfall has been proposed by Maldonado and Gamarra Dulanto (1978[1945]) to account for abandoned terraces in the Rimac Valley and by Donkin (1979:17) to explain the abandonment of terraces in general. A hypothesized association between a long-term trend of declining rainfall and terrace abandonment would best fit the upper belt of abandoned terraces in Lari above the current upper limits of agriculture at about 3,600 m. At the time of the *Visita de Lari-Hurinsaya* of 1604, some areas in this belt were being used to cultivate maize. These areas are now herding ranches (*estancias*). Larenos attribute their abandonment to the drying up of their sources of water, citing canals and reservoirs that fed them but are no longer in use.

Recent evidence based on an ice core taken from the Quelccaya ice cap northeast of Cuzco (Thompson et al. 1985) challenges the notion of a long-term pattern of increasing aridity. This ice core has been used to determine precipitation on an annual basis over the past 500 years and by decade over the past 1,500 years. The results show significant variation from a mean that has remained relatively constant. During the last 500 years, a dry period preceded an extremely wet period from 1500 to 1720 followed by a dry period lasting till about 1860 and, during the 20th century, a return to a wet period. Long-term trends in water availability should be evaluated alongside of factors such as the introduction of new cultigens (Mitchell 1985), tectonic uplift (Moseley 1983), and depopulation (Cook 1982) in explaining patterns of terrace abandonment since the conquest. This is the goal of a multidisciplinary project now under way in the Colca Valley (Denevan 1986).

The nature of the terrace-irrigation complex in the Colca Valley must be seen in the context of rainfall patterns encountered elsewhere in the Central Andes. As average annual rainfall increases or declines, the role of terracing can be expected to vary. In the inter-Andine valleys, rainfall increases to between 400 and 800 mm annually. Irrigation there is largely used to stabilize irregular and often late-arriving rainfall and to extend the growing season for maize (Mitchell 1976). Rainfall increases substantially along the eastern slopes of the Cordillera. Irrigation becomes less important than drainage to prevent the rotting of crops. Thus, in the eastern-slope village of Cuyo Cuyo, in the Department of Puno

11. For a fuller description and analysis of these data, see Guillet (1987).

in southern Peru, terraces are unirrigated and farmed under a sectorial fallowing regime (Camino 1982). Their features appear to be designed to help drain excessive water, which in this high-rainfall area can lead to crop rot.

Comments

DAVID L. BROWMAN
Department of Anthropology, Washington University, St. Louis, Mo. 63130, U.S.A. 4 III 87

The Lari data, along with a recent paper by Valderrama and Escalante (1986), give us a solid grounding in the terrace irrigation techniques of the Upper Colca drainage. Guillet's work is extremely useful; I have questions to raise or additional data to provide in three areas: social management of irrigation water, abandonment of fields, and climatic shifts.

Guillet suggests that demographic pressure has resulted in change in the length of the irrigation cycle. As important as changes in the interval between irrigation *turnos* is the duration of the period of access to water during a cycle. Gelles (1986:125) reports that demographic pressure in his Central Peruvian (Rimac) study area of Casta resulted in a shift from 6 *turnos* a day in the 1930s, with the complete cycle taking 10 days, to 8–15 *turnos* a day in 1985 and a cycle of 20–25 days. In Yanque, 10 km from Lari in the Colca, the irrigation cycle is 30–45 days, depending on the sector, elevation, stage of field labor, type of plant, type of soil, microclimate, size and dispersion of the fields each household has in that sector, and phase of the moon (Valderrama and Escalante 1986:187–89). The length of the cycle in Lari, ideally less than 90 days but sometimes up to 120 days, is in sharp contrast to those of both Yanque and Casta. Perhaps each *turno* in Lari is considerably longer?

The apparent difference between Lari and Yanque in access rights for households by sector is intriguing. Guillet indicates that water access is by some sort of seniority in the addition of land to the sector, with the last lands added being the last to receive water, while Valderrama and Escalante (1986:188) indicate that the size and number of fields each household has in the sector are more important variables. In the Yanque case, a farmer who has only one parcel in a sector is accorded higher priority for that parcel than the household with multiple fields in that sector.

Scarcity of water is argued by Gelles (1986:129) to result in centralized social control, though he notes that Guillet's Lari data appear not to support his theory. A central issue not remarked on by either Gelles or Guillet is the source of the water. Gelles's Casta water is all from a single riverine source, whereas in the Colca Valley water comes from different seeps, springs, and highland snowmelt. In both Lari, as reported by Guillet, and Yanque, as reported by Valderrama and Escalante, the water source defines the sector. Households for each separate sector and water source (or series of water sources) do in fact exercise strict centralized control of that supply, with a number of water judges who must oversee the opening and closing of sluice gates and a variety of fines and social sanctions imposed on violators.

In addition to climate, Guillet considers tectonic movement a possible reason for abandonment of the terrace irrigation systems. While I have argued that tectonic movement was important in the abandonment of irrigated fields in North Coast valleys (Browman 1983:568), the situation in the Colca area seems to have more to do with the nature of the water source (seeps, springs, and small snowfed reservoirs) in contrast to the river-fed system of Moche, for example. Guillet reports the abandonment of the Humaro terraces in the 1920s because the high-altitude seep dried up and of the Huaylincuna sector in the 1960s with the disappearance of the ephemeral stream that had fed it, and Clement and Moseley (1986) report a similar pattern for the nearby Ilo/Moquegua area.

Guillet suggests that the El Niño rains on the North Coast might be correlated with concurrent droughts in the southern highlands and altiplano, but this correlation exists only for the most severe El Niños. The El Niño is part of a more complex phenomenon known as the El Niño–Southern Oscillation, which is characterized by a poleward (or southerly) shift of the Intertropical Convergence Zone over the Pacific combined with a northward shift of equatorial and tropical Atlantic pressure centers and trade systems, resulting in weaker trade winds carrying less moisture across Amazonia (Flohn 1984:13; Francou and Pizarro 1985:16; Caviedes 1982:68; Rasmusson 1985:169). During a severe El Niño, these conditions produce abnormal rains on the Pacific coast and abnormal droughts in Amazonia and the south-central Andes, which derive their rains from Amazonian trades (Francou and Pizarro 1985:10; Caviedes 1984:289), but such severe conditions occur only three or four times a century. A very mild El Niño–Southern Oscillation is currently in progress, and rains in southern Peru as of January 1987 were reported to be quite normal.

Guillet notes that the majority of abandoned fields lie above 3,600 m. With Lari at 3,330 m, this indicates the possible contribution of a longer-term climatological factor. In the central sierra, Cardich (1982:17; 1985:305–7) noted that current cultivation limits are about 250 m lower than the maximum limits during the prehistoric Early Intermediate (A.D. 1–500) and Late Intermediate (A.D. 1000–1450) periods, with a maximum fluctuation over time of 400–700 m. Schoenwetter (1973:103) reports strong evidence for a longer growing season at higher elevations prior to the 14th century in the Asto area, and Donkin (1979:36) summarizes similar patterns of abandonment of terrace fields in the Titicaca basin, southern Bolivia, northern Chile, and northwestern Argentina. Table 1 summarizes recent climatic evidence for the altiplano (Browman 1986:60). Some researchers (Wright 1980:254; Hastorf 1983:44) argue that Andean

TABLE 1
Altiplano Climatic Shifts for the Last 1,500 Years

Radiocarbon Time A.D.	Precipitation	Temperature
600–950	Wetter	Cooler
1050–1450	Drier	Warmer
1500–1700	Wetter	Cooler
1700–1850	Drier	?

SOURCE: Modified from Browman (1986:60).

Holocene glacial advances are related primarily to cooler temperatures, but at least for the more recent periods in the southern Peruvian area the "warm glacier" phenomenon (Lauer and Frankenberg 1984:104) is more important. In this case, glacier growth is correlated with increased precipitation rather than decreased temperature (Sanchez and Kutzbach 1974:131; Lauer and Frankenberg 1984:104; Thompson, Mosley-Thompson, and Morales 1985:971). Thus glacial retreats may be provisionally correlated with periods of reduced precipitation or drought. Abandonment or expansion of terrace systems above or below the 3,600-m line in the Colca may relate to these longer-term climatic shifts. The complete Colca system may well turn out to be a very complex one; while the upper valley is influenced by these factors, the lower valley may be under the influence of a more coastal regime, with climatic shifts inversely related to the sierra pattern (Paulsen 1976:128; Smith 1985:614).

Diachronic change in the Lari system clearly is a function of a still poorly understood complex of both social and natural constraints. Guillet adds a significant series of observations that will help us decode the system.

TERENCE N. D'ALTROY
Department of Anthropology, Columbia University, New York, N.Y. 10027, U.S.A. 6 III 87

Guillet's article makes a useful contribution to study of land-use patterns in the Andean highlands. His principal argument is well-taken: the intensity of use of terraced land varies as a result of a complex mix of environmental, demographic, and social factors. He also provides interesting ethnographic evidence for shifts in water-management policy as a result of environmental and demographic changes in the region. There are, however, some issues that call for further scrutiny or presentation of more detailed information.

The first issue concerns the relationship between the intensification of agriculture through terrace construction and the management of irrigation water. Guillet correctly points out that decentralized kin-based control over local subsistence terrace and irrigation systems seems to have been widespread in late prehistory (e.g., Netherly 1984). He also cites archaeological evidence that places the two major phases of terrace construction during times of Wari and Inka expansion into the region, however, a pattern that has been suggested or documented for numerous areas of land improvement within the Andean highlands. At least in some of the major Inka projects of agricultural intensification, such as in Cochabamba and Abancay, the state took control over the productive resources, often bringing in colonists to cultivate the preferred maize crops (e.g., Wachtel 1982, La Lone and La Lone 1987). Over the course of the empire's development, these lands played an increasingly important role in underwriting the imperial political economy. They formed part of a significantly different kind of agricultural system than the local subsistence one in that they were intended for forced surplus production and were not subject to the same kinds of internal disputes over access to water. Because of this, the citation of family or kin-group management of irrigation systems here is curious. More likely is that irrigated or otherwise intensified state lands were managed by local functionaries supervised by central authorities.

This raises a broader issue of agricultural practices and socioeconomic processes. Because agricultural production may be increased in a variety of ways, an increase in imposed demands for the regional political economy (e.g., under the Inkas) or in market demands (e.g., in the modern cash economy) will not necessarily result in intensification of land use in any given locality. In general, increased yields at the regional level can be obtained by either (1) intensifying production on lands already in use or (2) bringing previously unused lands into production.

Guillet documents a pattern of intensified and diminished use of a relatively localized set of terraced lands. For a comparative case, I would like to draw on the results of archaeological research in the Upper Mantaro and Yanamarca Valleys of the Peruvian central highlands (Parsons 1978, Hastorf and Earle 1985). Studies of long-term patterns of land use here indicate that, because of warfare, the most productive maize lands were substantially underused in the century preceding the Inka conquest, while the higher tuber-complex zones were heavily cultivated. The most extensive premodern irrigation systems were constructed at this time, along with the larger terrace complexes and ridged-field systems. Under Inka rule (1460–1533), the underutilized maize lands were opened up for imperial and local use. Some terracing was probably carried out in the maize lands under the Inkas, but the intensity of land use decreased radically in the tuber-growing areas even though overall regional production increased. This shift was a result of (1) movement of most of the population to lower-elevation sites, so that maize lands formed a higher proportion of the immediate catchment zone of many communities, and (2) preferential cultivation of maize by the Inka state.

This example simply reinforces the point that an explanation of the use of one kind of subsistence resource—in this case, terraced lands—must include a consideration of the distribution of population, sociopolitical demands on production, and the population's access to other productive resources. It would therefore be useful to have additional information on patterns of agricultural activity on nonterraced lands in the Colca Valley and its environs to place this study in a broader context.

The data presented in the tables and figures raise an additional issue. Guillet suggests that there is a positive correspondence between rainfall (fig. 2) and land conversions from public to private control (table 2). While the evidence cited does fit this argument, more patterning may be present than he discusses. The highest numbers of annual conversions appear to have taken place two years after short-term peaks in rainfall (e.g., 1973, 1978), whereas the lowest numbers occurred shortly after local minima (e.g., 1967, 1971, 1980). This suggests that people may be leery of investing in private lands shortly after unproductive years, while productive years soon stimulate a spate of conversions. Decisions to convert may be made on an ad hoc basis, with short-term memory playing an important role in longer-term cycles of intensification and reduction in intensity of land use. Guillet notes that the data presented are scant, and the patterning I have suggested here may therefore be more coincidental than real, but it might be rewarding to see more information on this issue.

These comments should be taken more as a call for additional research than as criticism, since the article provides useful information and makes an interesting argument for cyclical use of intensified agricultural resources.

ROBERT C. HUNT
Department of Anthropology, Brandeis University, Waltham, Mass. 02254, U.S.A. 12 II 87

The basic point made by Guillet—that there is a mutual adjustment between (1) construction and use of terraces and (2) water supply for irrigating them in this part of the Andes—is welcome. It is rare that anthropologists measure two or more variables in real time. It would be better if in this case we had more precise measures of the number and area of terraces that go out of or come into production and for how long and more precise measures of the amount of water available. As it stands the account is largely impressionistic.

The use of the term "abandonment" of terraces not currently in production may be conflating conditions that are significantly different. Some terraces that are not currently being cultivated may be in fallow, and others may be uncultivated because their owners are away from the town and do not wish to jeopardize their ownership rights. These terraces are presumably in relatively good condition and perhaps even maintained. Some terraces (e.g., those above 3,600 m), in contrast, have not been cultivated for decades or centuries. (In these cases it would be interesting to know their property status.) All of these are apparently being called "abandoned" here. The term would therefore seem to be unproductively ambiguous.

Two points can be made about the water in the irrigation system. First, it is hard to believe that evapotranspiration or evaporation will be affected by lining the canals. Canal and reservoir lining usually affects only filtration. Second, percolation does not always have the negative effects suggested by Guillet in these cases. Percolation and filtration, if they occur from a canal into a field, can be either beneficial or detrimental to the crops in that field; the field can become dangerously waterlogged (and often salinized) or it can receive needed water that would otherwise not be available. Each field has to be specifically investigated: general rules are very hard to apply generally. It is also the case that the water lost from an upstream part of a canal can percolate underground and eventually appear in fields downslope, depending upon the characteristics of the various soils between the filtration point and the downslope field. This water may even flow back into canals and provide surface irrigation for downslope areas. I would therefore urge the author to have a closer look at the hydrological details of his site the next time he is in the field.

GREGORY W. KNAPP
Department of Geography, University of Texas, Austin, Tex. 78712, U.S.A. 23 II 87

Most irrigated terraces are constructed because ultimately they improve yields sufficiently to justify their huge labor inputs. The yield improvement comes not only through rationalized water supply but also through delivery of fertile silt, at least when the canals are unlined. Experiments in the northern Andes show that unlined canals deliver silt with up to five times more available phosphorus than nearby cultivated soils. Silt is harvested from reservoirs and canals and used as fertilizer (Mothes 1986). Without this external nutrient supply, slopes would have to be fallowed so often as to render uneconomic terrace wall construction and repair. Unirrigated terraces require nutrient application in another form. In the pre-Hispanic Andes this was probably camelid dung or guano, and it is likely that irrigated terraces received manure as well. The distribution of Andean terracing tends to mirror the pre-Hispanic distribution of extensive camelid populations—abundant in southern Peru, northern Argentina, and Chile (Field 1966), virtually absent in northern highland Ecuador. Terraces and herds were symbiotic. Fertility management is especially important for tubers, since the high labor requirements of tuber harvest make high yields necessary. The absence of potatoes in the Colca Valley is suggestive of worn-out soils; perhaps the abandonment of the upper terraces was due in part to the breakdown of dung-collection practices.

Where attractive alternatives existed, terraces were not constructed. Near the Lake Titicaca flats, perhaps the richest agricultural land in pre-Hispanic southern

Peru, the most elaborate terraces are on the islands. There is relatively little cultivable area in the (admittedly spectacular) valley-side terracing of the Vilcanota Valley, where attention was clearly focused on the valley floors. Even where there is no flat land, it is often possible to irrigate quite steep slopes without terraces, using the *canterón* or serpentine-furrow technique. Probably terraces were most important where (1) there was little flat land and (2) slopes had soils too shallow or stony for *canterón* irrigation but (3) there was abundant water with good nutrient characteristics and ideally (4) there were abundant camelid herds to supply dung. Under these circumstances, the labor inputs Guillet cites—equivalent to about eight person-years per terraced hectare!—become acceptable.

Guillet's discussion of terrace abandonment is reasonable. Perhaps the word "deintensification" is to be preferred to "abandonment," since uncultivated terraces are grazed and occasionally dry-farmed. Deintensification is linked in part to water supply but also to water demand. The demand of a crop for water depends partly on its maturation time, the time between planting and harvest when water is required for growth. Maturation times vary from crop to crop: maize has the longest maturation time of high-elevation crops and therefore requires irrigation for the longest period. The tubers have shorter maturation times. Might the upper terraces have been used at one time for tuber production, with resulting lower water requirements per hectare?

Maturation times increase with elevation. At higher elevations, crops are sown earlier and/or harvested later; a greater proportion of the crop cycle occurs outside the rainy season, requiring substantially greater irrigation. This effect can be muted if the rainy season is longer at higher elevations, but this seldom happens at the same rate that maturation times increase. Even though higher elevations are cooler, crop water demand (potential evapotranspiration) does not greatly decrease at higher altitudes. Other things being equal, it pays to irrigate a given crop at the lowest possible elevation. This phenomenon helps explain the observed altitudinal zonation of deintensification.

The link between climate change and deintensification is tricky. El Niño is probably not important. The events are sufficiently widely spaced—usually at 4–12-year intervals—that traditional farmers can cope with them readily. Also, not all Niños affect the highlands.

Another process affects the Andes: the North Atlantic Oscillation (Knapp 1984), which has been linked to the occurrence of the Little Ice Age. The effects of this oscillation seem to be most pronounced, however, at lower elevations, with a fade-out above 3,000 m as local convectional processes begin to dominate rainfall. If this is the case, processes related to solar radiation—atmospheric dust or changes in the solar "constant"—could be most responsible for variations in ice-cap behavior.

Guillet's paper is a welcome addition to the small but growing literature focusing on adaptive choice in Latin America (Denevan 1980, 1983). The focus on problems, challenges, and events in connection with specific components of technology makes possible a truly contextual approach which is also historical and person-centered. It is astonishing that there have been almost no scientific studies of terracing in the Andes since O. F. Cook's work over 70 years ago; fortunately, the work of Guillet, William Denevan, John Treacy, and others in the Colca Valley is now providing our first comprehensive picture of this technology.

THOMAS F. LYNCH
Department of Anthropology, Cornell University, Ithaca, N.Y. 14853, U.S.A. 3 XI 87

Guillet's interesting summary of terracing and irrigation in Lari may not represent a typical situation in the "Peruvian highlands," much less northern Chile, where he cites a terrace-abandonment figure of 80%. Throughout, he discusses "long-term trends in water availability" and "trends of increasing aridity" as if the causes were mostly natural rather than social and political. Yet, by his own admission, data from the natural sciences speak against a long-term pattern of increasing aridity, at least since preceramic times—despite occasional attempts by desperate prehistorians to explain all cultural changes in terms of droughts and other natural catastrophes. The disruption of water delivery by tectonic uplift and incision of coastal valleys is, of course, a phenomenon separate from Guillet's highland case. Furthermore, Lari's phreatic source of water should be more stable than the runoff used in most stream- and river-fed irrigation systems.

Water loss and terrace abandonment in the south-central Andes result in large part from social and political, not natural, causes. Important among these are the capture of irrigation water for the mining industry and urban water and sewer systems. The introduction of new cultigens, barely mentioned by Guillet, has also been important, as in the case of sugarcane, orchard crops, and even onions. In fact, wherever irrigation systems produce for national and international markets rather than local consumption, informants and ethnographers may report decreasing rainfall. I suspect that *rising* population, on a national scale, has led to more terrace abandonments in highland Peru than local "depopulation." And, to carry the argument a bit further, if areas used for maize production at the time of the 1604 *Visita* now produce forage and meat, this may have much less to do with "drying up of their sources of water" than with roads, trucks, markets, and other Western culture patterns.

In his largely futile search for natural causes, Guillet seems to me to be missing or skipping over much of the point and meaning of 19th- and 20th-century terrace abandonments. While once the Andean irrigation systems were traditionally governed to meet the needs of local consumption, they are being increasingly redirected (and often in subtle and unconscious ways) to serve market economies, modern states, and urban populations.

WILLIAM P. MITCHELL
Monmouth College, West Long Branch, N.J. 07764, U.S.A. 3 III 87

Water management is a central requirement of Andean agriculture. On the coast of Peru the problem is aridity; in the sierra both addition and elimination of water are required. The term "semiarid" to describe the sierra climate obscures the reality of the annual variation between a desert-like dry season and a very wet rainy season. Irrigation is used during the dry season to provide water for household consumption, to cultivate dry-season crops (*michka*), and to plant high-altitude maize in the major crop cycle (*hatun tarpuy*) (Mitchell 1976). Terracing has two major functions: irrigation of crops and facilitation of drainage at the height of the rainy season.

Guillet ably illustrates the relationship between terracing and irrigation in the Colca Valley, and I agree with his analysis of Camino's (1982) data on Cuyo Cuyo in Puno suggesting that there terracing is used for drainage. To understand the different functions of terracing, in addition to local variations in rainfall a difference in soils must, I think, be examined. In Quinua, a village in the Ayacucho Valley, the soils contain a great deal of clay and dry soil is rock-hard, whereas in the Colca Valley dry soil is much more friable. A major concern of Quinua farmers is to prevent root rot, especially of seedlings, during heavy rains. As in the Colca Valley, Quinua terraces are associated with irrigation, but they also provide both soil conservation and drainage (Mitchell 1985).

The association of terracing and irrigation with private land tenure to which Guillet points is also found in Quinua. In 1973 the government agency SINAMOS attempted to implement the agrarian reform law, which among other provisions would have rendered all land communal. Initially, the population was divided into two camps. After months of discussion and angry debate, the majority opposed the reform in the belief that irrigated lands were private property to be passed on to children and that only the lands above the irrigation system were communal property. Most Quinuenos feared that they would lose the right to transmit their capital-intensive lands to their children and to retain them if they were to emigrate. Even the smallest landholders were won over to this position, in spite of the widespread fear that opposing the reform would result in the imposition of taxes. Land tenure is a complicated issue (Mitchell n.d.), but this incident serves to demonstrate a definite association between irrigation and notions of private tenure.

I have one caveat about Guillet's description of Lari as a village "oriented toward the production of foodstuffs for consumption." This traditional description of Andean communities obscures the complex economic reality. My research demonstrates considerable economic exchange between Quinua and its coastal migrants: foodstuffs sent to the coast in exchange for medicines, other manufactured goods, and money (Mitchell 1982*a*, *b*; 1986). Guillet is certainly aware of that complexity (e.g., Guillet 1980); I simply want to suggest that we abandon the shorthand description of highland people as a subsistence-oriented peasantry in favor of terminology that better describes an economic reality in which they produce not only for their own subsistence but also for the market, exchange, long-distance trade, and the payment of rent (e.g., in sharecropping and other labor arrangements) (see Orlove and Custred 1980). Indeed, migration from local communities can be viewed as a mechanism by which such communities articulate with the international economic system (Mitchell 1987), a far cry from the subsistence-oriented peasant.

ANTHONY OLIVER-SMITH
Department of Anthropology, University of Florida, Gainesville, Fla. 32611, U.S.A. 3 III 87

The visitor to many regions in the Andes is often struck by the number of unused agricultural terraces. In the region of my own research, the Callejón de Huaylas, the ruins of terracing exist not far from contemporary field cultivation. Consequently, as an anthropologist long curious about this phenomenon and with a long-standing interest in the adaptation of Andean populations to their environment of extreme variations and high levels of risk, I find this article useful and informative, particularly from the technological and environmental perspectives. In addition to showing us how a native Andean irrigation and terracing system works mechanically, how to build one, and how to maintain and improve one with existing materials, Guillet has provided us with a good demonstration of the capacities of an Andean agricultural technology for coping with water scarcity and maximizing the exploitation of scarce land resources. However, given the increasing attention to long-term agricultural contraction and the fact that a majority of the 1,389 abandoned hectares in the community studied are above 3,600 m, I am a bit puzzled why tectonic uplift is not given more consideration as a possible explanation. None of the other possible explanations discussed specifically addresses the issue of higher-altitude abandonments. It is not clear whether the two historical examples of terrace abandonment account for a significant portion of the abandoned plots that constitute a third of the total available land in the community.

The strength of the article lies in its demonstration of the important relationship between terracing and irrigation and the role water plays in the expansion and contraction of terracing. Particularly interesting is the environmental vulnerability of the terracing itself. The role of terracing in reducing frost risk, bringing steeply sloped land into cultivation, and limiting soil erosion is also important to the ecological analysis, which clearly demonstrates the highly adaptive nature of the terracing/irrigation complex in an environment of extreme water fluctuations. However, I would have liked to see some of the social and ideological implications of the relationship between terraces (land) and irrigation (water) developed. While Guillet does give us a clear description of the institutions and principles associated with the management of water, the social and ideological contexts of these institutions and principles are not sufficiently well developed.

The politics of the situation are alluded to only briefly. Who gets elected(?) to the junta de regantes? How does a person qualify for the position? How long does he serve? What is the extent of his power, and what are the costs and benefits of serving in this position? How do these positions fit into the structure of internal differentiation in the community in terms of power relations? Are we to assume that labor for system improvements (as opposed to individual terraces) is organized in the traditional República fashion, or are there other arrangements? What is the relationship of the junta de regantes to the formal political authorities of the village? These and other questions concerning the politics of water management merit more attention if we are to understand the irrigation/terracing complex in its social context.

Another question that deserves further discussion deals with production goals and market access. Although I do not dispute the consumption orientation of the community, I note that it has an all-weather road to the provincial capital, which in all probability is a market town. Further, it becomes apparent in the discussion of the 1982–84 drought that there are marked differences in landholdings in the community, some people owning much more than others. I perceive a basic tension in a community with at least some internal differentiation in terms of landholdings between market access and a consumption-oriented agricultural system largely regulated by the communal control of water. The increasing penetration of market relations in the Andean region in general would accentuate this tension. I would also imagine that this tension would become particularly acute in the context of a drought, when prices for agricultural products in a market would rise and irrigation water would be cut back to survival limits, forcing larger landholders to abandon land. This principle of limiting irrigation water to survival levels, if it is accepted unprotestingly by all, indicates that irrigation has not only a major role in survival but considerable power in the working out of social relations and the ideological dimensions of community solidarity as well. Social relations and the viability of adaptive strategies, particularly in times of stress, are closely related.

Guillet's article is a valuable contribution to the ethnography of the Andes and a substantive addition to our understanding of terracing and irrigation systems. From the technological and environmental standpoints it is excellent. From a social perspective, I would have wished for a fuller treatment of the politics of water management and its role in social relations and community solidarity. Perhaps Guillet would see these issues as falling outside his goals of establishing a relationship between terracing and irrigation. I feel that the relationship of water and land in the Andes exists in a social context that merits somewhat more attention than it receives here.

JEFFREY R. PARSONS
Museum of Anthropology, University of Michigan, Ann Arbor, Mich. 48109, U.S.A. 26 II 87

This paper is a good example of what we need a lot more of in Andean anthropology: detailed studies of contemporary agricultural systems, especially those deeply rooted in indigenous adaptation. Guillet does an excellent job of informing us about several important aspects of the complex interrelationships between plant cultivation, water manipulation, local administration, and climate variability. This study and comparable investigations carried out recently in other parts of the Andes are beginning to provide good comparative data on variability over time and space in the role of agricultural terracing. The increasing frequency with which these ethnographic, geographic, and historical studies are being undertaken is particularly encouraging to me as an archaeologist trying to understand the significance of pre-Hispanic terracing in the Andes and in other parts of the ancient world.

Studies like Guillet's are forcing archaeologists to realize that terracing must be understood as the material manifestation of a series of dynamic interactions—of which natural elements like soil, water, erosion, and climate are only part of the picture. Guillet is at his best, it seems to me, when he reminds us that terracing in different areas may serve quite different functions (e.g., irrigation and water retention versus drainage) and when he stresses the close link between terracing and irrigation in arid and semiarid regions. He also provides archaeologists with very good insights into how local cultivators adapt to the basic characteristics of water supply (e.g., patterns of field configuration, water allocation, land tenure, field expansion or contraction, and reactions of local administrators to changing circumstances).

What is largely missing from Guillet's study, and what archaeologists and cultural geographers commonly tend to lose sight of as well, is a systematic consideration of the cultural forces that may be causal factors in terrace expansion and contraction. It seems to me that the search for these causal factors needs to consider things like tribute imposition (or tax increases), warfare, regional sociopolitical reorganization, changes in trade patterns, and population fluctuation as well as natural factors like soil quality or rainfall. The recent evidence (cited by Guillet) for the long-term existence of short-term cycles of rainfall fluctuation in his study region is a good example of the need to pay more attention to cultural factors in the search for explanations of change. Guillet explicitly recognizes the importance of population decline after initial European contact in the 16th century. He also notes the recent increases in local population. However, nowhere is there a real effort to grapple with the very interesting relationship between long-term changes in demographic pressures and changes in agricultural intensity.

What archaeologists need most from Guillet and his colleagues working with ethnographic and historic materials in places like the Colca Valley is a broad, regional perspective, with as much time depth as possible. Only then will it be possible for archaeologists to comprehend and appreciate the full complexity of the dynamic cultural and natural forces that have shaped the courses of agricultural intensification in the Andean sierra. Only with this quality of information will archaeologists interested in prehistoric agricultural intensification in the Andes be able to make use of ethnography, geography, and history to go beyond the comparatively simple environmental analogies that they have largely been satisfied with so far.

It was not to be expected, of course, that such a broad perspective and long time depth could emerge in Guillet's short paper here, with its necessarily limited scope. Nonetheless, for an archaeologist, this paper succeeds rather well in delineating some of the important elements of agricultural intensification in an Andean setting. Furthermore, it suggests that in its final form, the Colca Valley project should provide an extremely important foundation for future archaeological research in Andean agricultural production and long-term cultural change.

JEFFREY QUILTER
Department of Anthropology-Sociology, Ripon College, Ripon, Wis. 54971-0248, U.S.A. 5 III 87

Guillet's information on the hydrological, technical, and social units of irrigation in Lari covers the range of topics necessary to any investigation of irrigation systems from a local or a comparative perspective (Kelly 1983). The relationship of water sources to main canals and their articulation to feeder canals and reservoirs is of particular interest. To what degree is the difference between direct (from feeder canals) and indirect (from reservoirs) access the result of environmental, technical, or social factors? Guillet suggests that reservoirs are often associated with marginal land. If more terraces are available than are currently used, then what factors are important in the use of the marginal-reservoir terraces today? (Or are they mostly unused?)

As one especially interested in prehistory I was intrigued by a number of interesting points raised by Guillet with reference to past construction and use of the terraces. I am uncertain whether all terraces in use today were built during the Middle Horizon and Late Horizon (Inca) periods. If they were, why the absence of Inca hydraulic engineering techniques (lining of main and branch canals to reduce water loss)? Have these simply not been maintained as canals have been repaired? Though not the subject of Guillet's present paper, clarification of the sequence and nature of terrace constructions in the Colca Valley might contribute to current discussion on state expansion in the Andes (e.g., Paulsen 1976, Conrad and Demarest 1984).

Another valuable and important contribution to diachronic studies of terracing and irrigation is Guillet's estimate of the labor costs for constructing terraces and walls. More data of this sort could help us at least roughly calculate prehistoric energy investments. But did the informants who provided the figures for constructing a terrace have firsthand experience, or were they providing educated guesses? Expansion and deepening of discussion of this and related topics touched on by Guillet will be of interest, as will the continuing studies of the members of the Colca Valley project in general.

JEANETTE E. SHERBONDY
Department of Sociology, Washington College, Chestertown, Md. 21620, U.S.A. 24 II 87

Guillet's article is a major contribution to our knowledge of the dynamics of terracing. It is particularly important to know about short-term as well as long-term patterns not only to reconstruct a livelier culture history but to examine these patterns in relationship to contemporary problems of agrarian management. We have had a tendency to think in terms of an average year, which in reality rarely occurs. The usual climatic pattern in the Andean highlands seems to be years of drought and years of unseasonable or excessive rain. When the normal year occurs, it does so only in one area of the Andes, while in other parts there are valleys suffering from floods or droughts. Furthermore, there are longer-term trends of climatic variation. Given the contemporary crisis of agriculture of the highlands, it is urgent to study how the indigenous Andean peoples cope with those seasonal fluctuations within an agricultural system that has evolved in situ over several millennia, adapting to Andean ecology with terracing and irrigation technologies and with endogenous social relations of agricultural production.

Another valuable aspect of Guillet's article is his analysis of communal versus individual control over water. This system has the flexibility to accommodate fluctuations of individual families' needs and possibilities for cultivation. It permits larger families to expand their cultivated area to the limits of the ecological capacity of a zone during the relatively long periods of abundant water, maximizing the use of water resources. However, during the drier years communal authorities guarantee the stability of the community by distributing the water equitably to all families, thus preventing the formation of a dominant class based on a monopoly of the water. Social mechanisms of this sort would have been important in the maintenance of the ayllu throughout Andean history, but one wonders whether failure to recognize these communal rights may not sometimes have played an important role, for instance, in the early Inca period, in the development of classes that came to dominate farmers poorer in land and water.

Guillet's choice of the Colca Valley is significant in that it has a reputation for having particularly well-built terraces that imply economic importance in the pre-Hispanic and colonial periods. Now we need comparable studies in other valleys of the central Andes. This one sets a good example.

JOHN TREACY
Department of Geography, University of Wisconsin–Madison, Madison, Wis. 53706, U.S.A.
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The puzzle of land abandonment in the Colca is unsolved, although Guillet and also Denevan (1986) have made considerable headway. The central issue, as Guillet points out, is water. Irrigation systems embrace hydrological (including precipitation), technical, and social dimensions (Kelly 1983). Shortcomings within one or more of these could lead to abandonment; the task is therefore to discover within which dimensions failures have occurred. On the basis of my fieldwork in Coporaque, a village 12 km east of Lari, I suspect that social and historical changes can explain water shortages.

The fact that the valley has been so thoroughly terraced indicates that water there was always in short supply. Even the pampa fields show signs of embanking and leveling to conserve moisture. Typologically, almost all the Colca fields are terraces by virtue of being artificially leveled, and Guillet is correct in drawing attention to the notion of terracing as a hydraulic accommodation. Essentially, the valley was engineered to confront water scarcity.

The people of the valley also needed to reach far and high for water. Canals in Coporaque extend to the upper limits of the watershed, and an abandoned but salvageable segment crosses into the distant Apurimac drainage area. Other local sources have dried up (and occasionally reappear), but significantly large streams have been seized by neighboring villages at various times in the past. This suggests that the geographic range of water procurement was once greater and that valleywide distribution patterns may have been drastically altered by *reducción* resettlement and/or subsequent political adjustments. There is scattered evidence as well that ancient farmers collected and stored runoff (*lloqlla* in Quechua) in tanks now abandoned and forgotten.

Unused canals are linked to abandoned terraces in Coporaque, although most of these canals have their intakes on functioning watercourses now tapped downstream. Restoring abandoned canals and their high, distal-end terraces requires permission from the junta de regantes. As Guillet describes for Lari, in times of abundant water permission is often granted. However, opening new lands meets resistance from other farmers, primarily mayoristas from Coporaque Urinsaya, who fear there will be less water for their greater land endowments. Although farmers bemoan water scarcity, they often suspect that tenure inequalities and poor management are in part to blame.

The altered crop repertoire and the relationship between water and frost may have contributed to land loss. Colca farmers are caught in a calendric squeeze between the date of onset of the *puna* rains that feed their canals and the dates of the fall frosts. If water is not available for August through November planting and crops are seeded later, they may be severely damaged by May and June frosts. Timing as well as quantity of precipitation is a key to a successful crop in the Colca. Maize is relatively safe on valley-side bench terraces, but European grains and broadbeans now planted on frost-prone pampa fields are at risk. These fields are usually irrigated first for early planting and harvesting to beat the frost. Colonial *visita* data disclose that quinoa, a relatively frost-resistant cultigen, was widely seeded in those same fields. Thus pre-Hispanic and early colonial-period farmers may have had a grace period and could have started planting during the later, wetter months of the year. Drought conditions and frost may help explain why quinoa was seeded in large amounts in the Colca.

Water availability does indeed determine terrace expansion and contraction, but one need not invoke climatic shifts alone to account for water scarcity. Still, mysteries abound in the Colca. Almost 300 hectares of *unirrigable* terraces of uncertain antiquity and use are abandoned and crumbling in Coporaque. Also, archaeological evidence (Michael Malpass, personal communication) indicates that Inca-period cultivators restored terraces abandoned by earlier builders. Abandonment need not be entirely a postconquest phenomenon. We need to reconstruct climate histories to resolve the issue, but we also must try to reconstruct the human history of the Colca, which is still poorly understood.

Reply

DAVID GUILLET
Kansas City, Mo., U.S.A. 20 IV 87

My aim in this article was to bring ethnographic material to bear on the functions of terraces, arguing, in particular, that for the arid and semiarid Andes their primary role is to facilitate the irrigation necessary for agriculture. This appears to have been accepted by the commentators. I also sought to show how variation in the availability of water for irrigation could be used to explain fluctuation in the intensity of terrace use in the time periods for which I had data. This receives qualified support, with reservations concerning (1) the role of other "natural" factors, such as soil, climate, and tectonic movement, in explaining fluctuations in terrace use and (2) sociocultural forces that mediate the relationship between terracing and irrigation.

The association between terracing and canal irrigation can be expected to be best expressed in arid and semiarid areas of the Andes such as the west slopes of the cordillera. Future research should focus on terracing and other aspects of water control in relation to regional variation in precipitation, soil type, and other edaphic factors. Cost-benefit calculations based on labor costs and returns expressed in productivity measures will be useful, as Knapp suggests, in this effort. We will be better able to explain spatial and temporal variation in the location and elaboration of terracing, such as the concentration of terraces in the islands of the Lake Titicaca basin and the restriction of highly engineered terracing to the slopes of the Vilcanota Valley. The anomaly that Quilter points to, the lack of canal lining in an area such as the Colca Valley, plagued with filtration, may profitably be examined through the testing of land-use-intensity models. The refinement of terraces in the Vilcanota Valley may be attributed to proximity to Cuzco as the lack of refinement in Colca Valley terraces reflects distance from it.

Several commentators mention other natural factors that play a role in terrace dynamics. According to Mitchell, terraces in Quinua are instrumental in the drainage of hard-pan soils and the improvement of soil tilth. While farmers in Lari do have to be careful in managing the flow of water through a terrace, their loose, porous, soils do not present the same problem as in Quinua. In fact, Colca Valley soils are unusually fertile, with good tilth (Sandor 1986). Levels of organic matter are comparable to those of the mollisols of the U.S. Midwest. Soils are generally rich in total and available phosphorus. Productive soils are also suggested by crop-yield data: average yields reported by the Agricultural Ministry and local farmers for barley (1.2 tons/hectare, 1980–82) and wheat (1.7 tons/hectare, 1982) are comparable to average U.S. yields (barley and wheat both 1.7 tons/hectare) (Janick et al. 1974). The lack of significant potato production in the Colca Valley cannot be explained by worn-out soils, as Knapp surmises.

The use of terraces, actually irrigation canals, to deliver fertile silt to fields in the northern Andes is intriguing. My recollection of a presentation by Knapp on these systems is that reservoirs, cleaned periodically of silt for distribution to fields, are small and privately owned. In Lari, they are communal property. While there is an annual cleaning, division of the silt among all communal members is unwieldy, and it would be impossible to distribute it to fields via a canal. In response to Quilter, reservoirs allow water to be collected at night for distribution the next day. The marginal land on which they are located is usually an outcropping or rise that overlooks the land the reservoir is used to irrigate. Lining main, communal canals (but not branch canals) with cement is a popular improvement in the Colca Valley. It dramatically lowers the high filtration rates (but has no effect on evapotranspiration, as Hunt correctly points out).

Several commentators raise questions concerning long-term patterns of intensification and deintensification. Browman's comments on the role of climatic change in this regard are provocative. This dimension of long-term land use has not received the attention it deserves, perhaps because of difficulty in assessing its importance. I have found references in a 1604 visita of Lari-Hurinsaya to the cultivation of maize in upper areas that informants say are too cold at present for maize. Coca (*Erythroxylum coca* probably var. *coca*) is listed in the document as growing in a warm and protected section of lower terraces close to the Colca River. *Erythroxylum coca* var. *coca* is cultivated today in the moist, montane tropical forest along the eastern slopes of the Andes and in the wetter inter-Andean valleys, in the ecological zone of the montaña. It is largely grown between 500 and 1,500 m in elevation but may reach 2,000 m in some areas (Plowman 1984:133). The cultivation in 1604 of coca in the lower terraces and maize above the current upper limits of agriculture raises the possibility that temperatures have declined since that time. As Cardich (1974, 1985) has pointed out, a very small increase or decrease in mean annual temperature can have a significant effect on vegetation zone. Other evidence for crop and production-zone shift in the Colca may be lurking in the collection of visitas at Yanque.

D'Altroy's suggestion that conversions of communally controlled land to private control may be made on an ad hoc basis, with short-term recollection playing an important role in longer-term fluctuations in terrace use, is interesting. While the available data are insufficient, I do hope to address this in future fieldwork in the village.

Browman and Oliver-Smith suggest that tectonic shift may have been a factor in terrace abandonment. Most water that feeds the Colca Valley irrigation systems comes from the surface capture of snow and glacier melt and precipitation in the upper zones high above the village. Thermal springs that emerge in the porous soils of the lower alluvial terraces are a less important source, but, as is evidenced by Huaylincuna, they do dry up. Informants say that new ones emerge, a phenomenon also occurring in nearby Tapay (Karsten Paerregaard, personal communication). Whether spring movement is caused by tectonic shift and results in a net loss of water availability is not clear.

The flurry of recent attention in the El Niño phenomenon has been directed largely to the coast because of the devastating flooding of 1982–83. Its related impact on the highlands is less well understood. The issues raised by Browman and Knapp concerning the causes, range, thresholds, periodicity, and other aspects of El Niño coast-highland associations need to be addressed. Unfortunately, the necessary long-term precipitation records for the highlands are extremely poor, with the longest available series for the southern Peruvian highlands, from Chuquibambilla, beginning only in 1931. The coverage may be too spotty to resolve these issues at present.

Several commentators address the role of sociocultural forces in mediating the relationship between irrigation and terracing. Oliver-Smith asks for a broader treatment of these forces for a fuller understanding of the irrigation system. Parsons raises questions concerning their role in terrace contraction and expansion. And Lynch elevates them to a dominant role in explaining terrace use, downgrading natural forces.

I chose to focus narrowly on those aspects of the irrigation system that relate directly to water allocation and distribution and indirectly to terrace contraction and expansion. The Lari irrigation system is very complex, and limits had to be established for the purposes of the paper. It will be the subject of a longer treatment in which the politics, ideology, and social organization of irrigation will be dealt with in much greater detail. I will be able to address, in response to Parsons, long-term demographic changes through the analysis of excellent records available in the Yanque parish archives and elsewhere. Many of these issues are the subject of ongoing research in several Colca Valley communities by a number of individuals.

It is possible to make some tentative observations about certain of these issues. The politics of water allocation and distribution, mentioned by Treacy, Browman, D'Altroy, and Oliver-Smith, is a case in point. First, in response to Browman, the landowners within a toma do elect water judges (regidores). The principles that they follow in water distribution are set in a higher-level villagewide irrigation association. It is most accurate to describe the irrigation system as centralized at this level rather than within separate tomas. While centralized, however, irrigation management is no longer the responsibility of municipal officials. The creation of a special-purpose institution is of recent origin, dating from the intervention of the Ministry of Agriculture in the 1960s. In Tapay, a more difficult-of-access neighbor of Lari, the irrigation system was only last year (1986) reorganized into a villagewide association under the guidance of Ministry officials (Karsten Paerregaard, personal communication). Under the Inca, and perhaps earlier, as D'Altroy suggests, a great deal of local autonomy was granted water judges and irrigation management (Garcilaso de la Vega 1966[1609]:248; Guaman Poma 1980[1584–1614]:1058; Sherbondy 1982). The rather recent organization of villagewide irrigation associations separate from the authority of municipal officials is a step, at least in the Colca, toward returning independence to irrigation management. But it raises the question of the extent to which local irrigation systems under Incan hegemony, while autonomous, were internally centralized above the level of water judges and tomas.

Oliver-Smith and Mitchell note the importance of market forces in the Andean highlands and ask whether they may have played a role in mediating the relation between terracing and irrigation in Lari. This is certainly an appropriate question. First, the usual indicators do not suggest marked class divisions and agrarian conflict in the Colca Valley. Haciendas are absent because of the peculiar nature of the impact of the mining boom in the 17th and 18th centuries (Manrique 1986). The region did not participate in the peasant movements of the 1960s. Indicators of stratification based on land measures do not show significant class differences (Guillet n.d.). The wool circuit has pulled the region into regional and international markets, but its effect has been felt largely in the higher, pastoral zones. A major obstacle to the emergence of stratification has been communal control of water, in particular, the principle of a subsistence minimum invoked during droughts.

Lynch decries the role attributed to natural forces in explaining terrace expansion and contraction, positing social and political causes such as the diversion of water to mines and cities, the introduction of new cultigens, and roads, trucks, and markets. He supplies no evidence to make a case for these factors in Lari or elsewhere in the Andes. In the Lari case, the Caylloma mines were located in a separate watershed high above the Colca Valley and never competed with it for water. Until the 1980s, the Colca Valley has been one of the most difficult-of-access regions in the Peruvian highlands. The province, during the colonial period, was so isolated that corregidores there were able to act relatively independently of the crown, forcing it to appoint special officials to oversee their fiscal responsibilities. It was extremely difficult to find individuals who would accept an oversight position in such a distant province, and seven successive corregidores successfully ignored them (Lohman Villena 1957:483–84). Few mestizo and European travellers from Arequipa to Cuzco in the 18th and 19th century visited the valley, preferring an alternative route that bypassed it (e.g., Hill 1860:133–80). The Incaic road passing through the Colca Valley may have been used after the Conquest largely by peasants in their exchanges between different ecological zones. At any rate, until the construction of a rather good road network connecting the valley with Arequipa in the 1980s, it can hardly be said that transportation and communication networks were sufficient to have had the impact on the valley that Lynch suggests.

The introduction of new cultigens, mentioned also by Treacy, may have had an effect on terrace use by increasing demand for water in some cases. The substitution of barley and broad beans for quinoa should be evaluated for its effect on water use. It seems unlikely that it would have resulted in terrace deintensification on the scale known to have occurred in the Colca and elsewhere in the Andean highlands. Alfalfa, for example, an apparently water-intensive forage crop, has been introduced into the valley within the last 30 years. However, its incorporation into irrigated agriculture has been carefully controlled so as not to jeopardize the water available for subsistence crops. Only the minimum amount of water necessary for sustained growth is allocated alfalfa, not the large, continuous quantities necessary for optimum yields. Indeed, the fact that alfalfa can survive under drought and frost conditions (it has very long roots) is cited by many farmers in Lari as the reason for its adoption. Upper areas used for maize in 1604 are either too cold or lack the water necessary for agriculture. Their shift to seasonal grazing cannot be attributed to market forces. There may be something to Lynch's contention, but a critique on the merits of the case presented here or elsewhere in the Andes would better serve the discussion than mere assertions.

This should not be taken to suggest that long-term agrarian change in the Colca Valley can be explained entirely in terms of water availability. A number of other factors are the object of inquiry in the Colca case, including depopulation due primarily to epidemic disease, climatic change, tectonic uplift, management efficiency, changes in land use, social access to water, and rural-urban migration (Denevan 1986). They should and will be tested in the archaeologic, historic, geographic, and ethnographic studies now under way and in the planning stages. When completed, the research will add a significant new chapter to our understanding of land use and patterns of agricultural intensification and deintensification in the Andes.

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