Agricultural Terrace Evolution in Latin America

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Abstract
Incipient terraces can evolve as a normal consequence of hillside cultivation, depending upon environmental factors and farming practices. When slopes are concave, soils contain large amounts of unconsolidated rock, and a permanent source of irrigation water is available, it is possible for farmers to coax wide contour terraces into existence by controlled erosion. When the cultivation surface is leveled physically, rather than incrementally by erosion, there will be a powerful incentive to build narrow terraces. The fact that very wide terraces were developed in pre-Columbian times when cultivation was entirely confined to use of hand tools, strongly suggests that such terraces evolved incrementally by controlled erosion.
Key words: *incipient terrace, incremental surface leveling, contour terrace, irrigation canals, retaining walls, pre-Colombian agriculture*

> "   Si baja sola, par qué he de bajarla?" "If it comes down by itself why would I have to carry it?" (a farmer's response when asked if he had carried soil to level his terrace; 5 km northwest of Comitán, Chiapas, Mexico; March 1988).

Study of hillside agriculture reveals that farming practices will frequently promote incipient terrace formation and that actions required to speed and formalize terrace evolution are mostly self-evident and sometimes routine. These observations are neither original nor controversial. Incipient terraces and other leveled features resulting from controlled erosion practices have been widely noted (Spencer and Hale 1961, 3-11; MacNab 1965, 279-89; Donkin 1979,42,61,88; Doolittle 1984; Wilken 1987,87-113). It is suggested here that incremental slope leveling is a normal adjunct to hillside farming and that environmental constraints and farming practices are prime causes for terrace form. This paper also explores the hypothesis that, under favorable conditions, elaborate systems of formal terrraces can be coaxed into existence by controlled eroosion with relatively little planning and effort beyond that required to build and maintain irrigation canals.

This hypothesis has far-reaching implications. An incremental origin suggests that diffusion is not a prerequisite for the spread of terrace culture, and that relatively little innovation is required for independent development. It suggests that the distribution and form of agricultural terraces are not determined by attitudes toward land management and engineering skills of builders. To the extent that this hypothesis is correct, modern efforts to promote terrace construction by provision of direct subsidies and educational programs may be misguided. Greater success may be achieved by identifying and fostering those conditions that enncourage terrace evolution.

It is not suggested that all terraces evolved incrementally, or that there has been no diffusion of ideas and methods, or that all aspects of design and form are determined by the environment, or that farmers necessarily pursue a least effort method of terrace construction. There are obvious exceptions. At issue is the degree to which incipient terrace evolution and controlled erosion practices are responsible for the existence and form of terraces generally. That question cannot be completely resolved in this paper. The ennvironmental and cultural constraints on terrace evolution vary in detail from site to site and even the general controlling forces are obvious only after learning what to look for and what questions to ask. Each time I have gone into the field, new ideas and questions have emerged that were not examined or asked at previous study sites. Fresh viewpoints will probably produce modifications of the hypothesis presented here. A primary intent of this study is to provide stimulus for continued investigation of terrace formation processes.

There have been many studies of agricultural terrraces in Latin America, and several have included substantial bibliographies (Donkin 1979; Denevan 1986; Wilken 1987). Although most observers have acknowledged slope leveling by erosion on hillside plots, they have not attempted to tie formal systems of bench terraces to incremental processes or controlled erosion practices. For example, Treacy (1987, 53) stated that whereas some unirrigated, segmented terraces and some on less-sloping bottomland fields were filled incrementally by erosion, irrigated terraces on valley sides were probably planned and constructed by physically leveling the surface. Donkin (1979, 33-34) stated that in contrast to most terraces which are small and irregular, constructed piecemeal by single families or small groups, terracing organized by the Incas was part of a systematic and empire-wide policy of land improvement. Similarly, Wilken (1987, 115) stated that bench terraces are not leveled to an acceptable degree by natural forces and that direct labor investments are neccessary for almost all phases of construction.

Notwithstanding the relatively large literature on terraces, the questions of how formal systems of terraces were constructed, and why farmers using hand tools would have built very wide terraces, have not been adequately answered. Shea (1986,376) reported that with regard to methods of construction of formal terraces in the Andes, his literature search "was not rewarding." Also absent in terrace literature is careful study of terrace dimensions and design, and the work requirement according to the method of construction. Work of this nature was undertaken as part of a United States Agency for International Development (USAID) study (Williams et al. 1986, Annex 1), and that work is the prime source for technical materials presented in this paper.

FIELD INVESTIGATION

The model of terrace evolution presented here is based on study of hillside farming practices in several regions of Latin America and Japan. Terrace development by controlled erosion was observed in the states of Trujillo and Mérida, Venezuela, in 1977 and studied in detail in 1985 (Williams et al. 1986; and Williams and Walter 1988). The intent of that study was to examine the potential application of the controlled eroosion method to USAID sponsored terracing programs in Peru and Guatemala. Field investigation in Venezuela included examination of terraces in 21 project sites, in-depth interviews with 20 farmers, and informal discussions with a large number of other farmers and project directors. That work also included a field survey of USAID sponsored terracing projects in the Cuzco region of Peru and near Quetzaltenango in Guatemala.

Agricultural terrace development was studied in Mexico in 1988. A total of 42 sites, including most of those described by Donkin (1979, 39-76) in central, central east, and southern Mexico were examined. In-depth interviews were conducted with farmers at 19 of those locations. A comparative study of terraces was conducted in Japan in 1985 and 1986, focusing on terraces used for vegetables on the islands of Ogijima and Megijima in the Inland Sea, and citrus near Uwaajima in Shikoku (Williams et al. 1986, 133 and Annex 2).

INCIPIENT TERRACE EVOLUTION

Terraces of sorts can be formed by wild animals and a hillside grazed by cattle can be transformed into a rather remarkable system of incipient terraces. The latter, known as 'terracettes' or 'sheep tracks' in New Zealand (MacNab 1965, 284), have the appearance of a series of narrow paths along slope contours. Careful examination will reveal randomly spaced intersects beetween narrow benches so that they are more akin to shallow grade switch-back paths than parallel contour terraces.

Terraces that evolve in response to hillside cultivation are readily distinguishable from those made by grazing animals. Viewed from a distance these freequently give the appearance of randomly spaced "arete-like" features that have been scooped out of the hillside with a giant spoon. On steep slopes, plots are typically small but still much wider than those made by grazing animals. They are generally bounded by rock outcrops or perennial plants and debris discarded from the plot. Unless constrained by sedimentary strata or irrigation canals they will usually be scattered over a hillside in an irregular pattern. Although environmental factors, including slope steepness and shape, soil characterisstics, erosivity of rainfall, and geologic conditions, help to determine the form of incipient terraces, the prinncipal causes are related to hillside farming methods. Slope leveling is mostly the result of accelerated erosion of cultivated soil and by down-slope hoeing or plowing.

To prepare the soil for planting the farmer will generally begin at the bottom of the plot. Using a hoe--usually a short-handled hoe in those cases observed--the farmer, facing uphill, will chop into the soil and pull it over in a downhill direction. The depression created is filled with soil pulled over from the area immediately above; in this way the work is assisted by gravity. The effect is to move a layer of soil, perhaps 15 to 25 cm deep, down the slope a quarter of a meter or so and to leave a steep soil bank at the top of the plot. Grasses and shrubs will tend to spread over the soil bank at the top of the field creating an incipient earthen retaining wall. The loose soil will slip downnslope under the weight of the farmer working the field and will erode more rapidly when subjected to heavy rainfall.

Soil eroding down-slope will tend to be impounded at the bottom of the plot by perennial plants. The bottom of the plot becomes a convenient place to discard unwanted rock and other debris which will tend to reinforce that point as an erosion barrier. Each time the plot is cultivated it will tend to rotate slightly toward horizontal and the incipient retaining walls become more pronounced above and below. Over a period of several years a hillside can be transformed into a series of irregular terraces.

On a concave slope, rotation toward horizontal is encouraged by more rapid erosion on the steeper top half of the field and deposition on the lower half. Absence of incipient terraces on cultivated hillsides is often associated with convex local relief (personal observation in southern Mexico). When slopes are convex, soil eroding from above is not likely to become impounded on an even steeper slope below. In such cases, hillside cultivation will not promote slope leveling and terrace construction will require considerable effort on the part of the farmer to overcome the natural inhibiting forces.

Incipient terraces were observed in Venezuela, Mexico, Peru, Guatemala, and Japan during field research for this study. In those areas studied most cultivated hillsides show evidence of incipient leveling unless slopes are convex or farmers were making an effort to prevent it, such as up-slope plowing or hoeing. Spencer and Hale (1961, 3) noted that placement of any kind of obstruction laterally across a slope will result in flattening the surface, and that incipient terraces may be found almost all over the agricultural world. Wilken (1987, 105) reported that down-slope surface wash can be partially checked by nothing more than a row of logs or rocks laid perpendicular to the slope gradient, and described 'sloping terraces' as incipient features that develop with or without purposeful effort by farmers. MacNab (1965, 280) stated that in New Zealand a post-and-wire fence is sufficient to check soil movement and create a small terrace behind fence lines; he observed the process of incipient terrace formation in Japan and suggested that similar features called 'lynchets', that have existed in Britain since 1000 B.C., evolved in this way.

FARMER INTERVENTION

Those farmers interviewed were well aware of incremental slope leveling. Many of those in Venezuela and Mexico were able to comment in detail on how far the top of a field had dropped and how much leveling had taken place over the past several years of cultivation. Actions that will promote more stable and formal terrraces are self-evident and relatively easy if attention is directed toward speeding and controlling the natural processes already at work. Down-slope hoeing or plowwing will speed the leveling process and the stability of incipient retaining walls can be enhanced with a protective cover of perennial plants.

If the soil contains large amounts of unconsolidated rock there will be a powerful incentive to use that rock to build retaining walls. The amount of rock on the surface will tend to increase as it is unearthed by culltivation and left behind as soil erodes away. Farmers may be obliged to remove rock and will usually find it easier to carry or throw it downhill to the bottom of the plot. Thus, rock needed for the wall may already be available at the building site and a pile of rock will take less space if stacked in a wall.

In Venezuela farmers built rock walls along slope contours; these were double walls with rock debris fill so that they would stand upright without physically moving fill behind them. Surface leveling was accommplished over a period of several years by erosion and down-slope plowing (Williams et al. 1986, 35-41). Physically moving soil was confined to throwing sub-soil from the foundation trench of the retaining wall to the uphill side, where it would be buried by topsoil eroding down from the field above. The resulting terrraces are similar to much older features in that region that were described by Donkin (1979,84-86).

The Venezuelan example provides incontrovertible evidence that modern hillside farmers can produce wide contour terraces using controlled erosion. Project directors reported that many farmers had prior experience with construction of free-standing rock retaining walls and that most others could be trained in that skill in a few days (Williams et al. 1986, 37-38). In fact, the controlling factor for terrace development was not knowledge or ability, but motivation. Farmer participation was secured with subsidy payments, based on the cubic meters of rock wall built, and in some cases by preferential access to water from sprinkler irrigation systems included within the project.

The most surprising outcome of field investigation for this study was the finding that hillside farmers are often indifferent to surface leveling, or actually prefer to work a sloped field. In Venezuela some farmers refused to participate in the terracing project and some others destroyed retaining walls after the project was completed (Williams et al. 1986, 111). Some farmers noted that an inclined surface is easier to work because gravity will aid in turning the soil over, and less bending over is required---the bending problem is made worse by the use of short-handled hoes. Improved drainage on slopes can be important in heavy clay soils, and a slope may present a better aspect for solar raadiation, especially for morning sun on east-facing slopes in areas where afternoon cloudiness is common. The fact that the terrace is smaller than the original slope, just as the side of a right triangle is shorter than the hypotenuse, and the wide rock walls also reduce the cultivation surface.

Donkin (1979, 34) reported that convenience of a level surface and erosion control are rarely the reasons for terrace construction. He and others noted that conntrol of irrigation water is frequently a motive for surface leveling (Donkin 1979,34; Price 1971, 31; Treacy 1987, 52). However, those farmers interviewed in Venezuela and Mexico who irrigated hillside plots with sprinklers, or by hand from canals, usually did not consider surrface leveling important (personal observation). In fact, farmers that did not have access to irrigation water were more likely to prefer surface leveling because of the need to maximize infiltration of rain water.

Water harvesting-maximizing water infiltration was the main purpose of USAID sponsored terraces in Peru and Guatemala. As a result, the emphasis was on creating a leveled or back-sloped cultivation surrface. In the Cuzco region of Peru some terraces were constructed in a single massive effort: the topsoil was removed and replaced over subsoil that was moved from the back half of the terrace to the front half (W illIiams et al. 1986, 53-70). In other cases incipient terrraces, referred to locally as *pata-pata* fields because of their staircase appearance, were formalized with some minor leveling and retaining wall construction (Willliams et al. 1986, 127-28, 143). Near Quetzaltenango in Guatemala the USAID project involved physically leveling narrow bench terraces that are similar to the traditional *tablón* system described by Mathewson (1984) and Wilken (1987). In Mexico some government sponsored terracing programs include surface leveling, usually with bulldozers, for the purpose of water harvesting. These were observed in the Milpa Alta region in the Federal District where rock retaining walls are used to stabilize terrace benches for nopal cactus cultivation, and in Oaxaca and Puebla where nopal or agave is used to stabilize retaining walls on fields planted to grain. Surface leveling with hand labor was observed in the Rimac River gorge just inland from Lima for intensive horticulture plots, and in near Uwajima in Shikoku, Japan, on terraces used for citrus production (personal observations).

Notwithstanding examples noted above, surface leveling with hand labor is not common. Even when increased water absorption and/or erosion control is the objective, physically leveling the surface is not imperative. A degree of erosion control and increased water absorption can be achieved by contour plowing and constructing ditches to retain water or channel it away from the crop. The velocity of runoff, and hence the potential for erosion or water infiltration, is a function of both the steepness and length of the slope (Hudson) and with a retaining wall; leveling can then be achieved by erosion.

In Mexico many hillside farmers reacted to questions on the origin of terrace fill and method of leveling with puzzlement or even amusement. The possibility that rational people would spend months or years moving soil downhill does not warrant much consideration from Mexican farmers. Indeed, incremental leveling is apparently so common and obvious that farmers do not consider leveled or partly leveled fields worthy of any special designation or concern. The term *terraza* (terrace) was not used or associated with leveled fields by those farmers interviewed in central and southern Mexico. The terms *cerco* or *cerca* (enclosure, hedge, wall or fence) and *pretil* (battlement or breastwork) are used but these apparently identify only the retaining walls rather than the leveled surface (personal obserrvation).

IRRIGATION CANAL MAINTENANCE AND CONTROLLED EROSION

The most spectacular examples of agricultural terraces in Latin America are broad contour terraces associated with canal irrigation. These features are sometimes 20 meters or more in width with retaining walls 3 to 5 meters high following slope contours for great distances--conditions that allow for cultivation with heavy machines. Terraces of this type can be observed near Tochimilco (State of Puebla, west of Atlixco in Mexico), with irrigation canals that bring water from Popocatepetl volcano (Donkin 1979, 50; and personal observation). However, they are most commonly asssociated with highland Peru, where they date to the pre-Columbian period. These massive contour bench terraces appear to have been engineered and constructted according to a master plan with soil conservation or even aesthetic considerations as the major goal (Donkin 1979, 132).

It is argued here that wide irrigated terraces may have evolved incrementally with little effort to level the surface or plan the final layout. This assertion is supported by three lines of reasoning. First, the systematic design of broad contour terraces can be acccounted for by controlled erosion in conjunction with a least-effort approach to irrigation canal maintenance. Second, in contrast to controlled erosion, planned connstruction of wide terraces would have required an extravagant investment of labor to achieve a characterristic of little additional utility to farmers using hand tools. Third, the controlled erosion model of terrace evolution is potentially verifiable and preliminary evvidence appears to be supportive. These three lines of reasoning are explored in detail below.

THE CONTROLLED EROSION MODEL

An irrigation canal must follow the contour of a hillside with just enough gradient to maintain the flow of water. Canal builders would, of course, use flowing water to find the proper canal gradient and could be sure that any errors would quickly become apparent. If sufficient water is available, a hillside suitable for cultivation might have a series of parallel canals along slope conntours. Viewed from above the canal system will appproximate a relief map with a contour interval set acccording to the amount of water carried in the canals and the land that can be irrigated by them.

Cultivation of the land between canals will promote slope leveling. In contrast to randomly spaced incipient terraces, these might be very wide-depending upon the initial distance between canals-and follow slope contours for great distances. The slope leveling process will move soil down toward each canal from the field above, and will move soil away from the base of each canal on the field below. The problem of soil and rocks blocking the canal because of erosion from above can be solved by building a retaining wall on the uphill side of the canal. A retaining wall of sorts will probably already be located there because subsoil and rock dug from the canal channel would most likely have been thrown uphill where it would be buried by erosion, rather than downhill where it would cover topsoil. This may be stabilized with a vegetation cover. If rock has been discarded from the field above, the earthen wall can be faced with rock, effectively disposing of the rock and reducing future retaining wall maintenance. A very large amount of rock can be used to build free-standing walls up-slope from canals which will impound soil eroding down and reduce the problem of canal maintenance for many years.

After several years of cultivation, soil erosion away from the canal on the downhill side will tend to leave the canal stranded a meter or so above the field-a condition that increases the probability of canal failure. Canals traversing hillsides typically have a steep bank falling away on the downhill side and another rising above on the uphill side. It might appear that the canal was trenched into an existing physical feature. Howwever, it is most improbable that a natural earthen bank would happen to follow a slope contour with precisely the gradient required to maintain the flow of water in a canal. In fact, the proper flow gradient in the canal cannot be maintained if the canal is allowed to move down the slope along with the topsoil. Stabilizing the location of the canal will cause it to become an erosion barrier retaining material moving down from the field above and leaving a steep bank on the downhill side as soil erodes away.

As the position of the canal deteriorates farmers must work to slow the pace of erosion and/or build and maintain retaining walls above and below. The labor investment for canal protection may greatly exceed potential benefits to fields directly above or below a given section. All farmers receiving water from a canal normally provide labor for annual maintenance and are on call at any time in the event of canal failure.

Erosion over the top of the wall above can be preevented by building the retaining wall higher. However, it is easier to build the wall above the canal higher than to build the wall below the canal deeper. The more difficult problem is to prevent erosion on the downhill side from undermining the canal, or undermining the retaining wall that protects the canal. Possible solutions are generalized into three options (Fig. 1).

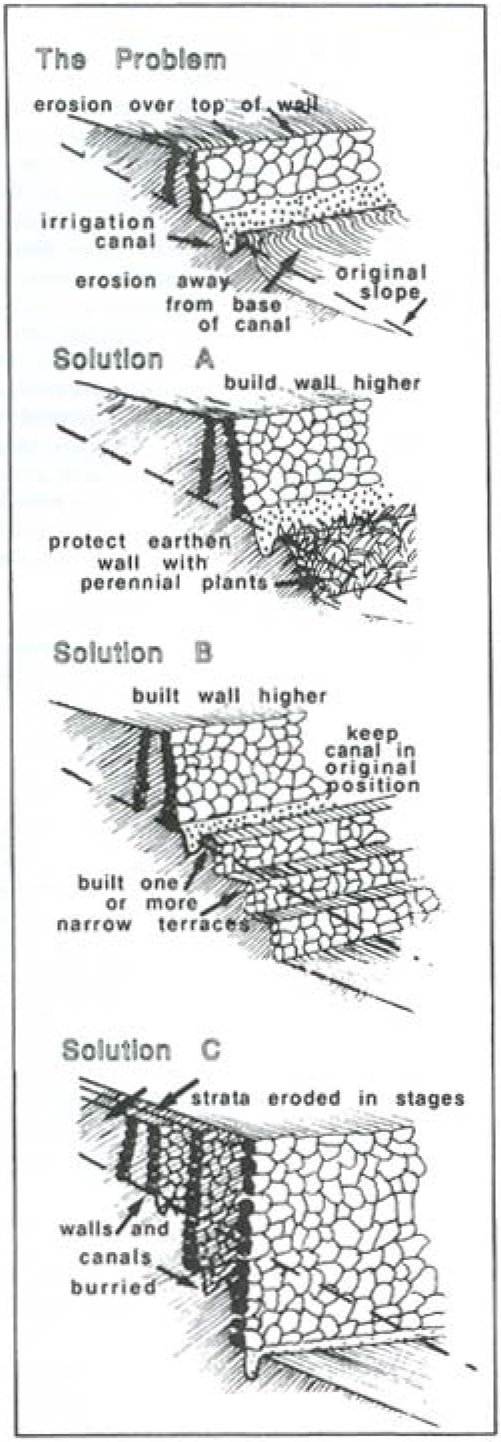

Fig. 1. Generalized solutions to problems of erosion damage to hillside irrigation canals.

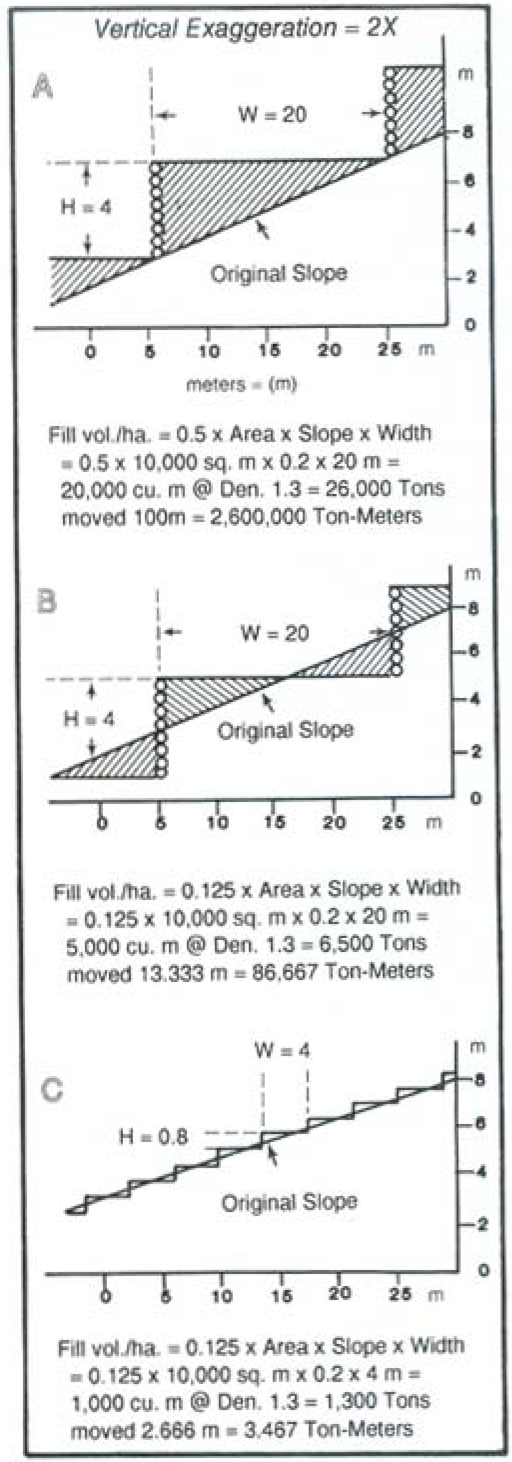

Fig. 2. Impact of fill source and terrace width on work requirement.

Solution A

The easiest solution, probably chosen initially in all cases, is to stabilize the steep soil bank below the canal with perennial plants. This system can be maintained for many years with attention to the retaining walls and efforts to prevent or compensate for erosion, such as up-slope plowing or hoeing. This method was observed in all those areas studied in Latin America and Japan.

Solution B
A second solution is to build one or more narrow terrraces below the canal. The work would be done in stages-perhaps several decades apart-with each genneration of farmers responding to the need to formalize the earthen bank left by erosion away from the previous wall. They might choose to build a new narrow terrace below (as shown in Fig. 2B), or incorporate the previous narrow bench into a single higher terrace. The irrigation canal would remain above the main field and require sluice gates and vertical channels down the wall or walls to the field below.

When the cultivation surface below the lowest wall is approximately level there will be no further erosion and terrace evolution is complete. At no stage in the process would farmers have needed to plan or engineer the final layout of the terrace system. This technique was incorporated into many controlled erosion terraces in Venezuela, although the lower terraces were gennerally retained by earthen walls rather than rock, and was observed by Donkin (1979, 112) in Yucay, Peru, although he did not speculate on the origin.

Solution C
A third solution is to move the canal down to more level ground. The old canal channel will be a convenient place to discard the subsoil excavated from the new canal and a new protective wall can be built on the uphill side of the new canal. Some of the rock from the previous wall may be removed and used to build the new wall or, if a large amount of rock has been discarded from the field above, most or all of the old wall will remain and eventually be buried by erosion. After a decade or two erosion would begin to undermine the second canal, and farmers might again move the canal down-slope and repeat the process of digging a new canal and building a new retaining wall. When the slope of the field below is approximately level the system is completed. As in Solution B, no planning or engineering is needed beyond that required to solve the immediate problem of canal protection.

The retaining wall would still be subject to periodic failure and require rebuilding. However, the wall would more likely be rebuilt in the same location. The priimary reason for building a new wall below-erosion at the base of the canal-is no longer a problem, and cultivation of a level surface is not likely to unearth large amounts of rock that require disposal.

Solution C will result in characteristics that greatly augment the durability of the terrace. The buried walls help to support the weight of fill. More importantly, buried walls and rock debris increase permeability of fill, helping to prevent water-logging, and shift the presssure of the fill downward rather than horizontally toward the final wall. The pressure on a retaining wall is a function of the weight of the material retained and the internal friction of that material. The internal fricction of large-textured materials such as rocks is high so that pressure is mostly vertical; internal friction decreases, and thus horizontal pressure toward the wall increases, with decreasing particle size from gravel to sand to silt. The finer-textured silts and clays are also less permeable. Water-logging increases horizontal pressure for two reasons: first, it increases the weight supported by the wall; and second, the internal friction of liquid is nil so that the entire weight becomes horizontal pressure toward the wall (Lambe and Whitman 1969,67).

Even a very stable terrace requires periodic mainntenance, and wide terraces are more likely to have received that maintenance over the past 500 years. Although the marginal utility of a wider cultivation surface, beyond a couple of meters, was probably small for pre-Columbian farmers who worked the land with hand tools, it would have been important for colonial farmers who used oxen and enormous for modern farmers using tractors. It is important to remember that there is a process of elimination at work; we are able to observe only those pre-Columbian terraces that did survive-probably because they were of superior design and/or because they proved to be worthy of periodic maintenance by the past twenty generations of farmers.

WHY NOT PLAN AND CONSTRUCT WIDE CONTOUR TERRACES?

Donkin (1979, 34) noted that canal irrigation first appears in the archaeological record of the Americas at about the same time as agricultural terracing, and the association between elaborate systems of wide contour terraces and irrigation canals has been noted by other observers (Price 1971,31; Treacy 1987, 52). This association suggests that terraces must have been planned and built to accommodate the irrigation system. For example, Donkin (1979, 34) stated that a leveled surface is essential where irrigation, *except by hand*, is practiced (emphasis mine). Treacy (1987,52-53) stated that irrigated terraces were essentially hydraulic feaatures for controlling irrigation water; that indented vertical channels and horizontal stone-embanked canals at the wall bases indicate irrigation planning accompanied terrace construction; and that farmers probably moved the soil into a level position rather than waiting for natural erosion processes because an irrigated terrrace must be level to economize on water.

The logic that ties terraces and canals together as a planned and constructed system is not compelling. Terrace construction is not a prerequisite for hillside irrigation. When a small hillside plot is irrigated, the farmer-who must be present in any case-can easily guide water by gravity flow from a canal above the field over a sloped surface with a hoe or shovel assuring adequate moisture to all parts of the field (personal observation). Even if surface leveling would signifiicantly economize water use it is not clear why farmers would invest the labor required to achieve maximum efficiency during the first season of irrigation. Traditional farmers rarely need a massive increase in production in a given year, and avoidance of risk and uncertainty argues against a radical change in farming strategy. Wilken (1987, 100) noted that the "processs-rather-than-project" approach is characteristic of traditional farm management systems today. There is no compelling reason to believe pre-Columbian farmers behaved in a radically different manner.

The strongest evidence favoring the "process-than-project" method is the extraordinary width of many pre-Columbian irrigated terraces. In theory a farmer is able to exercise choice on terrace width, as well as whether to use off-site or in situ fill, and to physically level the surface or allow leveling to take place incrementally. In practice, decision making is strongly constrained by environmental factors and the work requirement. Constraints on terrace width, acccording to source of fill and method of leveling, are examined below.

Use of Off-Site Fill

The cross-channel type terrace system consists of a series of check dams constructed across an erosion gully. Because topsoil is mostly absent in such features, fill behind check dams must be from off-site. Off-site fill can accumulate incrementally behind a series of check dams because flood water can carry large amounts of material in suspension and because an overflow channel is maintained to carry excess water over each check dam and on to the one further down the gully. A retaining wall built in an erosion gully will usually have a firm foundation on subsoil or bedrock, and can therefore better support the large amount of fill required when off-site fill is used.

If a series of walls are built along the contours of a slope relatively little off-site fill can accumulate incrementally--that is, relatively little material can erode over or through the retaining wall above each bench. An exception, observed in southern Mexico, consists of a series of wide contour bench terraces designed to receive flood water from an erosion gully. Storm water is diverted from the gully into ditches constructed along the contours of an alluvial skirt. Massive rock walls built on the up-slope side of the ditches impounded soil that eroded and was plowed down from the back half of each terrace. The main purpose of diverting storm water over the terraces is to increase water for the crop; however, some nutrient-rich off-site fill is deposited periodically by storm water from the erosion gully (personal observation a few kilometers east of Tamazulapan, Oaxaca in March of 1988).

In most cases the use of off-site fill for contour terrraces will require the material to be physically transported from another location. Off-site fill might be carried to a small garden plot or a topsoil dressing might be applied to a larger field, and huge quantities of organic material are routinely transported to fields. However, carrying fill to level large terraces would probably have been exceedingly rare. If off-site fill is used the amount required is four times greater, since the entire triangle formed by the wall and slope must be filled (Fig. 2A and 2B). Erasmus (1965, 285) estiimated that an individual can transport by hand 1.76 cubic meters of earth 100 meters in one 5-hour day. At that rate moving 20,000 cubic meters of fill (using the example in Fig. 2A) would require about 45 person-years per hectare of land terraced, not counting time required to excavate the material, and assuming a source of fill is available within 100 meters. That massive effort would produce a terrace of doubtful stability. The weight supported by the slope is greatly increased-an average of 2 to 3 tons per square meter of surface and much higher immediately behind the retaining walls (based on example in Fig. 2A). That weight rests on the original surface material, probably causing it to slip downhill more rapidly than it would have if terraces had not been built.

Use of In Situ Fill and Physically Leveling the Surface

For most hillside terraces the fill behind each retaining wall will be from the back half of the terrace created by it, and the farmer's decision is whether to move it into place physically or allow it to erode down incrementally. Fill origin from the back half of the terrace, whether physically moved or allowed to erode into place, can be confirmed for ancient terraces by excavation which establishes the location of the original surface to be at the mid-point of the final wall. When off-site fill is used, the base of the wall will be at or slightly below the original slope surface (Fig. 2A and 2B).

If fill is physically moved into a level position there will be good reasons to build terraces as narrow as possible consistent with the requirements of the farming method. This is because construction of a wider terrace will require an enormous increase in labor. A wider terrace requires a higher retaining wall which may be more difficult to build and maintain.[1] It will also require a deeper cut at the back of the terrace to provide fill for the front, because the depth of the cut is equal to one-half wall height. Narrow terraces might be leveled by simply moving topsoil; the wider the terrace the more likely the need to excavate compact subsoil and hence the need to remove topsoil and reeplace it over the leveled surface.[2]

Surface leveling is the main component of increased work requirement for wider terraces. Several observers have noted that the volume of fill required for surface leveling is proportional to terrace width (Spencer and Hale 1961, 18; Arledge et al. 1984,3; Wilken 1987, 115-116). In fact, "work" is defined as the product of weight of material and the distance it is displaced. In terrace construction both the amount of fill and the distance it must be moved are directly proportional to width; therefore, total work in ton-meters increases by the square of terrace width.

Using the example presented in Figure 2, the 5-fold greater width in example B, compared to example C, means 5,000 rather than 1,000 cubic meters of fill are needed per hectare. Since the distance that fill must be moved is also five times greater, total ton-meters of work is 25 times greater for example B.[3] If work is measured in time, rather than ton-meters, the expoonent on width may be reduced somewhat if there is a "longer-haul advantage;" nevertheless the exponent will greatly exceed 1.0 and therefore work, however measured, will increase exponentially with width (for an in-depth discussion see Williams et al. 1986, Annnex I).

Probably most terrace builders would prefer relaatively wide terraces. However, the utility of width varries with method of cultivation. When farmers work terraces with heavy machines the marginal utility of added width is high and machines are available to accomplish the added work. When the land is worked by hand, as in pre-Columbian times, the marginal utillity of terrace width beyond two or three meters is much lower in comparison with the cost.

Use of In Situ Fill and Incremental Leveling

If the farmer's efforts are directed toward building caanals and protecting them with rock walls, and surface leveling is allowed to occur incrementally, there are good reasons to expect the resulting terraces to be very wide. The 20 meter option in Figure 2B means 500 meters of canal length that must be built and protected per hectare; the 4 meter option requires 2,500 meters of canal length. The greater the distance between canals the wider the final terrace. The amount of fill needed for a wider terrace is inconsequential if leveling is achieved incrementally. The wider option will eventually require higher, and probably thicker and better built retaining walls. However, they can be built in spare time over a period of decades, or even generaations, and the slow pace of soil removal from the back half of the terrace will allow time for exposed subsoil to be incorporated into topsoil along with enhanceement with crop residue and other organic material.

The fact that many of the pre-Columbian terraces are very wide strongly suggests that surface leveling was not a part of the construction effort. Rather, it suggests that terrace width was predetermined by the wide interval between the original canals, and that pre-Columbian farmers, like farmers today, were concerned with managing their fields and producing crops as efficiently as possible.

ARCHAEOLOGICAL EVIDENCE

Excavation of pre-Columbian terraces at Coporaque in Peru has produced evidence consistent with an incremental origin (Malpass 1986, 154-166). Malpass identified buried walls and canals. He surmised that the terraces were constructed in at least two or three phases, with the earliest walls constructed on the mountain slopes and the others proceeding down-slope. Soil analysis indicated local origin. His profile of an excavated terrace indicates that the first (earthen) wall was wide and built on the original soil surface; remains of a second rock wall and canal were found about one meter downhill and a meter deeper. The final wall is located about 1.5 meters further downhill and another three-quarters of a meter deeper. Malpass did not interpret his findings as evidence of incremental leveling; rather he suggested that buried walls may represent a separate terrace that was contemporaneous with another down-slope.

A study of abandoned terraces in Mexico revealed evidence of very old low terraces covered by younger and higher terraces produced by a second wall (Guzman, as reported in Spencer and Hale 1961, 30). Donkin (1979, 74) also reported buried walls in southern Mexico.

In Venezuela farmers built double-faced walls with rock debris fill so that they would stand free while erosion and down-slope plowing provided fill (Willliams et al. 1986,37). Donkin (1979, 32) noted that the more massive walls usually consist of two faces separated by rubble and Shea (1986, 322) observed double walls buried behind a more recent wall only one course of stones thick. Likewise, double-faced walls with rock debris fill are used in Japan when walls are meant to be free-standing (personal observation). When fill is physically placed behind the retaining wall, a single tier of rock is sufficient (Treacy 1987, 54; and personal observation in Peru and Japan). It appears that the function of the double wall is to allow it to be initially free-standing; therefore, the existence of such walls may be evidence of incremental terrace leveling by erosion as opposed to physically leveling the surrface.

DISCUSSION

Modern hillside farmers in Latin America lack the motivation, and may even lack the ability, to plan and build massive systems of irrigated terraces as single-effort engineering projects. If ancient terraces were planned and built in that way, then pre-Columbian people must have possessed technology and/or attiitudes toward land management that are no longer known or applied.

This "lost art" explanation is appealing for pre-Columbian terraces. The systematic design of some of those in Peru certainly suggests design according to a master plan. No one has explained how or even why farmers confined to hand tools constructed such masssive features. Denevan (1985, 17) stated that virtually all terraces in Peru were constructed in prehistoric times and have since been repaired and rebuilt periodically. Donkin (1979, 132) stated that the Incas carried the art of terrace building to the point where it ceased to have mere utilitarian value, and that aesthetic appeal and demonstration of imperial power or even an obsession arising from the difficulty of shaping stone without metal implements, may help to account for terrace characteristics. Cook (1916,493), who examined ancient Peruvian terraces early in this century, reported that Indians living near pre-Columbian terrrace sites prefer to believe terrace construction was the work of enchantment. The lost art-or even extraterrrestrial origin -view has been widely held in the Cuzco region in recent years (personal observations based on approximately 3 years of experience in rural Cuzco between 1963 and 1986).

Nevertheless, the lost art theory is not well founded or documented. Studies of pre-Columbian terraces have quite naturally focused on areas where most or all slopes are terraced. For example, Treacy (1987, 52) reported that in much of the Colca Valley of Peru "unterraced but 'terracable' slopes do not exist". Farmers in the Colca Valley, as well as those in other areas in Peru such as the Urubamba Valley and Anta Basin, have a wealth of experience with terrace maintenance and probably terrace rehabilitation. However, they have no experience at all with the critical decisions for terrace development--that is, on terrace width, origin of fill, and method of leveling--and even the idea of building a new terrace would probably be a very exotic notion. Terrace development cannot be adequately understood with study of completed terraces or terrace rehabilitation. For example, it was only after searching out cultivated hillsides where incipient terrace formation is absent that the role of convex slopes as an inhibiting factor became apparent (personal observation in southern Mexico).

There are many other areas in Latin America where terrace development continues, and hillside farmers do understand the consequences of decisions on terrace width and method of development. Donkin (1979,46, 50, 73, 84, 124) has documented existence of terraces in most regions of intensive hillside cultivation in Latin America and the fact that terraces are being built by contemporary hillside farmers in many areas. Cardich (1 987, 36) stated that in Peru terraces and canals are being constructed in new places. Likewise, Wilken (1987, 96-128) described contemporary terrace connstruction in many areas of Latin America. In central and southern Mexico retaining wall construction and incremental surface leveling is a normal adjunct to hillside cultivation (personal observation).

It can be argued that the extent of terracing in Peru and greater frequency of wide contour terraces are partly and perhaps mostly accounted for by the extent of environmental and social conditions that encourage their evolution. Cultivation on basin and valley floors in highland Peru frequently presents a severe risk of frost, especially when night-time air drainage is from glacier-topped mountains, as in the Urubamba Valley. Glaciers provide a large and permanent source of gravity-fed irrigation water, and hillsides are mostly out-wash fans that are sometimes "choked with colluvium and rock waste" (Donkin 1979, 108-112). Such conditions did not mandate construction of irrigation caanals and rock retaining walls. However, they would have provided the opportunity and stimulus for that development and they would probably have eliminated the possibility of dense agricultural settlement there if terracing had not developed.

We have no proof that ancient terrace technology was superior to that used today or that terrace technology has been lost. We are able to observe only those pre-Columbian terraces that have survived for five hundred years- by elimination those of superior design. The hillsides in Peru may have been as cluttered with incipient terraces and eroded plots under the Incas as they are now and the pre-Columbian farmer who built the final wall of a bench terrace may have had no more idea or concern about how the system began than the farmer who repairs or rebuilds that wall today.

If broad contour bench terraces evolve incrementally then we could observe such a system at a mid-stage of development only if a hillside with necessary site and social pre-conditions were brought into production a generation or two ago. We do not know what all of those site and social pre-conditions are but they would certainly include arable hillside land with access to canal irrigation, farm size of no more than a hectare or so, and a tenure system that encourages proper land management. To the extent that suitable hillside land with irrigation water available by canal has been locked in large estates for the past several hundred years, farmer willingness and ability to produce broad contour terraces are untested.

Would we, or the farmers working the land, recognize contour bench terraces in an early or mid-stage of evolution if we did see them today? In 1985 I observed broad contour semi-terraces in association with canal irrigation in the Chinchero Basin near Cuzco, just above the Piuray Reservoir. Previous slopes of perhaps 25 percent had been reduced to about 15 to 20 percent by 1.5 to 2.0 meters high earthen retaining walls just above irrigation canals. Photographs taken at the site reveal a canal blocked by a collapsed earthen wall; farmers were already on hand to clear the canal (Williams et al. 1986, photos 30 and 31, 143-44). Will these farmers build rock walls to secure the canals? If they do, they will set into motion a process that could produce terraces similar to those that have survived from the pre-Columbian period; if they do not, it will certainly not be because they lack the required techhnology and engineering skill.

Hillside agriculture of the sort associated with terrrace evolution is relatively unproductive even within the context of a poor country-although intensive marrket gardening and production of fruit and vine commodities are often exceptions. The carefully terraced slopes of Peru, now partly or mostly abandoned, are indeed testimony to the ingenuity of ancient Peruvians; they are also testimony to the extreme population presssure on resources and poverty (very low marginal return to labor) that must have existed at that time. Reductions in farm population pressure today, by out-migration or alternative employment opportunities, will probably inhibit terrace formation and may cause further terrace abandonment. An end of terrace culture, if prompted by more rewarding employment opporrtunities, would not be an undesirable turn of events. However, for those farmers who have no alternative to hillside cultivation, terrace evolution can provide a sustainable source of subsistence. Establishment of legal and social infrastructure that permits and encourages terrace evolution may be an essential prerequisite for this form of conservation. An understanding of how terraces evolve and the identification of those factors that encourage their evolution should be one prime objective for students of agricultural terraces.

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NOTES

1. The total vertical surface of retaining wall per hectare is strictly a function of slope; for example, leveling a 20 percent slope requires 2,000 vertical square meters of wall (10,000 m2 x 0.2). Wall height (H) is equal to the product of width (W) and slope (S): (H = WS); for example, a 20 percent slope reduction on one hectare of land could be achieved with 1,000 m of wall 2 m high or 500 m of wall 4 m high. Therefore, the length (L) of retaining walls for a given area of land (A) is inversely proportional to terrace width: (L = AI W).

2. The work required to remove and replace topsoil is a function of the depth and density of the material moved. The removal and replacement can be accomplished in a single operation by working the land in narrow strips perpendicular to the slope, and shuttling the topsoil from an original position to a nearby strip where the subsoil has been leveled. Thus, for the most part the topsoil is displaced only once, and only a convenient shoveling distance. This method is described in detail by Arledge et al. (1984) and was observed in Japan (personal observation).

3. The volume of fill needed per unit of area is proportional to the slope and width: Vol. = 0.125 ASW. Fill weight is equal to volume times density; for Figure 2 a density value of 1.3 is used (after Wilken 1987, 102). The distance fill must be moved is equal to the horizontal distance between the centers of gravity before and after the move--two-thirds the terrace width: (0.666 W)--the vertical portion of the downhill transfer is accomplished by gravity. Work in ton-meters is equal to the product of weight and distance. Because both weight and distance are proportional to width, work is a function of the square of width: Ton-Meters = 0.08333 dASW2, where the value 0.08333 is the product of 0.125 (ratio of material moved to width) and 0.666 (ratio of distance moved to width), and d is the density of the material moved. This formula will yield the same result as the longer method used in Figure 2B and 2C. If the material moved is compact subsoil, additional work is required for excavation and the density may be higher.

REFERENCES CITED

Arledge, J. et al. 1984. *Manual técnico de conservación de suelos*. Lima, Peru: Ministerio de Agricultura.

Cardich, A. 1987. Native agriculture in the highlands of the Peruvian Andes. *National Geographic Magazine* 29(6):474-535.

Denevan, W. 1985. Peru's agricultural legacy. *Focus* 35(2):16-21.

__________. ed. 1986. The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru. Technical Report to the National Science Foundation and the National Geographic Society. Madison, WI.

Denevan, W., K. Mathewson, and G. Knapp (eds.) 1987. *Pre-Hispanic Agricultural Fields in the Anndean Region.* Proceedings International Congress of Americanists, Bogota, Colombia. British Archaeological Research International Series, No. 359.

Donkin, R. 1979. *Agricultural Terracing in the Aboriginal New World*. New York, NY: University of Arizona Press (Viking Fund Publications in Annthropology, No. 56).

Doolittle, W. 1984. Agricultural change as an incremental process. *Annals of the Association of Amerrican Geographers* 7 4(1): 124-137.

Erasmus, C. 1965. Monument building: Some field experiments. *Southwestern Journal of Anthropology* 21(4):277-301.

Hudson, N. 1977. The factors determining the extent of soil erosion. In *Soil Conservation and Management in the Humid Tropics* eds. D. J. Greenland and R. Lal, 11-16. New York, NY: John Wiley and Sons.

Lambe, T. and R. Whitman. 1969. *Soil Mechanics.* New York, NY: John Wiley and Sons.

MacNab, J. 1965. British strip lynchets. *Antiquity* 39(156):279- 290.

Malpass, M. 1986. Prehistoric agricultural terracing at Chijra, Corporaque. In *The Cultural Ecology, Arrchaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru* ed. W. Denevan, 150-166. Technical Report to the National Science Foundation and the National Geoographic Society. Madison, WI.

Mathewson, K. 1984. *Irrigation Horticulture in Highland Guatemala: The Tablón System of Paanajachel.* Boulder, CO: Westview Press.

Price, B. 1971. Prehispanic irrigation agriculture in nuclear America. *Latin American Research Review* 6 (3):3-60.

Shea, D. 1986. An hypothesis concerning terrace construction in the Colca Valley. In *The Cultural Ecology, Archaeology, and History of Terracing and Terrace Abandonment in the Colca Valley of Southern Peru.* ed. W. Denevan, 376-385. Technical Report to the National Science Foundation and the National Geographic Society. Madison, WI.

Spencer, J. and G. Hale. 1961. The origin, nature, and distribution of agricultural terracing. *Pacific Viewpoint* 2(1): 1-40.

Treacy, J. 1987. Building and rebuilding agricultural terraces in the Colca Valley of Peru. *Yearbook*, Conference of Latin Americanist Geographers 13:51-57.

Wilken, G. 1987. *Good Farmers: Traditional Agricultural Resource Management in Mexico and Central America*. Berkeley, CA: University of California Press.

Williams, L., B. Walter, and L. Cooperband. 1986. *Agricultural Terrace Construction: The Valles Altos Project of Venezuela as an Example for AID.* Washhington, D.c.: United States Agency for International Development, Regional and Resource Development Division, Bureau of Science and Technology.

Williams, L. and B. Walter. 1988. Controlled erosion terraces in Venezuela. In *Conservation Farming on Steep Lands,*> eds. W.e. Moldenhauer and N.W. Huddson, 188-196. Ankeny, IA: Soil and Water Conserrvation Society.

Resumen

Las terrazas incipientes pueden desarrollarse como consecuencia normal del cultivo de ladera según factores del medio ambiente y de prácticas agrícolas. Cuando la curva gradual de la pendiente es cóncava, los suelos son pedregosos, y hay agua de riego accesible, los agricultores pueden fomentar terrazas ámplias poco a poco mediante el control de la erosión. Cuando la superficie cultivada se ha nivelado por el trabajo físico, en vez de poco a poco por erosión, habrá un incentivo enorme para construir terrazas angostas. El hecho de que se hayan desarrollado terrazas muy anchas en la época pre-hispánica, cuando el cultivo se hacia completamente a mano sugiere que tales terrazas evolucionaron mediante la erosión controlada.

Palabras claves: terraza incipiente, nivelación incremental, terrazas de contorno, canal de irrigación, muros de retención, terrazas prehispánicas.