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APPLICATIONS OF PREHISTORIC ANDEAN TECHNOLOGY: EXPERIMENTS IN RAISED FIELD AGRICULTURE, HUATTA, LAKE TITICACA: 1981-2

Clark L. Erickson

Intensive hydraulic agricultural systems of the New World are just beginning to be the subject of detailed archaeological and ecological investigation (Denevan 1970, 1982). This paper describes a project which is in the process of studying the prehistoric intensive agricultural features of the *altiplano* of the Lake Titicaca Basin in the Department of Puno, southern Peru (Figure 1). It includes archaeological ground reconnaissance, limited archaeological excavation, and construction of experimental raised field-garden plots.

Raised fields, known locally as *camellones* or *waru-waru*, are elevated planting surfaces. It is thought that they were constructed for a combination of better drainage, climate and micro-environmental modifications, such as improved soil and growth conditions and moisture control (Denevan and Turner 1974). These systems have been located in various tropical lowland and highland contexts throughout the New World (Denevan 1970, 1982), most commonly in zones of severe seasonal inundation, such as the tropical savannas of the Llanos de Mojos in Bolivia and the flat pampas surrounding Lake Titicaca in Peru and Bolivia. In the Titicaca Basin, the fields range from some 20 cm to 75 cm tall, 4 to 10 m wide and up to 50 m long or more with intervening canals or swales.

Max Uhle (1954) first reported the Lake Titicaca raised field systems. It was not until the late 1960s that these raised fields received scientific attention in a detailed descriptive study undertaken by geographers Smith, Denevan and Hamilton (1968, 1981). In 1977 Tom Lennon investigated the vicinity of the Rio Ilpa (1982). It has been estimated that Lake Titicaca raised fields cover a total of 82,056 ha, some 56,533 ha of which are located in the archaeological study zone surrounding Huatta (Smith, Denevan and Hamilton 1968, 1981). The range of form in the fields is impressive (Figures 2 and 3). These variations in form may reflect chronological, functional and/or cultural differences (Erickson 1982).

Environment of Lake Titicaca

The Lake Titicaca plain extends through southern Peru and northern Bolivia in the high *altiplano* at an elevation of 3803 m above sea







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Figure 2: Various raised field patters of the Huatta area: A. "Open Checkerboard" (Candile SAN 176-70-1005)

- B. "Riverine" (Coata SAN 176-70-1007) C. "Irregular embanked" (Huanina SAN 176-70-1003) D. "Linear" (Capachica SAN 176-70-945)

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(Terminology from Smith et al. 1968)

level. Because of the high altitude, irregular rainfall, and generally poor soils, much of the *altiplano* is considered marginal for agriculture (ONERN-CORPUNO 1965a, 1965b). Some of these challenges to agriculture are ameliorated by the moderating effect of the lake on its immediate environs. For instance, rainfall is much higher and slightly more regular at the lake edge and minimum temperatures are somewhat higher, with less diurnal-nocturnal variation (Kessler and Monheim 1968; ONERN-CORPUNO 1965a). In addition, the rich alluvial soils in protected areas adjacent to the lake are suitable for intensive agriculture.

These factors have an important impact on present day settlement patterns and settlement density and probably exerted similar effects on prehistoric populations. As a result, the rural population density around Lake Titicaca is one of the highest in the Andes (Smith, Denevan and Hamilton 1968, 1981). Even special varieties of maize can be successfully grown in sheltered areas around the lakeshore. In addition to agricultural wealth, the lake provides rich resources in the form of fish and bird life, and numerous vegetable products, utilitarian as well as foodstuffs, such as totora reed, lake weeds, etc. (Labarre 1948; Collot 1980; Henek 1982; Richardson 1977).

A major drawback to the agricultural utilization of the lake plain is that most of the rich soils are waterlogged year-round, creating vast areas of marsh. In addition, the irregular rainfall within the watershed of Lake Titicaca causes lake levels to fluctuate substantially both seasonally and cyclically (Hill 1959; Kessler and Monheim 1968). Average seasonal lake level fluctuation is 60 cm, but may be as much as 4.6 m (Hill 1959). As a result of the extremely flat topography of much of the lake plain, such fluctuation can cause widespread inundation or expose large area of potentially rich farmland.

Frost damage to crops is a constant threat to farmers of the *altiplano* even around the shores of Lake Titicaca and is especially critical in lowlying areas around the lake where cold air drains from surrounding higher ground (Smith, Denevan and Hamilton 1968, 1981). In addition to frost, inundation, and waterlogging of soils, drought is also a threat to agriculture in this area. During the winter dry season, areas which were waterlogged during the wet season may become parched with crusts of alkaline deposits. On average, one crop in five is lost as a result of rainfall deficiencies or frost (Weil 1974).

Environment of Huatta

Huatta is located some 30 km north of the city of Puno within the vast pampa, northeast of Lake Titicaca. The Huatta pampa is a flat

landscape, created by the processes of lacustrine deposition and alluvial action by the Ilpa and Coata rivers. Micro-topographic relief is found in the form of numerous abandoned stream and river channels, low levee formations and cultural features, such as low prehistoric occupation mounds, some of which are still used as house sites, raised fields and canal networks.

Soils of the pampas have been classified as Gley Humic Andean Planosols of the "Titicaca" and "Limno" associations. These are characterised by fine textured lacustrine and alluvial deposits with poor drainage because of the high water table and low relief. The pH is high (8.5 in places) and subsoils gleyed. The Gley Humic Andean Planosols are considered to have "limited agricultural potential" (ONERN-CORPUNO 1965b).

Major vegetation consists primarily of a variety of grasses (<u>Stipa</u> sp., <u>Festuca</u> sp., <u>Mulenhmergia</u> sp., <u>Calomograstis</u> sp., <u>Poa</u> sp. etc.), while communities of aquatic plants (<u>Schoenoplectus tatora</u> L., <u>Myriophllum</u> sp., <u>Potamogeton</u> sp., <u>Chara</u> sp., <u>Nitella</u> sp., and <u>Sciaromiu</u> sp.) are found at the lake shore (Collot 1980; ONERN-CORPUNO 1965b; Smith, Denevan and Hamilton 1968, 1981).

Current use of the pampa is generally limited to grazing of cattle and sheep, and only a few privately owned fields are cultivated. In these fields, narrow ridges (50-75 cm wide), called *wachos*, are constructed from overturned sods cut from the pampa with a team using *chakitaqllas*, the traditional Andean footplow. A large portion of the pampa is controlled by the SAIS Buenavista Central Moro Cooperative which stresses pastoralism over cultivation. Frequent frost and irregular rainfall, creating either drought or inundation, are factors considered to make large scale intensive agriculture in the pampa impractical. The same conditions were most likely a problem to the indigenous prehispanic populations of the Lake Titicaca Basin, but were solved by developing a complex agricultural system of raised fields and canals.

Culture history and economy of the Lake Titicaca zone

There is some evidence that the mixed economy of cultivation, primarily of potatoes, and the herding of camelids common in the *altiplano* today may have begun before 1000 BC (Erickson and Horn 1979).

The Formative Period (1800-100 BC) is more fully documented in the archaeological record than the previous preceramic era, but there is

relatively little detail. The camelid pastoralism, tuber, and chenopod grain cultivation economy appears to have intensified and some degree of regional interaction appears to have taken place, for the zone is clearly influenced by the ceremonial and urban center of Pukara during the Early Intermediate Period (Kidder 1943; Lumbreras 1974; Lumbreras and Amat 1968).

In the Middle Horizon, a much tighter political and/or religious centralisation appears to have been organised at Tiwanaku, embracing the cultures at the northern end of the Titicaca Basin probably under its influence.

A series of smaller kingdoms replaced the Tiwanaku centralised control after the end of the Middle Horizon. In the Puno area the Lupaca and Colla have been well documented ethnohistorically, as powerful kingdoms before finally being conquered by and incorporated within the Inca empire in the fifteenth century (Murra 1968; Julien 1979; Lumbreras 1974; Lumbreras and Amat 1968). Throughout this history. there is little to suggest any major changes in the economy other than intensification, but unfortunately there is relatively little archaeological data on this. It may have been that the Inca introduced a new emphasis on the cultivation of their sacred crop, maize, and the construction and use of terraces, but proof awaits further excavation. It is certain that major changes in economy were brought by the Spanish, who introduced new crops, such as wheat, barley, oats, fava beans and new domestic animals, cows, sheep, and pigs. It should be noted that, although the new domesticates were accepted, they did not substantially change the traditional pattern of the mixed economy. It is not until modern times that there are indications that the patterns of resource exploitation change, with the attempts of agricultural developers to introduce high technology monocropping of commercial, rather than indigenous, subsistence cultigens.

The chronology, origin, and evolution of the raised field agricultural systems are unknown. The early chronicles of Andean history make no reference to these systems, although commentary is made of the indigenous terraces, *andenes*, and irrigation canals of the southern Andes. It is likely that the use of raised fields had ceased to exist by the time of the arrival of the Spanish. Archaeological survey conducted in 1981 has located some 50 archaeological occupation sites associated with the raised field complexes of the Huatta pampa. Ceramics from these sites span the known cultural chronology of the Lake Titicaca Basin. The earliest datable sites are from the Formative Period, some 3000 BP. Precise chronological placement of the raised fields will have to wait until stratigraphic excavation of occupation sites and raised fields is undertaken in 1983.



Figure 3: Prehistoric raised fields near Huatta in the dry season and and shows the organic deposits which form in the canals.



Figure 4: Experimental raised fields (center) and prehistoric raised fields (foreground) on the pampa of Machachi. Water has collected in the old field canals.

Experimental raised field research

Experimental raised field plots have been constructed in the Maya lowlands of Belize (Puleston 1976), various locations in Mexico (Gómez-Pompa 1976; Gómez-Pompa et al. 1982), the Llanos de Orinoco in Venezuela (Zucchi 1975a, 1975b) and in Illinois, USA (Riley and Freimuth 1979). Unfortunately scanty details on crop productivity, labor input, soils and micro-climate and ecological modifications can be gleaned from the reports available on these experiments. The exception is the work of Puleston (1976) which details construction, labor input, and preliminary results for one year's planting. Puleston's experiments are not directly applicable to raised fields in the highlands, because of a tropical lowland context and different construction techniques.

Experimental raised fields in Huatta (Figures 4-6)

Two small experimental plots were constructed in the month of November, 1981. Two different pampa locations were selected for experimental sites. The first, Machachi, is 3 km west of the town of Huatta in a pampa where little cultivation is currently practices, because of frequent problems with frost damage to crops. The other is Candile, some 3 km east of Huatta and 1 km from Lake Titicaca, where climate is more temperate. This pampa is afflicted with plant pests such as potato worms and nematodes. Both experimental fields were constructed on actual prehistoric relict raised fields, carefully selected especially to be representative of raised fields within each pampa.

Preliminary test trenches were excavated to obtain information on the original canal morphology and depths, silting, and canal reexcavations. Soils and pollen samples were also taken with a soil probe. The Machachi fields consist of 3 linear ridges with a total of 168.2 m^2 of planting surface and approximately 33.64 m^3 of earth was moved during construction. In Candile, 54.45 m^2 of planting surface on 2 ridges was created, and a total of 25.94 m^3 of earth was moved.

Construction and tools

The experimental fields were constructed over a 5-day period with teams made up of 2-3 workers. Tools utilised in construction were traditional, the *chakitaqlla* and the *rawkana*, a small adze-like hoe; and, at times, shovel and pick. Blocks of sods were cut from the canals and partially turned over by *chakitaqlla* on two contiguous sides. These were then lifted and piled on the ridge, where they were broken into smaller clods. The original canal depth was deeper than that



Figure 5: Experimental raised fields in the pampa of Candile, planted in potatoes, quinoa and canihua.



Figure 6: Machachi pampa experimental raised filed. The crops are potatoes and quinoa.

utilised, but the canal fill consisted of a heavy dark clay, but only the humus-rich topsoil was removed (Figure 3). The chakitaqlla was much more efficient than the shovel while working in sod, but neither was very effective in heavy, wet clay. It is more than likely that the prehistoric builders took advantage of the sod construction techniques. The metal blades of the present day chakitaglla and rawkana are probably somewhat more efficient than the prehistoric blades used in the original construction of raised fields, but it is doubtful whether that difference is as great as that between the digging stick and shovel. Many fragments of ground and flaked stone hoe blades made from a dark grey basalt have been recovered during the archaeological survey. Several of these are very thin and sharp and could probably have functioned almost as efficiently as modern metal blades in the pampa soils. La Barre (1948) indicates that a wooden-bladed chakitaqlla-like tool was in use in historic times and it was probably used in prehistoric times. An experimental test of the efficiency of both wooden and stone bladed tools will be made in the coming year. Wooden clod-breakers are still commonly used, and often preferred to the metal bladed rawkana.

Labor calculations

Labor calculation data were collected during construction of the experimental raised fields. Daily output varied relatively little even though different men worked on different days and soil conditions varied from wet to dry (Table 1). The work teams were made up of men of varying ages from the community, in addition to the author and his wife.

	Number of Workers	Total time Worked (hrs) ¹	Total of construction (m ³) Volume excav.	Earth moved per person (m ³ /hr/ person)	Earth moved per day (5 hr day) (m ³ /day/ person)
Machachi Candile	2	15 10	33.64 25.94	1.12	5.6 4.33

Table 1: Labor calculations for experimental raised field construction

1 The labour time estimate includes the time utilised to break up the clods as well as the building up of the ridges with sod blocks. Since wachos are the traditional technique for preparing fields in the Huatta pampa, a comparison of the labor involved in this system of field preparation to that of raised field construction is of interest. Data from two fields located near the experimental field plots is used for this comparison (Table 2).

<i>Wacho</i> field name	Total earth moved (m ³)	Total earth. moved per person (m ³ /hr/person)	Earth moved per day per person (m ³ /day/person)
Machachi wacho	108.0	3.6	18.0
Candile wacho	38.42	2.561	12.805

Table 2: Labor calculations for wacho construction

The table shows that in wacho construction, up to three times more earth can be moved in a day. In wacho construction, sods are only flipped over on the side after being cut out by chakitaqlla teams, whereas in raised field construction, the sod must be transferred from canal to ridge surface, a distance of up to 5 m. This may partially account for the differences in labor input. In addition, the labor calculation for the experimental raised fields presented above included the breaking up of sod and clods on the planting surface whereas the estimates of wacho construction did not include this labor. The working up of the soil is considered an extra day's work by informants since the clods tend to dry out rapidly.

Denevan (1982), using unpublished data from Mathewson (1978) and Stemper (1978), has attempted to calculate labor involved in construction of the raised fields of the Lake Titicaca Basin. Based on data from Erasmus 1965, he uses a labor figure of 2.6 m³/person/work day of 5 hours for excavation with digging sticks over a total of 37,746 ha of raised field surface and an average of 1 m tall ridges. He estimates that 377 million m³ of earth were moved involving 145 million man days of labour. This indicates an impressive amount of labor investment in raised field construction. Other labor estimates have been suggested in experimental work. Puleston (1977) in experiments in Belize using metal tools, found that 2.7 m³/day/person

of marl could be excavated. Denevan and Mathewson (1982) estimate that 1 m³/day/person could be moved in dry season and 2 m³/day/person couldbe moved in the wet season during experiments in lowland Ecuador. Turner and Harrison (1981) cite Mexican *chinampa* construction figures of 0.172 m³/hr/person.

Preliminary results from the present experimental raised fields construction demonstrate that the labor involved (an average figure of 4.965 m³/person/day) is much lower than Denevan's estimate (2.6 m³/ person/day) for the excavation of earth. This is probably the result of the efficiency of the chakitaglla as an agricultural tool and the strategy of sod excavation, instead of digging in hard or loose soil as in the case of the experiments of Puleston and Erasmus. Denevan's impressive total labor input was also based on his estimate that the ridges were 1 m high. The height of the experimental fields was only augmented 20 cm and this was found to be sufficient for potato growth. Digging beyond the sod humus level brought up heavy clay soils, presumably less suited for cultivation and very difficult to work in construction. It is fairly certain that a field did not reach its maximum height all at once, but grew in a series of stages. Thus, a one meter high field might represent a period of 100 years or more of gradual construction and erosion, making it a misleading indicator of the labor investment necessary at any one time to raised fields. Using the same figures as Denevan, but with the revised labor estimates from the experimental field construction of 4.965 m³/day/person, a lesser figure of 75,931,520 man days of labor can be calculated.

Knapp and Denevan (this volume) suggest that enormous expenditures were involved in the construction and maintenance of canals, and the production of "muck" for double cropping the raised fields in Highland Ecuador. However, in the case of the Lake Titicaca raised fields, ditch cleaning does not appear to be essential because great amounts of silt do not appear to accumulate. In addition, these canals would not require much labor if sod was allowed to form, as it could then be easily removed.

Planting and maintenance of the fields

The experimental raised fields were planted with indigenous Andean crops. The majority of the field surfaces were planted in potatoes (<u>Solanum</u> sp.) and the rest in oca (<u>Oxalis tuberosa</u>), isañu (<u>Tropoleum tuberosum</u>), quinua (<u>Chenopodium quinoa</u>), and cañihua (<u>Chenopodium paulidicaule</u>).

Little labor input was involved in field maintenance during the first year because few weeds grew in the fields. Soil was periodically

mounded around the roots and forming tubers of potatoes and other tuber crops and the experimental fields were worked 2 times each, a total of 5 man hours, normal for potato cultivation in the Huatta area. Some additional 4 man hours were necessary to irrigate the fields splashing water from the canals by hand.

Soil humidity

Rainfall and the high water table of the pampa maintained water to a depth of 30-40 cm in the excavated swales between the fields throughout most of the growing season. It is likely that the dense and relatively impermeable clay strata left in the swales aided in water retention. This water provided substantial soil moisture for the crops, filtering into the ridges within the root zones of the cultigens. The first part of February 1982, usually the rainiest month of the year, was dry. While other fields showed effects of the drought, the experimental fields were irrigated by hand when necessary. The functioning of raised fields against the opposite problem of inundation has not yet been investigated.

Frost

One of the hypotheses regarding the function of the Lake Titicaca Basin raised field agricultural systems is that they served to prevent or minimise frost damage to cultigens in the low lying pampa (Smith, Denevan and Hamilton 1968, 1981). This hypothesis is based on the fact that cold air is denser than warm and drains into lower zones of a field, such as the swales of the raised fields, thus minimising damage to the crops from the cold air. Changes of a few degrees temperature difference between the ridges and swales during nights with frost have been documented for raised fields in Illinois (Riley and Freimuth 1979), New Guinea (Waddell 1972), and highland Ecuador (Knapp and Denevan, this volume). It was found, however, that the elevational differences between field surface and canal, up to 1 m, may not be the most important factor in the Lake Titicaca raised fields. Since high rainfall, runoff, and a high water table during the wet season keep the pampa well saturated, the reconstructed canals between the fields contain at least some water throughout the rainy season, which having a higher heat capacity, radiates long wave radiation to the surrounding area at night. The difference in temperature between the ground or plant surfaces and the water would set up small convection cells during calm, windless nights when frosts are most prevalent. This, in itself, may substantially raise the temperature enough to make a difference . during a light frost. Morlon (1979) suggests that raised fields would serve to "roughen" the terrain of the pampa so that even a slight air

movement would cause air turbulence over the fields, mixing cold frost and warmer air above during a radiation frost, and thus, protecting the plants.

Campesinos, living near the Machachi experimental fields, stressed that frost was particularly common in this pampa, and that planting of anything other than relatively frost resistant crops, such as *ruki*, (a variety of bitter potato used for *chuño*), barley quinua, or cañihua was bound to fail. It was said that oca, isañu, and non-ruki potatoes would not survive.

The first few months of the growing season, the plants flourished, even though they had been planted approximately a month later than most other Huatta fields, at the end of November. There were no serious frost problems until the middle of February when the night of the 15th a serious frost hit the Machachi pampa seriously damaging fields throughout the area. In a brief survey one day after the frost, it was found that only *ruki* and *anachu* varieties of potato and quinua and cañihua were unaffected, while the top half of other plants had turned black the day following the frost. The raised fields were similarly affected, though not to the same extent. The top third of each potato plant was destroyed, and the oca had completely withered.

After several days of light rainfall, with the exception of the oca, all plants recovered. The assessed damage after recovery was much less than the pampa *wacho* fields. The denser vegetation canopy cover may also have provided some protection from the severity of the frost by creating a more favorable micro-climate.

The hypothesis that raised fields served against frost damage seems to have been refuted, however the frost of February 15 may not provide an adequately conclusive case. It should be kept in mind that the raised field plants, though affected by the frost, fared better than the nearby *wacho* field plants. The failure of the canals to function effectively as a heat sink may have been due to a low water level, as February was unseasonally dry this year. It is also important to remember that there are degrees of frost, and that of the 15th was unusually severe. Against some frosts there may not be any possible protection, and how the fields would have functioned against a slightly milder frost is still unknown.

Soil fertility

It was found that the rich soil from the canals was a fertile growing medium. Since the native vegetation of the canals needs standing water for most of the growing season, they quickly die and

decompose in the ridge tops. Thus, they do not compete with the cultigens, but rather form a green manure, and the mat of soil and vegetation produces a friable, easily worked texture.

Soon after the construction of the experimental fields, a new sod layer of vegetation began forming in the waterlogged swales. Roots of *chinca* not removed during the construction sprouted new plants and began to cover the canal floors and walls. A thin layer of algae formed on the surface of the stagnant water. Both of these species will increase the organic content of the canal soils. Within a couple of years, this new humus level could be removed as sod or "green manure" and placed on the planting surface for an increase in fertility.

It has been suggested that raised fields are important in fertility maintenance in that the canals would produce fertile organic "mucks" which could be periodically used as field treatments to maintain fertility in addition to cleaning out of canals (Denevan and Turner 1974; Denevan and Mathewson, this volume; Denevan and Knapp, this volume). This has been demonstrated in *chinampa* agriculture and in raised field agriculture in New Guinea (Waddell 1972) and elsewhere. In the case of the Titicaca raised fields, it is not known if the field canals retained water year-round to produce good quality "muck", such as the *chinampas* of Mexico. The drastic moisture regime differences between the wet and dry season and fluctuating water table in the Lake Titicaca Basin may have prevented similar "muck" formation.

After a year of use, the canals had a thin layer of silt washed off the field surfaces (less than 1 cm), dead algae, and a new sod level of *chinca* was beginning. From excavations in the pampa to obtain sod blocks for *champa* wall construction, one can see that the vegetation recovers quickly if some of the roots are left, and a new layer of sod will probably form within 3-5 years. A new topsoil rich in humus and organic matter will presumably form in raised field canals within a relatively short time, and could be removed as sod and placed on the field ridges.

With the use of *chakitaqlla* to cut the sod, this method may be an easier process in terms of labor investment than "mucking" if the canals are dry part of the year. In fields located in lower zones with a year-round high water table or near the present lake edge, it may be more feasible to periodically "muck" the fields. In these areas, aquatic vegetation, such as totora or *llachu*, could be managed and utilised for green manure and more production as they are utilised today by the Urus for small plots on floating islands. Since the pampa canals do not have running or flowing water, the silting up of channels would not be as serious a problem as in irrigation systems or other contexts.

Soil analysis

An initial series of soil samples from locations associated with the experimental raised fields were tested. Soil samples were taken from original humus levels, surfaces of original ridges, worked surfaces of ridges, soils below humus in the canals, the canals after one year, planting surfaces after one year, etc. (Table 3).

With the limited number of soil samples processed, only broad general interpretations can be made using these samples, but the data show that some significant differences can be noted from within and among different field micro-topographies.

As the ONERN soil studies note (ONERN-CORPUNO 1965b), the altiplano pampa soils are variable in pH, but highly alkaline soils have been documented for the lake edge pampa zones (as high as 8.8). This alkaline component sometimes is so severe that white deposits of alkaline form on the pampa surface after the rainy season as water evaporates. Local informants say this tends to "burn" the plants in these zones. Especially affected by these deposits are the surfaces of the raised fields in low zones around Huatta and near the lake. The results of soil analysis demonstrate micro-environmental differences in pH levels between swales and ridges of the raised fields. The pH is substantially lower in the swales than on the unmodified ridges. In terms of plant growth conditions, the slightly acidic to neutral soils of the original swales was more favorable than the very highly alkaline soils. Swale soils, when placed directly on top of the unmodified ridge and broken up, provided a pH favoring potato growth (pH 4.8-6.5). No data was available on the pH ranges for other Andean crops. It is hypothesised that potatoes were the major crop prehistorically grown on the raised fields and functioning raised fields provided a favorable growing medium in terms of pH.

Of the three macro-nutrients, nitrate nitrogen, phosphorus, and potassium, it was found that higher proportions of these elements were found in the swales. Nitrate nitrogen was found to be even higher on the worked surfaces, probably due to the incorporation of green manure during construction. Phosphorus was lower on the modified ridges and swales of Candile. This may be due to leaching losses since the samples were not taken immediately upon field construction. All of these elements were found to be in quantities adequate for crop growth.

Medium levels were initially present but have dropped after the first year of cropping. It is anticipated that the humus level in the canal will increase with the formation of organic "muck" and new vegetation, but one year's growing season has not indicated this.

Table 3: Soil test reports

 $= - \int dx \, dx \, dx \, dx$

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	Ph	N	P	K		Ca		Mg	Mn	Al		
1 1	6.4	7.5	75	175	low	1000	low	low	med	very high	62.5	<50
2	5.8	17.5	50	150	med	1000	very low	low	med low	very low	7.5	<50
3	7.4	5	100	130	med	1750	very low	low	low	low	2.5 -7.5	1000
4	6.4	20	100	200	med high	1750	very low	low med	med low	very high	25 - 62.5	50
6	6.6	25 - 30	50	150	med	1000	very low	low	med	very high	7.5	<50
5	8.2	5	100	200	med	5000	very low	low	low	low	7.5	- 250
7	7.0	5	62.5	•	low	3500	·	low med		high	7•5	100
14	5.6	20 -	50	175	low	1490		low	med low	very high	25	50- 100
15	5.6	20	50	175	low	1750		low med	med	high	25	50

All figures expressed in <u>parts-per-million</u> (except pH) Key to sample number locations:

Sample number 1. Swale, Machachi

2. Worked ridge surface, Machachi

3. Unmodified ridge surface, Machachi

4. Swale, Candile

5. Worked ridge surface, Candile

6. Unmodified ridge surface, Candile

7. Below humus in canal, Candile

14. Ridge surface after 1 year of use, Candile

15. Canal surface after 1 year of use, Candile

Calcium was highest on the unmodified ridges, and abundant in all samples. Ammonium nitrogen, magnesium, and manganese were present in low to medium, non-toxic, quantities. Aluminium concentration was high in the unmodified swales and lower on the unmodified ridges, but high aluminum concentrations are not toxic to plants unless in association with extremely acidic soils. Ferric iron was high on unmodified ridges, but low to medium in unmodified swales and on modified ridges. Crops, however, appeared healthy and showed no tendency to a chloritic condition. It is interesting to note that after one year, the iron content of both the planting surfaces and swale increased.

Only one experimental field has been analysed after one year's cropping. In Candile, the nitrate nitrogen and potassium has remained the same, levels of phosphorus dropped somewhat. The canal soil analysis showed lower nitrate nitrogen and phosphorus, and higher levels of potassium. It could be expected that organic "muck" formation will take a couple of years to improve the fertility of the canals.

In general, the pampa soils appear to be moderately fertile, enough to support full scale agriculture. It was found that the swales appear to be more fertile than the old eroded ridge surfaces and most importantly, lower in pH. The tests document that there are substantial levels of all major soil macro-nutrients and micro-nutrients.

From the limited number of processed samples and limited distribution of samples, no generalisation can be made for all the pampa soils associated with raised fields. The striking variation in soil pH and mineral content suggest that the micro-topography of the raised fields plays a significant role in the cycling of minerals, but more research will be needed to define and interpret these pathways. Further work is also being done in regard to soil profile studies, soil samples collections and soil analysis to provide a more general picture of the soil fertility in the pampa. In addition, the collection of soil samples each year after harvest will give an idea of successive cropping potential of the raised field agriculture.

Animal life

The only non-domestic animals attracted to the new micro-environment created by the raised fields were toads and birds. Soon after planting, the canals were filled with tadpoles. The populations probably aided in the build up of fertile soil in the canals, an eventual benefit for the planting surfaces. Tadpoles and small toads could also nourish fish, and the canal system of the raised fields provides an excellent setting for the practice of pisciculture.

Birds were only a problem at harvest time when they arrived to eat the mature quinua and cañihua seed, knocking a large percentage to the ground in the Candile fields. It is likely, however, that the ancient field systems, with more extensive bodies of water, provided a more attractive habitat for ducks and other edible game birds and animals. Such wildlife is presently found closer to the shores of the lake and rivers.

Pests

Plant pests were not a problem in the raised fields, but they did affect nearby wacho fields and fields along the slopes of the cerro at Huatta. This was probably the result of the fact that the experimental fields had not been recently cultivated and the majority of the planting medium was the rich soils of the swales where pests had not built up populations. When wacho fields are built on relic raised fields, the swales are normally left untouched. Thus, populations of pests had not invaded the fields. A few potato worms were found at harvest, and two plants had spots of leaf fungus, but little damage was done to the plants or tubers. More problems are expected with pests in next year's crops in these fields.

Production on the experimental raised fields

The production of potatoes and other crops grown on raised fields during the first year of experimentation was very good. Since the quinua, cafiihua, and isañu were not planted in large blocks on the fields, it is difficult to precisely calculate production of these crops with respect to area. Potatoes were grown extensively during 1981-2 and their productivity has been estimated (Table 4).

The average figure for potato production for all the experimental plots is 16,879.326 kg/ha. This figure should be halved to compare it to "regular" field production figures, since half of a raised field's total area is canal, and therefore, not cultivated. The resultant figure is 8,439.663 kg/ha. Denevan (1982), using data from Christiansen (1976), notes that the average potato yield for the Department of Puno between the years 1955 and 1964 was only 3,050 kg/ha/yr, which included some bad years, whilst 5,340 kg/ha/yr is the average given for the Peruvian Sierra. The 2.77-fold difference in potato production between the experimental raised field plots and the Department of Puno average is certainly striking, but must be considered with caution. It is difficult to compare a 10-year, department-wide average to a one year, 183.52 m^2 average. The first year's planting was done on fallowed soil and it is not yet known if this production can be sustained over

several croppings. The Department of Puno data averages poor potato producing areas with good producing areas and the majority of the fields were probably not fallowed soils. On the other hand, Puno fields generally receive a treatment of organic and inorganic fertilizers, while the experimental fields received none.

Ridge name	Field planting surface area	Production of potatoes	Extrapolated production per hectare #		
Machachi West	55.1 m ²	64 kg	11,615.25 kg/ha		
Machachi East	55.1	85	15,426.5		
Candile West	40.64	90.5	22,268.7		
Candile East	32.68	59.5	18,206.854		

Table 4: Potato production on raised fields

* This calculation includes only the planting surfaces, excluding the canals.

Denevan (1982) has calculated that a density of 5.7 persons/ha could be supported on the Lake Titicaca raised fields (calculating field surface area) with a total population of 215,000 people supported on the production of raised fields (assuming 100% utilisation of the fields). In new calculations, using the revised estimate of 16,879 kg/ ha/yr for the field surface area only and Denevan's figures, a figure of 31.7 persons/ha can be calculated which would give a total population of 1,194,782. This figure is strikingly different than the estimate calculated by Denevan in regard to the total number of people potentially supported by raised fields.

Conclusion

The feasibility of raised field agriculture is supported by the results of the growing season of 1981-2. This intensive prehistoric agricultural technology in the Titicaca Basin provides an alternative worth further serious study to current development schemes for the Department of Puno. Current agricultural development projects in Puno commonly stress high capital input based on heavy farm machinery, chemical fertilisers, herbicides, irrigation, and introduced seed, most of which are non-indigenous crops, such as rapeseed, alfalfa, wheat and barley. A large percentage of the pampas surrounding the Lake Titicaca Basin have been considered by ONERN-CORPUNO to be of limited agricultural potential, the very zones that are covered with the prehistoric relic raised field and were under intensive exploitation at some time before the arrival of Europeans. Today, only a small portion (3-5%) of the pampa of Huatta is under cultivation, but much more could be utilised through construction of raised fields. This form of cultivation requires minimal capital investment, utilises traditional collective family labor, and well-adapted traditional indigenous crops are grown. Local *campesinos* have shown varied degrees of interest in the project, ranging from apathy to enthusiasm and support. Several farmers have said they will construct raised fields next year and many have asked for advice or further information. Whether this form of agriculture will be fully revived remains to be seen.

The experiments will continue in the 1982-3 growing season on a much larger scale and with more systematic planning. At the same time as the raised field experiments are being undertaken, large expanses of relic raised fields are being levelled by heavy machinery, to prepare the land for agriculture. Within the last year, some 8 hectares of raised fields have been plowed under by the SAIS Buenavista Central Moro Cooperative near Ilpa. These were at one time some of the best preserved fields of the Huatta pampa. This is regrettable when these prehistoric field technologies may very well provide a better solution to Peru's agricultural development.

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References cited

Christiansen, J.

1967 El cultivo de la papa en el Peru. Lima Peru. Collot. D.

1980 Les Macrophytesde quelques Lacs Andins (Lac Titicaca, Lac Poopo, Lacs de vallees D'Hichu Kkota et D'Ovejhuyo). Travaux realises au cours du VSNA en Bolivia, La Paz, Bolivia.

Denevan, W.M.

1970 Aboriginal drained-field cultivation in the Americas. Science 169:647-654.

Denevan, W.M.

1982 Hydraulic agriculture in the American tropics: forms measures and recent research. *Maya Subsistence*, edited by K.V. Flannery, pp.181-203. Academic Press, New York.

Denevan, W.M. and G. Knapp

1981 Ecology of prehistoric wetland agriculture in some highland basins of Ecuador. This volume.

Denevan, W.M. and K. Mathewson

1982 Mounding, mucking, and mangling: age/area analysis of the raised fields at Guayas Basin, Ecuador. This volume.

Denevan, W.M. and B.L. Turner

1974 Forms, functions, and associations of raised fields in the Old World Tropics. Journal of Tropical Geography 39:24-33.

Erasmus, J.

1965 Monument building: some field experiments. Southwestern Journal of Anthropology 21:277-301.

Erickson, C.L.

1982 La investigación de los sistemas prehispánicas intensivos agrícolas y la organización social en la hoya del lago Titicaca, Peru. Preliminary report presented to the Centro de Investigacion y Restauracion de Bienes Monumentales, Instituto Nacional de Cultura, Lima, Peru.

Erickson, C.L. and D. Horn

1977 Domestication and Subsistence Implications of Plant and Animal Utilization of the Titicaca Basin. Manuscript on file at the Department of Anthropology, Washington University, St Louis. Gómez-Pompa, A.

1978 An old answer to the future. Masingira 5:50-55.

Gómez-Pompa, A., H. Morales, E. Jiménez and J. Jiménez

1982 Experiences in traditional hydraulic agriculture. Maya Subsistence, edited by K.V. Flannery, pp.327-342. Academic Press, New York.

Henek, G. (editor)

1982 La pesquería en el lago Titicaca (Peru): presente y futuro. Documentos Técnicos de Pesca. Organización de las Naciones Unidas para la Agricultura y la Alimentación, Rome.

Hill, R.

1959 Inflow of Lake Titicaca. Journal of Geophysical Research 64: 789-794.

Julien, C.

1978 Inca administration in the Titicaca basin as reflected in the provincial capital of Hatuncolla. Unpublished Ph.D. dissertation, Department of Anthropology, University of California, Berkeley.

Kessler, A. and F. Monheim

1968 Der Wasserhaushault des Titicacasees nach Neueren Messergebnissen. Erdkunde 22:275-283.

Kidder, A.

1943 Some early sites in the northern Lake Titicaca Basin. Peabody Museum of American Archaeology and Ethnology 27(1), Harvard University, Cambridge.

La Barre, W.

1948 The Aymara Indians of the Lake Titicaca Plateau of Bolivia. American Anthropological Association Memoirs, No. 68.

Lennon, T.J.

1982 Raised fields of Lake Titicaca, Peru: a pre-hispanic water management system. Unpublished Ph.D. dissertation, Department of Anthropology, University of Colorado.

Lumbreras, L.G.

1974 Los reinos post-Tiwanaku en el area altiplánica. Revista del Museo Nacional de Lima 40:55-86.

Lumbreras, L.G. and H. Amat

1968 Secuencia arqueológica del Altiplano Occidental del Titicaca. Actas y Memorias 37, Congreso Internacional de Americanistas (Buenos Aires 1966), 2:75-86.

Mathewson, K.

1978 Estimating labor expenditures for raised-field complexes in the New World Tropics. Ms on file, Department of Geography, University of Wisconsin, Madison.

Morlon, P.

1979 Apuntes sobre el problema agronómico de las heleadas aspecto meteorologico. *Estudio Agroclimatologico de la cuenca del Lago Titicaca*, No. 2, Convenio Peru-Canada, Puno.

Murra, J.

1975 Un Reino aymara en 1967. Formaciones Económicas y Políticas del Mundo Andino. Instituto de Estudios Peruanos, Lima. ONERN-CORPUNO

1965a Programa de inventario y evaluación de los recursos naturales del Departamento de Puno. Capitulo II: Climatologia. ONERN, Lima, Vol. I.

ONERN-CORPUNO

1965b Programa de inventario y evaluación de los recursos naturales del Departamento de Puno. Capitulo V: Suelos. ONERN, Lima. Vol. 3. Puleston, D.E.

1977 Experiments in prehistoric raised field agriculture: learning from the past. Journal of Belizean Affairs 5:36-43.

Richardson, P.J., C. Widmer and T. Kittel

1977 The limnology of Lake Titicaca (Peru-Bolivia). Institute of Ecology, Publication No. 14, University of California, Davis. Riley, T. and G. Freimuth

1979 Field systems and frost drainage in the prehistoric agriculture of the Upper Great Lakes. American Antiquity 44(2):271-285.

Smith, C.T., W.M. Denevan and P. Hamilton

1968 Ancient ridged fields in the region of Lake Titicaca. Geographical Review 134:353-367. Also published in La Tecnología en el Mundo Andino-I, edited by H. Lechtman and A.M. Soldi, pp.25-50, 1982. Mexico.

Stemper, D.

1978 Raised fields and population densities: an analysis for South America. Ms on file, Department of Geography, University of Wisconsin, Madison.

Turner, B.L. II and P.D. Harrison

1981 Prehistoric raised-field agriculture in the Maya lowlands. Science 213:399-405.

Uhle, M.

1954 (1923) The aims and results of archaeology. In *Max Uhle:* 1856-1944, edited by J.H. Rowe. University of California

Publications in American Archaeology and Ethnography, Berkeley. Waddell, E.

1972 The mound builders: agricultural practices, environment, and society in the Central Highlands of New Guinea. University of Washington Press, Seattle.

Weil. T.E.

1974 Area handbook for Bolivia. Foreign Areas Studies of the American University, Washington D.C.

Zucchi, A.

1975a Campos de cultivo prehispanicos vs. modulos de Apure.

Boletín Indígenista Venezolano 16:37-52.

Zucchi, A.

1975b La tecnologia aborigen y el aprovechamiento agricola de nuestras sabanas. *Líneas*, No. 219, Caracas.