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Prehistoric Landscape Management in the Andean Highlands: Raised Field Agriculture and its Environmental Impact

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ABSTRACT: The terrain within the Lake Titicaca Basin in the Andean highlands of Peru and Bolivia is a highly human-modified landscape. Archaeological investigations document that massive landscape modifications were undertaken throughout prehistory in order to intensively cultivate marginal lands. The paper focuses on raised fields, large earthen platforms which prevent waterlogging and flooding, increase soil fertility, conserve moisture, insure nutrient production and recycling, and improve crop microclimates. The environmental implications of the construction of over 82,000 hectares of raised fields for local vegetation, microclimate, soils, sedimentation, and hydrology are examined. The reuse of raised field agricultural technology to solve some problems of current land management is also discussed.

INTRODUCTION: THE CREATION OF PAST AND PRESENT ANDEAN LANDSCAPE

To the contemporary agronomist, the *altiplano* or high plain located at 3800 m above sea level around Lake Titicaca in southern Peru and northern Bolivia is considered to be a marginal landscape for agricultural pur-

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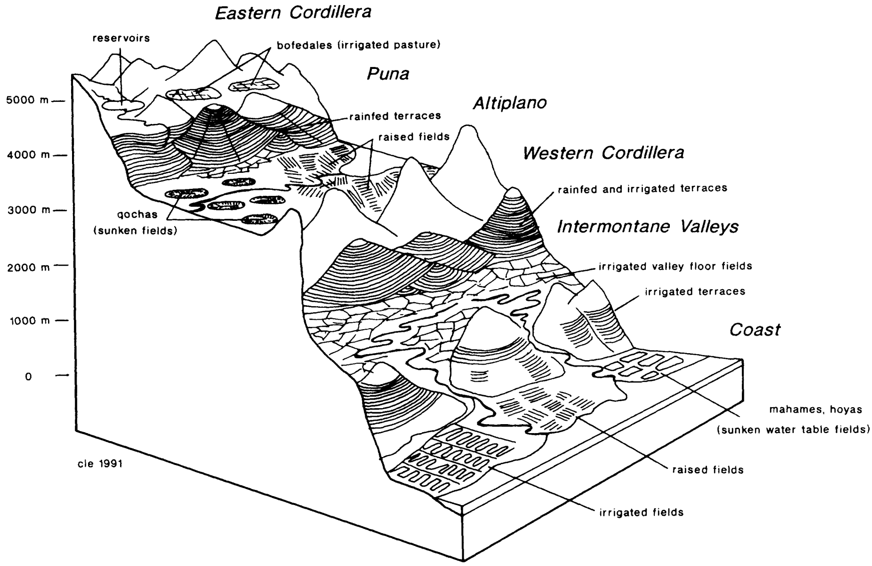
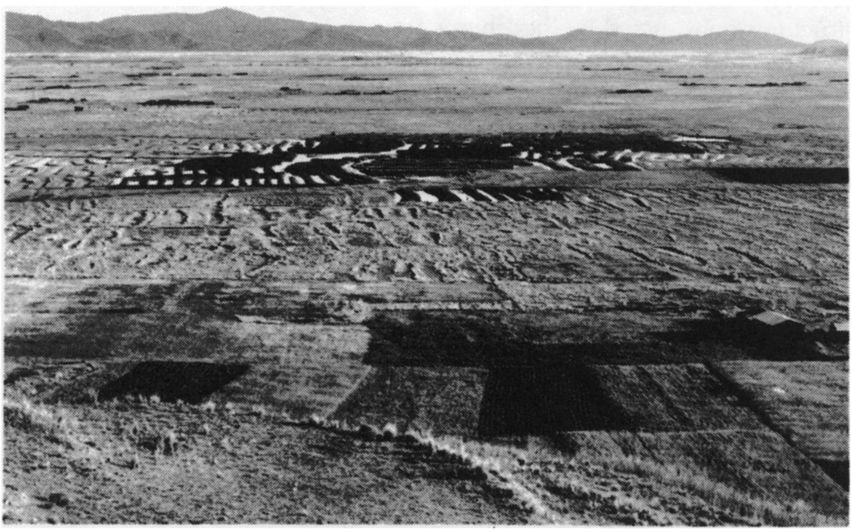
FIGURE 1. Block diagram showing the location of the major prehispanic agricultural systems of the central and western slopes of the Peruvian Andes (not to scale).



suits. The soils are heavy and waterlogged in the flat *pampas* or plains, and thin and poor on the steep slopes. Killing frosts, severe droughts and heavy flooding are frequent occurrences. Crops generally have a low productivity. Unequal land distribution since the early colonial period and lack of transportation and markets further hampers production and the distribution of crop production. In contrast, to the native inhabitants (the Quechua and the Aymara), the *altiplano* is a cosmic landscape, an ordered cultural space filled with sacred features (*huacas*), and the home of Pachamama ("earth mother"). As part of a complex belief system of reciprocity, the earth gives crops to the native farmers; in return, the farmers give elaborate *pagos* (offerings, "payments") to the earth. To the archaeologist, historian, and geographer, this landscape is a palimpsest of past and present cultures, as each one has left significant traces of human modification on the local landscape. The result is a totally human-created landscape, the result of thousands of years of both intentional management, and at times unintentional mismanagement, by its inhabitants. What is most striking is that the land was much more intensively utilized in the past than today. In this article, I would like to briefly discuss one major land modification strategy, raised field agriculture, as an environmental management system and the substantial impact it had on the Andean ecosystem.

For thousands of years throughout the Andean region, prehistoric peoples have totally remade their landscape into a cultural artifact (Figure 1). Ecosystems on the desert coast of Peru, such as the *lomas*, vegetation communities supported by fog banks, have been heavily utilized and often overexploited over time. Massive irrigation networks created as early as 2,000 BC in desert coastal valleys turned them into productive breadbaskets for prehistoric inhabitants and provided the foundations for complex society (Moseley, 1983). The 113 km long Chicama-Moche intervalley canal combining aqueducts and other sophisticated hydraulic structures constructed by the Chimu around AD 1400 is probably the best example of indigenous water management knowledge. The area prehistorically farmed in the Moche Valley was 20-40% more than that which is presently cultivated using modern techniques. In other desert zones, *mahames* (or *hoyas*) or sunken gardens were excavated into the dry soils to the water table or served to divert and capture seasonal runoff and flooding (Soldi, 1982). In Peru alone, the ancient master agronomists of the highlands converted an estimated one half to one million hectares of steep slope into cultivated fields using terracing. Most terraces provide flat surfaces for the complex distribution of water through elaborate canal, catchment reservoir structures in addition to conserving soil. Today, over 50-75% of these terrace covered slopes have been neglected and abandoned (Denevan, 1986-88; Masson, 1980; Donkin, 1979). Another type of highland agricultural feature, the *qocha* or circular sunken field basin, is either human-made or a highly modified natural feature (Flores Ochoa, 1987). Many have elaborate canal systems which alternately fill the depressions with water or drain them for agriculture. In a single continuous area of 256 km^2 in southern Peru, an estimated 25,000 of these agricultural structures have been located; unfortunately only a few of them are still in active production. In the Lake Titicaca Basin, the raised fields [discussed below] which cover an estimated 82,000 hectares of flat, poorly drained, and frost susceptible land represent a massive earthmoving endeavor. Even the high *puna* grasslands between 4,000 and 5,000 m above sea level have been heavily modified by pastoralists and their domestic camelids (llamas and alpacas), probably since 4,000 BC. A common feature near *puna* water sources are *bofedales* or vast artificially created irrigated grasslands for pasture (Palacios, 1981). Other nonagricultural modifications of the land have also had major effects and helped shape the present landscape. These include extensive road networks, stone fence

FIGURE 2. Raised fields in Viscachani Pampa, Huatta, Peru (March 1989). The prehistoric field and canal patterns are easily delineated during the inundation in the wet season. Evidence of abandoned fields extend across the plains to the hills at the horizon. The darker fields (center) are recently reconstructed raised fields, part of the experimental program in collaboration with the community of Segunda Collana.

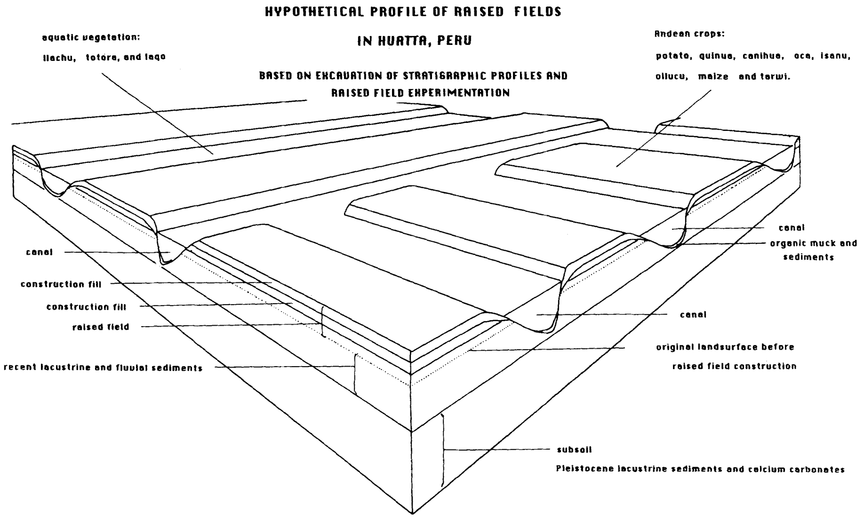


lines, causeways, lynchettes, stone piles, ditches, burial towers, corrals, and buildings constructed before the arrival of the Spanish.

RAISED FIELDS: A MAJOR LANDSCAPE MANAGEMENT SYSTEM

One of the most impressive technologies in the prehistoric Andean farming repertoire is raised field agriculture (Erickson, 1985; 1986; 1987; 1988a; 1988b; Erickson & Brinkmeier, 1991; Erickson & Candler, 1989; Kolata, 1986; Smith et al., 1968; Lennon, 1983; Garaycochea, 1986;

FIGURE 3. Hypothetical block diagram of typical raised fields based on information obtained through the excavation of stratigraphic profiles and raised field experimentation (1981-1986).

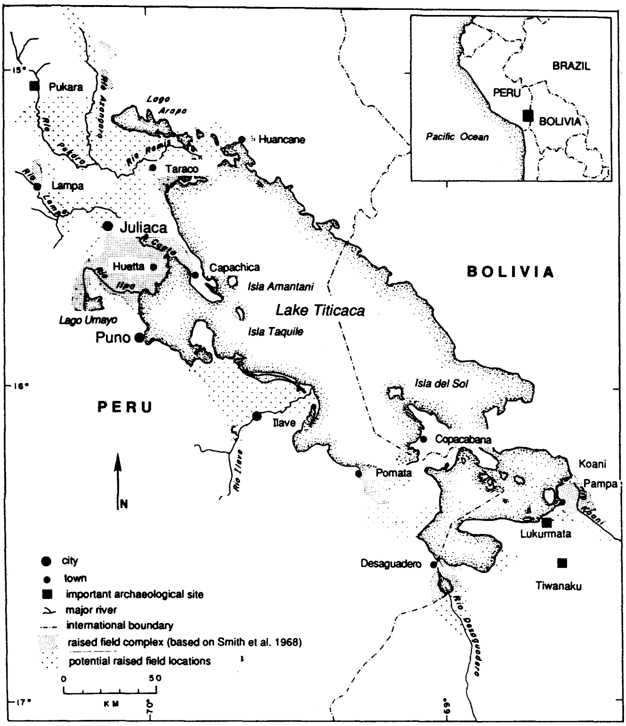


1987).[1] Raised fields are large planting platforms which have been elevated above the natural surface through the accumulation of soils from adjacent canals (Figures 2 and 3). Raised fields are distributed throughout some 82,000 hectares of lowlying lands (*pampa*) around Lake Titicaca in southern Peru and northern Bolivia (Smith et al., 1968) (Figure 4). All of the raised fields in the Lake Titicaca Basin were apparently abandoned prehistorically and the badly eroded remains were difficult for the untrained eye to discern. Most of the land with these remains now lies fallow and is used only for limited grazing.

In 1981 through 1986, I directed a small multidisciplinary project to investigate prehistoric raised field farming (Erickson, 1986; 1987; 1988a; 1988b; Erickson & Candler, 1989). We began an archaeological investigation of the raised field systems and the associated prehistoric settlements which were inhabited by the ancient farmers who built and maintained the fields. At that time I was most interested in defining the cultures responsible for constructing the fields, determining the time when the fields were

[1]Various raised field studies done in the Americas are reported in Darch 1983, Farrington 1985; Denevan 1970, 1982; Denevan et al. 1987; Gomez Pompa et al. 1982; Turner and Harrison 1983).

FIGURE 4. Map showing locations of archaeological raised fields and potential raised fields in the Lake Titicaca Basin of Peru and Bolivia.



created, tracing the evolution of the system over time, estimating the carrying capacity of this form of agriculture, and projecting the level of social organization necessary for the construction and maintenance of the system. I was also interested in ascertaining how the fields functioned, finding evidence of which crops were cultivated, and finally, addressing the issue of why the fields were subsequently abandoned. This involved archaeological reconnaissance and mapping and limited excavation of field remains and settlements (for more detail, see Erickson, 1988a).

The investigation indicated that raised field agriculture has a long and complex history in the Lake Titicaca Basin. In the northern Basin, raised field farming began around 3000 years ago with narrow fields. We found a complex superposition of fields upon fields, evidence of continuous construction and various rebuilding phases to expand field size and elevation. The system was apparently abandoned for several hundred years around

AD 300 and a later resurgence of field construction occurred between AD 1000 and AD 1450 (Erickson, 1987; 1988a).

Another approach utilized in this investigation was that of experimental or applied archaeology, a strategy in which raised fields were reconstructed as accurately as possible, following designs determined from the excavation of ancient fields. These rebuilt fields were planted in indigenous Andean crops and farmed using local traditional methods. The rehabilitated experimental raised fields were located on community, government, and privately owned lands. All construction was done by local Quechua-speaking farmers using traditional tools, with labor organized in a traditional manner.

The results of the experiments were impressive. We found that raised fields increased cultivation soil depth and fertility, provided drainage and conservation of water, improved crop microclimates, and produced and recycled nutrients which could be utilized on the fields. The experiments also demonstrated that raised fields, although initially laborious to construct, are very efficient, highly productive, and inexpensive to maintain over the long run.[2] Surprisingly, we found that the complexity of social organization necessary to mobilize labor and plan activities is low, well within the means of small families, groups of neighbors, or traditional Andean communal landholding groups (*parcialidad, comunidad*, or *ayllu*).

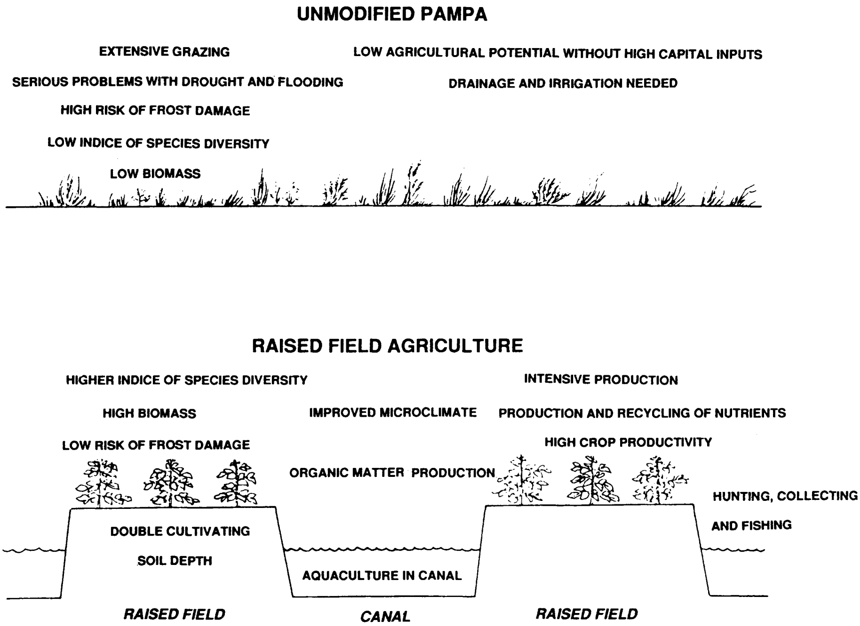
The following discussion presents both archaeological and agronomic experimental data relating to raised field functions, management, and environmental effects, and both the positive and negative implications of raised field farming.

LANDSCAPE MANAGEMENT AND ENVIRONMENTAL IMPACT OF RAISED FIELD AGRICULTURE

The consequences of landscape management through raised field agriculture are complex. In the following section, I would like to briefly discuss some of the major components of raised field farming as determined through our research: 1) soil modification and disturbance; 2) hydrology; 3) changes in plant and animal communities; 4) erosion, sediment capture, and production and recycling of nutrients; and 5) microclimate modifica-

[2]Although detailed comparative analyses have not yet been done, it is clear at this point that, apart from the construction of fields the first season, raised field farming is not much more labor-intensive than traditional farming methods practiced on the pampas, nor does it require a degree of cooperation or centralization of authority beyond the traditional community structure (Erickson 1988a).

FIGURE 5. Comparison of the typical *pampa* environment and the human modified raised field environment.

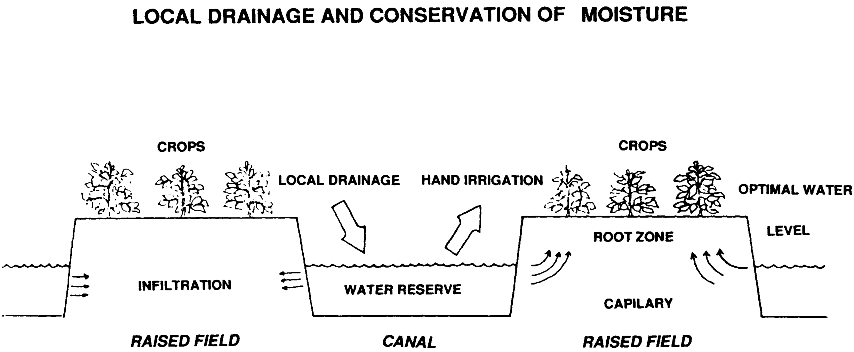


tion. The selection of only a few aspects of management and environmental impact is somewhat artificial. The actual situation is much more complex than can be discussed in this brief presentation. It must be noted that these are interrelated features of a very sophisticated system of landscape management.

Soil Modification and Disturbance

The practice of raised field agriculture greatly modifies natural soil conditions and local plant communities. The excavation of soils to create the canals and the construction of the large elevated platforms is a major earth-moving process. The extent of these disturbances was not known until we excavated trenches across raised fields to record the internal stratigraphy. In all of these trenches (11 in total), the depth and extent of human-caused soil disturbance is impressive. Most of the original canals extended to a depth of at least 1 meter below the present surface and some extended as deep as 2 meters. The soil profile within the raised field zones

FIGURE 6. Landscape management in raised field agriculture: Local drainage and conservation of moisture.



is truly *anthropogenic*. The ways in which the soils were modified are diverse, including mixing and reworking of sediments and soil horizons; altering moisture levels through the creation of the microtopography of ridge and swale conditions; lowering soil pH levels; incorporating organic matter, trapping sediments from outside the local system; and improving the nutrient components of the soils.

Hydrology

The construction of raised fields and canals greatly altered local hydrology. Heavy rainfall, runoff from the hillslopes, flooding river, and the rising level of Lake Titicaca during the wet season (November through May) are responsible for the waterlogging and, in places, shallow inundation of the *pampa* where raised fields were constructed. The construction of raised fields elevates the planting platforms to keep crops out of standing water and waterlogged soils. This was certainly the most basic function of raised fields, but complete drainage was obviously *not* the goal of the original farmers. In fact, most of the canals and field patterns would actually *hinder* drainage. The key to the functioning of the system was the management of water—to drain the field surfaces, but also to conserve water for long and short term droughts, to extend growing seasons, to maintain optimal levels of water in canals and adjacent field soils, and to move water to and from field blocks. This is done through a complex hydraulic system consisting of a network of canals, reservoirs, spillways, dikes and embankments, and raised aqueducts. In Koani Pampa, Bolivia, there is even evidence of large scale river channelization associated with raised field farming (Kolata, 1986). In some areas around our research site, large canals were constructed to bring additional water to lowlying areas, to expand the natural wetlands rather than drain them.

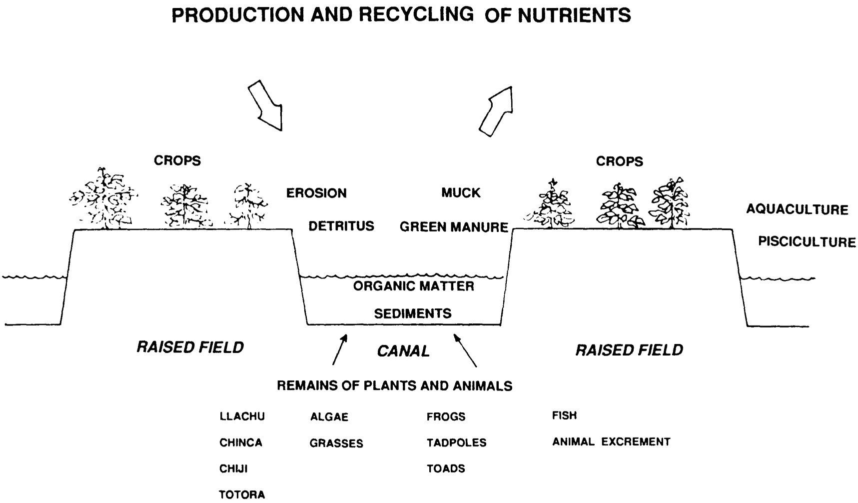
Raised fields proved their value during the severe drought of 1982-3 by making possible limited crop production, while nearby nonraised fields completely failed. The meager rainfall of that season was captured and stored in the canal for splash or bucket irrigation of the adjacent crops. When canals dried up later in the growing season, irrigation water could still be easily obtained through shallow pits dug into the base of canals. At the other extreme, raised fields produced excellent yields during the heavy rainfall and massive flooding of 1985-6 while other lowlying nonraised fields were severely inundated.

Salts and alkaline deposits frequently form on the surface of *pampa* fields and are found in ground water. We believe that raised field farmers may have been able to manage the salt and pH levels to minimize damage to their crops in areas where this may have been a problem. The hydraulic system discussed above, especially the canals and embankments, probably functioned to remove, dilute, or separate water with high levels of salts and alkalinity from fresh water.

Changes in Plant and Animal Communities

The generally flat and homogeneous environment of the unaltered *pampa* supports a relatively sparse vegetation community, consisting primarily of several species of grasses maintained by seasonal wet and dry conditions and contemporary pastoralism. The habitats within the shallow wetland areas near the edge of the lake and rivers entering the lake are much more complex. Raised field agriculture creates a complex microtopography of alternating raised beds and canals which permits the establishment of a very diverse vegetation and animal ecosystem, in addition to the cultigens. The rich productive environment of lake and river marsh is expanded artificially into what was previously a relatively simple grassland environment. Aquatic vegetation (reeds, algae, and floating plants) and aquatic animals, in particular fish, birds, and amphibians, rapidly colonize and fill the canals. In the experimental fields, grasses and weeds were established at the field borders and canal edges. The extent of these changes has not been quantified, but other studies indicate that wetlands can be up to three to four times more productive in biomass than grasslands. Much of the vegetation and animals, especially fish, are economically useful to local farmers. We suspect that some of these wild species may have been cultivated or "curated" in the canals.

FIGURE 7. Landscape management in raised field agriculture: Production and recycling of nutrients.

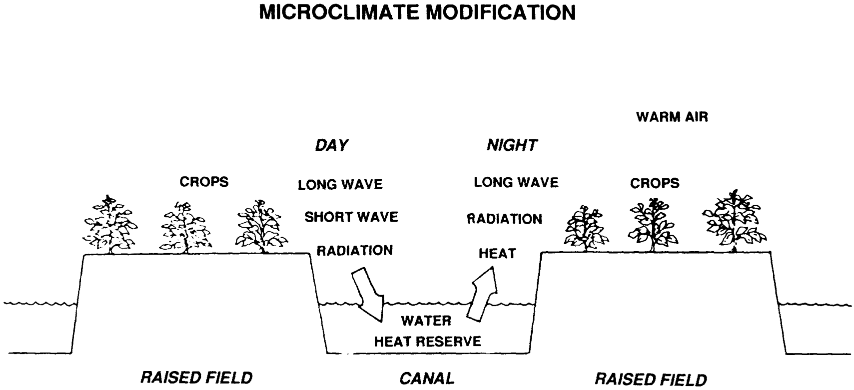


Erosion, Sediment Capture, and the Production and Recycling of Nutrients

Soil erosion is a major problem in the Andean region, especially where hillslopes are intensively farmed such as in the Lake Titicaca Basin. Much of this productive topsoil is eventually lost. It was evident from our excavation in raised fields that the canals were efficient in the capture of sediments, both sediments eroded from the adjacent fields and those carried in from outside the system. Our soil studies showed that this soil has a much higher organic content than the normal *pampa* soils.

The experimental fields demonstrated that the canals were very important in the production of green manure. Aquatic plants flourished in the canals, often choking them with a dense mat of vegetation. Detritus, rotting vegetation, animal and crop remains accumulate in the bottoms of the canals and this can periodically be removed, either placed on the fields as organic muck or collected during the winter season when canals are dry. Experiments suggest that continuous production may be possible on raised fields without application of fertilization other than that produced locally in the canals.

FIGURE 8. Landscape management in raised field agriculture: Microclimate modification.



Microclimate Modification

Raised fields had a considerable effect on the improvement of local crop microclimate. We have demonstrated that radiation frosts are minimized by raised fields (Erickson, 1986; n.d.; Grace, 1983). The water and aquatic vegetation in the canals functions as a heat sink for the capture of solar radiation. This heat is gradually released at night, blanketing the fields in warm air. We also hypothesize that the surface geometry of alternating fields and canals and the orientation of fields to the cardinal directions would improve crop conditions by maximizing energy capture, retention, and storage. These slightly higher temperatures can eliminate frost problems or minimize them. During two nights of frost, we demonstrated that not only were temperatures higher in raised fields than surrounding *pampa* (by 1-2° C), but also that the frost was of shorter duration (4 vs. 6 hours). The experimental data was collected on small blocks of reconstructed fields. We expect that in functioning blocks of fields covering several square kilometers, the microclimate improvement effect would be even greater. Temperatures may have been raised several degrees throughout the zone of raised fields and also may have had a favorable impact on nearby hillslope farms.[3]

[3]Detailed modeling of raised field temperatures has been recently conducted by Kolata and Ortloff (1989).

CONCLUSIONS: LONG TERM EFFECTS OF RAISED FIELD FARMING

It would be naive to argue that all of the prehistoric uses and modifications of the Andean landscape were environmentally sound. The massive modifications discussed above certainly had a drastic effect on the original natural vegetation and animal communities, which in many cases were completely replaced by a human-made environment. Ecologists and palynologists inform us that much of the *altiplano* was covered by humid forests in the not-too-distant past; now the trees have been replaced by agricultural fields and expanding grasslands. In the worst cases, overexploited slopes were completely denuded, and the loss of topsoil through erosion rendered them useless for agricultural production. Convincing arguments have been made that many of these destructive processes began long before the Spanish arrived in the Andean region. Despite the potentially negative impact on the natural environment caused by intensive farming, I feel that raised field farming was highly successful and, in general, environmentally sound for the reasons discussed above.

The view of many contemporary agronomists and development institutions working in the developing world is that traditional systems of landscape management are inherently backwards and primitive. Systems that are labor intensive, use traditional land races of crops with limited use of fertilizers, insecticides, and herbicides, and the lack of mechanization, all characteristic of traditional agricultural systems, are considered bad by outside experts. Common goals of development institutions tend to focus on uprooting the age-old native practices, replacing them with western capital intensive systems or appropriate technology developed for other areas.

Sustainability of agricultural systems is a major contemporary concern of agronomists, developers, and social scientists. From a technical and social point of view, raised field agriculture of the Lake Titicaca Basin could be considered a sustainable agricultural system because of its high efficiency, low capital input, low maintenance, and high continuous productivity over the long run.[2] Certainly for the local farmers and those populations supported by them, raised field agriculture was a highly productive and efficient technological system. Our experimental fields produced enough potatoes to support 37.5 persons/hectare of field surface/year. When the total area of raised field surfaces are considered (at best a very conservative estimate), a population of 1.5 million people could have been sustained by this system alone in the Lake Titicaca Basin (Erickson, 1988).[4]

[4]Assuming 100% of the fields in use at the same time, a highly unlikely situation.

FIGURE 9. Communal raised fields constructed by Quechua farmers in Sacanagachi, Capachica, Peru, as part of a national applied program of raised field rehabilitation (March 1989). The crop growing on the fields is quinoa (*Chenopodium quinua*), an indigenous high altitude crop rich in protein.

Between 1981 and 1986, several indigenous communities in the northern Lake Titicaca Basin collaborated with the experimental program in raised fields. After several successful seasons of cultivation, a small development project working closely with government and nongovernment agencies was formed to diffuse the information about raised field technology (Erickson & Candler, 1989). By early 1989, an estimated 100-200 hectares of raised fields in indigenous communities in the northern Lake Titicaca Basin had been rehabilitated and put back into production (Figure 9) (Erickson & Brinkmeier, 1991). With recent land reform, much of the *pampa* is now back in the control of local communities and available for cultivation using raised fields. The ancient Andean technology may, in the near future, become productive again and may become useful as a viable sustainable alternative to introduced Western systems of agriculture in the *altiplano* (Erickson, 1988b; Erickson & Brinkmeier, 1991; Burgo & de la Torre, 1986).

Indigenous knowledge systems of landscape management need to be studied and evaluated before they disappear forever (Altieri 1987). In cases where the prehistoric infrastructure has been completely abandoned, investigations using archaeology and agricultural experiments may be able to recover sufficient information on how these systems functioned to adequately evaluate them and potentially put them back into use. Both contemporary and prehistoric systems may hold the clue to future rural development in regions such as the Andes where farming has many limitations. In many cases, the current social, political and economic context, *not* the indigenous technology, is the cause of low production and poverty.

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