Appendix 2
The Role of Ramon in Maya Subsistence

Dennis E. Puleston[1]

Introduction

IN recent years, anthropologists have focused increasing attention on the process by which cultures have attained the status of statehood and civilization. Environmental factors appear to have been of considerable importance. Time after time, the combination of semiarid environments and fertile river valleys appear to have provided the essential ingredients for the development of agricultural systems dependent on large-scale irrigation and strong central governments to control them. Early developments in the Indus, Hwang Ho, Tigris—Euphrates, and Nile valleys provide classic examples. With minor modifications this explanation has been applied to Prehispanic civilizations of the New World, including the Valley of Mexico where lakes, rather than rivers, provided the principal water resource.

Despite the broad application of the hydraulic hypothesis, there have been some very interesting exceptions. Perhaps the most notable of these is that provided by the Classic Maya civilization which achieved its greatest development in the northern Peten of Guatemala (A.D. 300—900). Here the combination of dense tropical forests along with the peripheral distribution of rivers seems to provide an environmental antithesis of what might be expected to produce civilization on the basis of the other examples.

The apparent inconsistency has not gone unrecognized. A. V. Kidder (1950:6) in his introduction to the Uaxactiin excavation reports wrote "I still feel that the unbroken Peten forests would have been an almost prohibitively difficult environment for pulling oneself up, so to speak, by one's own bootstraps." J. Eric S. Thompson in his *Rise and Fall of Maya Civilization* (1954:26) writes, "To me, one of the greatest mysteries is why Maya culture should have reached its

[1]Deceased.

ISBN 0-12-259780-X

greatest peak in this region so singularly lacking in natural wealth, where man, armed only with stone tools and fire, had everlastingly to struggle with the unrelenting forest for land to sow his crops." More recently, Lowe (1971:237) has offered the following statement on the Maya heartland. "With little doubt this is the least desirable environment for human occupation in Mesoamerica."

The image of determined agriculturalists beating back the relentless jungle with stone tools so that a civilization could rise and prosper for a time is intriguing, but hardly satisfying. The historian Toynbee (1947) attempted to provide a rational explanation for the Maya exception with the suggestion that it was the very adversity of the lowland environment that provided the stimulus for their incredible success in an environment that was outwardly so hostile and difficult. Rathje (1971), following what is ultimately a very similar reasoning, has suggested that the ancient Maya, made up for environmental deficiencies by cleverly working out a means of expertise in religion.

It is my intention here to suggest that our view of the relationship between ancient Maya culture and its environment, particularly with regard to subsistence practices, has been totally wrong. Perhaps heavily biased by our own agricultural heritage, western archaeologists have been extremely slow to question long-accepted basic assumptions about the Maya. Far from being "the least desirable environment for human occupation in Mesoamerica," the tropical forests of the Maya Lowlands, in fact, seem to have offered certain specific resources which, because they were utilized skillfully, permitted the rise of a state society, which was sustained by one of the highest regional population densities in the prein-dustrial world. The key to this success appears to have been the utilization of the seed crop produced by a single tree species, *Brosimum alicastrum* Sw. This essentially unknown tree, with the common names of breadnut or *ramon* is of such staggering potential it is difficult to imagine how the magnitude of its significance has escaped more than passing notice until the initiation of our investigations of the tree began at Tikal in 1967.

Slash-and-Burn Agriculture

The synonomy of Maya civilization and maize fields cut out of tropical forests has been one of the essential truisms of Maya culture throughout time. It is a fact, however, that as Meighan *et al.* (1958:132) point out, "even in areas of known archaeological development such as Mesoamerica, the interpretation of a site as representing an agricultural economy is often a mere assumption, not an inference from anything in the archaeological picture." The assumption that slash-and-burn maize cultivation provided the subsistence base for ancient Maya civilization is the keystone for the supporting arch of an entire superstructure of secondary assumptions and hypotheses, cultural reconstructions, and elaborate evolutionary schemes that have been developed over a period of more than a hundred years.

At this point, I intend to remove that keystone and present the evidence and the barest outlines for the implications of a dramatically different structure. I begin with a review of the evidence that has traditionally been used to sustain the assumption of maize agriculture for the ancient Maya. The most frequently cited items include

1. the overwhelming importance of maize to postconquest and modern Maya populations (Morley 1946),
2. the frequent appearance of maize motifs and "maize gods" in ancient Maya iconography (Thompson 1954),
3. the dispersed nature of ancient Maya residential settlement patterns, presumably the result of the land requirements of slash-and-burn agriculture,
4. the discovery of maize cobs in the excavation of Maya sites like Tikal and Uaxactun, and
5. the ubiquitous appearance of *mono* and *metate* fragments, presum ably used for the grinding of maize at ancient Maya sites all over the Maya Lowlands (Rathje 1971).

Taken together, these separate pieces of evidence might appear to provide a substantial basis for the assumption of a primary role for maize. The problem arises, however, when we consider the long-range liabilities and limitations of slash-and-burn agriculture in the tropical forest environment. It is these considerations that lie at the root of several decades of frustrating discussion and debate about Maya subsistence, the collapse of Classic civilization (ca. A.D. 850), and slash-and-burn agriculture in general. Though slash-and-burn agriculture has traditionally been viewed as a wasteful and destructive form of agriculture (Leach 1959:64), it recently became fashionable "to blame poor returns on the soils and to describe shifting cultivation as a wise adjustment to environmental conditions" (Carter 1969:9). Now the tide has begun to turn again against slash-and-burn agriculture in all but those situations where population densities are low. The arguments for the potential of slash-and-burn agriculture for large and relatively densely settled areas have been no more cogently argued than by Dumond (1961). Despite this, however, there are critical problems that he does not address. I will examine these briefly now.

For the most part, the difficulties of slash-and-burn agriculture are linked to the effects of open-field cultivation on tropical soils. Upland forest soils in the vicinity of the Classic Maya site of Tikal are characteristically thin and, like other tropical limestone soils, heavily dependent on a rapid recycling of nutrients in order to prevent loss of them. An intensive survey of soils around Tikal reveals that where nutrients have been kept under forest, fertility is high. As part of a dynamic system that includes the forest that grows on the nutrients, however, they are subject to marked changes when the forest cover is stripped away and burned. One of the important first steps in slash-and-burn agriculture is the burning of trees and shrubs after cutting. During this process somewhere between 227 and 408 MT of organic matter per ha may be destroyed to bring nutrients—stored above the ground in tree trunks, stems, and leaves—down into the soil; 270—410 kg of fixed nitrogen alone may be released into the atmosphere and lost from a single acre (Gourou 1966:32 — 33). Soil fertility is thus temporarily lifted, but at a tremendous cost to the forest—soil system as a whole. The full effect of the high temperatures produced by burning on soil is poorly understood, so I will not go beyond this point here; but it is clear that completion of burning does not terminate destruction. As shown in studies like that of Likens *et al.* (1969), the removal of forest cover, even without burning, is highly detrimental. They found that clear-cutting of a New Hampshire forest greatly accelerated nutrient loss by terminating the uptake of nutrients by plants and increasing the quantity of drainage water passing through the system, which had the effect of flushing nutrients out in solution. Of all nutrient losses, that of nitrate was the highest, increasing from less than 1 mg/liter before cutting to more than 50 mg/liter after cutting. Foliage, a continuous supply of leaf litter, and extensive networks of fine roots also perform the vital function of breaking the impact of falling rain and preventing erosion. On the New Hampshire watershed, the loss of particulate matter was increased ninefold by cutting down trees and shrubs. There is no reason to suppose that these factors would be any less significant in the tropical lowlands where rainfall is 1,500—2,000 mm.

In the tropics, foliage performs the additional function of protecting soils from higher levels of solar radiation, which raises soil temperatures, which in turn increases the volatilization of many nutrients and retards humus formation. The critical temperature for humus formation appears to be in the range of 25°-26°C. Above this temperature, humus decomposition exceeds the rate of its formation with a loss of 17—29 kg of humic nitrogen per degree rise in temperature per ha per annum (Gourou 1966:22). June and July daytime temperatures of 7 mi/pa soils in the vicinity of Tikal ranged from 28°-32°C with an average of 29°C. A similarly measured sample of 20 soils under forest averaged 26°C. Clearly, soils in the Maya Lowlands are very near the critical level for humus formation and, once cleared of forest vegetation, appear to move well above it.

The effect of some of these factors is diminished somewhat once milpa crops (including the broad-leafed cucurbits and maize) begin to grow, but there is little doubt that rapidly declining yields on continuously cropped land is significantly augmented by elevated soil temperatures. In fact, measurements of soil fertility in comparative plots of milpa and forest soils at Tikal indicate dramatic declines in organic matter, nitrates, and soluble salts, confirming earlier studies carried out by Ursula Cowgill (1961).

Another contributor to nutrient loss is crop removal. Since the Maya do not practice manuring or use fertilizers on slash-and-burn fields, nutrients, including phosphorus and magnesium (which are high in corn and beans), represent a significant drain on the system when they are not replaced.

In the tropics, where soils tend to be shallow and thus have small reserves, the cumulative detrimental effects to field agriculture can be partially negated by fallowing the land. Ursula Cowgill (1962:279), on the basis of interviews with 40 modern Maya farmers living in the vicinity of Lake Peten, estimates that a stable slash-and-burn agriculture could be carried out with a four-year fallow after a single crop. For long-term considerations, this may be too short. The British Honduras Land Use Survey team found that in areas where population pressures were not high, preferred fallowing periods were in the range of 8 to 15 years (Wright *et al.* 1959:217). Here lies the crux of the problem. The fallowing requirement for slash-and-burn agriculture reduces the overall carrying capacity to a level that is grossly inconsistent with estimates of prehistoric settlement density based on prehistoric settlement densities. On the basis of her data, Cowgill (1962) estimates an average production of 1,620 kg of maize per ha on first-year plots. With a minimal 4-year fallow, the average yield per ha for a full 5-year cycle would be 324 kg/ha/year. Two harvests from the same piece of land provide even less (306 kg/ha/year) because of the necessity of extending the fallow. It is estimated on the basis of present techniques and currently used varieties of maize that 30-75 people/km^2 can be sustained by maize agriculture in the Peten (Sanders and Price 1968; Cowgill 1962). With 4-year fallows, this means a family of 6 would require from 8 to 20 ha of good agriculture land within a reasonable walking distance of home.

This brings us to consideration of one of the more puzzling inconsistencies in the traditional models for ancient Maya society. The combination of fallowing and a poorly developed system of transport would appear to make it most efficient to keep settlements small and compact. It is this hamlet pattern that characterizes nonindustrial Maya settlement in Yucatan today. Classic Maya settlements, however, were large and relatively dispersed in a pattern, which is exactly the converse of what would be expected (Puleston 1973). In the central 16 km^2 of Tikal, there were apparently more than 1,900 contemporaneously occupied houses in Late Classic times (Haviland 1969). In a situation where ease of transport would seem to be vital for the maintenance of a densely populated region, we find the largest and seemingly most permanent centers in the heartland where navigable rivers do not occur at all.

It has been around this seemingly impossible situation that for so many years, debate and earnest speculation has surged. As might be imagined, there has been no shortage of explanations as to why the collapse of Classic Maya civilization might have occurred. Hypotheses involving exhausted soils and erosion have appeared more frequently than any other for more than 60 years (Cook 1909; Morley 1920; Cooke 1931; Ricketson and Ricketson 1937; Meggers 1954; Cowgill 1962; Sabloff and Willey 1967; Willey and Shimkin 1971).

In many cases, the arguments were so well taken it seemed difficult to rationalize the existence of the Classic Maya for any period of time at all, to say nothing of a collapse.

"We will take the position here that the breakdown came, not necessarily because of an inadequate subsistence base alone, but more importantly, because the 'sociological imperatives' of the subsistence as reflected in Maya milpa agriculture were such that the maintenance of a class-structured state organization was, while not impossible, extremely difficult" (Altschuler 1958:193). Betty Meggers (1954), with a realization of the impossibility of the situation, postulated that Classic Maya civilization could not have been indigenous to the lowlands but must have been brought in full blown, only to begin a decline that must have started almost immediately. W. R. Coe (1957), in a reply, was without an alternative, but pointed out that this hypothesis was totally inconsistent with the available archaeological data, which indicated a gradual and orderly growth over a long period of time. A body of literature has recently grown up around the question of whether or not residential structures were occupied contemporaneously. Sanders (1962), claiming that they were not, has proposed that 75% of all the residential groups must have been abandoned during the peak occupation of the Late Classic period (A.D. 550-830) Haviland (1970:191-192) has demonstrated fairly conclusively that the situation was otherwise.

Thus, though practically every essential element in what amounted to a model of ancient Maya ecology had been examined and questioned (including the carrying capacity of maize, prehistoric settlement density, the contemporaneity of occupation, and the amount of labor actually needed for the construction of the great architectural centers), the model was still unworkable, exhibiting grave internal inconsistencies. Settlement densities were much higher and seemingly more stable than could be expected. The material achievements were simply too great. Somewhere there was a flaw. Despite the impossibility of the situation, there was one basic assumption that had never been seriously questioned. This was the assumption of a central role for some form of slash-and-burn cultivation of maize. In fact, it was not until Bronson (1966) proposed the hypothesis that root crops played a major role in Classic Maya subsistence that serious consideration was given to any alternative. In favor of his argument were the much greater yields of root crop per unit area in comparison to that of maize. The assumption of slash-and-burn cultivation with all its liabilities, however, remained unchallenged. The low nutritional value of root crops and unfavorable soil conditions for potentially one of the most important of these, manioc, have been indicated as problems (Cowgill 1971). The limitations of open-field slash-and-burn agriculture are still unresolved, and without any specific archaeological evidence in support of a primary role for root crops, the hypothesis remains just that. I will now present the case for a second alternative to maize, the fruit-producing tree *Brosimum alicastrum* Sw. or ramon.

The Ramon Survey

It was at this point that our attention was drawn to the ramon. Three features made the ramon stand out: (1) it showed a close association with sites, (2) it was an edible staple, and (3) it was storable. Over the years, various archaeologists and botanists including Lundell (1937), J. E. S. Thompson (1930), andO. F. Cook (1921) have noted the physical association of the ramon tree with Classic Maya site areas. Typical are comments such as those of Bullard (1960), who in the course of his trail survey of the northeast Peten observed a "striking correlation between the presence of Maya ruins and groves of the ramon 'breadnut' tree ... throughout the survey." Though the fruit of this tree contains a large edible seed, preferred by wild animals and commonly used by the Maya today when other food resources fail, the association was *never:* investigated further. Lundell alone suggested that these trees might be relic populations of a Maya cultigen, though even at that, he did not question the role of maize. Others, including Thompson (1930) and Higbee (1948), while indicating that the edible fruit might have been used, suggested that the tree (along with other fruit-producing species) was simply left standing when encountered in the course of clearing for milpa, the primacy of which again was left unquestioned.

My own investigation of the ramon began with the intention of examining in detail associations of several tree species with ancient Maya ruins as noted by Lundell (1937). In 1967, with the assistance of Jeffrey Parsons and Richard Blanton, I completed four Vi-km wide settlement survey maps, which extended 12 km north, south, east, and west from Tikal. We were in an ideal position to quantify the suggested association and, by this means, possibly to identify fruit trees that had been cultivated in association with residences. The ramon seemed to fall in a special category because it produced an edible seed that would be more amenable to storage than would the products of the more than 50 softfruited species. It might seem that the outcome of this survey must have been self-evident at this point, but it was not. The density of the forest, along with the necessity of carefully examining foliage in order to separate out 1 tree species from the more than 200 others that occur in the area, made it impossible to generalize about ramon distribution outside of the site nucleus, which was the only place its abundance had been recognized.

Having decided to work with the ramon, our first objective was to test quantitatively the reality and extent of the relationship between ramon trees and Maya ruins. I was anxious to discover if dense concentrations of the tree were limited to the nucleus of major temples, pyramids, and "palace" structures within a kilometer or two of the site center, or if indeed it extended into the 5-6 km radius of primarily residential settlement within the earthworks system that surrounded this nucleus. Of the four strips, we selected the south one for our investigation since it offered the broadest range of terrain and settlement combinations, including a good sample of elevated, well-drained forest that was lightly settled and far from the site epicenter.

Our survey technique was basically quite simple; it involved the mapping of all ramon trees that (1) occurred on a 100-m-wide strip that extended down the center of the 12-km-long settlement survey strip, and (2) had a diameter of 5 cm or more. (The survey was carried out by my brother, Peter O. Puleston, with the assistance of Elias Contreras, who assisted in tree identification.) A total of 1985 trees were mapped on the 12-km-long strip. The broader but overlapping settlement survey strip produced a total of 739 structures. The survey data were broken up into Vi-km-long sections, and the number of trees and house platforms in each were tabulated. Application of the standard product-moment correlation formula (Puleston 1973:274) produced a high 0.86 correlation between trees and structures that was significant at the 0.01 level. The distribution of the trees is a function of terrain only insofar as settlement is influenced by this variable. Between 6.5 and 10 km out, the trees are comparatively scarce despite the presence of high well-drained ground. This high degree of correlation was considerably greater than we had anticipated, and suddenly drew into focus the idea that we were probably dealing with the descendants of an ancient Maya cultigen that had been grown in the vicinity of residences. Possible alternative explanations for the association, at best, appeared to be unlikely.

One of these—the possibility that the mounds themselves offered a preferred microhabitat for the ramon trees—was examined. In fact, the collapsed-building microhabitat does appear to be partially responsible for the frequency of the trees in the ceremonial nucleus of Tikal, where the rubble mounds are more than 2 m high. Outside this hub of large collapsed palaces and temples, however, where low house platforms predominate, this factor seems to lose its importance since trees do not occur with any higher frequency on mounds than they do in surrounding areas. Soil samples taken at 500-m intervals along the strip were also examined to see if there might be a generally higher level of some nutrient, such as nitrates or phosphorus, in the area of higher settlement densities, such as that which might have been produced by former occupation. The results were completely negative and strongly suggestive of the conclusion that whatever differences may have existed in the past had long since been obliterated by factors relating to slope and drainage. Finally, the possibility that the trees moved into cleared land ahead of other species at the time of abandonment was eliminated by observation of the fact that the species is not typical of the secondary growth vegetation found on abandoned milpas today (Lundell 1937:46), probably because of the poor dispersal capabilities of the heavy seeds. In summary, I would agree with Lundell, who wrote, regarding the ramon, "we may assume that the dominance on Maya sites is due to an initial advantage occurring to the species through its presence in large numbers when the places were abandoned" (Lundell 1937:10).

Productivity

On the basis of these data then, it seems highly probable, if not certain, that at the time of Tikal's abandonment in the ninth century, ramon trees were growing in large numbers around Maya houses. If such was the case, it is unlikely that much maize was growing there, since maize requires as much sun as it can get and does not grow well in situations where incomplete clearing leaves the plants in shade for part of the day. Why would valuable land be sacrificed to trees? In a situation where food-producing land must have been at a premium, such a sacrifice on such a grand scale would only be made if there were some advantage to be derived from it. I will now turn to the question of ramon productivity.

Short acquaintance with the tree is all that is necessary to bring one to the realization that it is a heavy producer. The ground beneath the trees during the fruiting season is literally covered with small round seeds from which the soft pericap is quickly eaten by insects. In 1967, we collected 32.6 kg from beneath a single tree. While Gonzalez (1939) reveals that a large tree can produce up to 60 kg, Martinez (1936:100) reports that in humid areas a medium-sized tree can yield 75 kg of edible seed annually. Since fruit trees are often quite variable in what they produce from year to year, however, data on a single tree for one season would have to be considered insufficient for calculating yields per unit area.

In order to circumvent this problem, I set up a grid on a 900-m^2 plot of forest floor at Tikal. This plot was divided into 100 3-m^2 subplots from which a sample of 25 was randomly selected for systematic collection and weighing of the seed fall during the fruiting season. This was done over a period of three years, during which time the plots yielded an average of 1,763 kg/ha/year. This was despite the fact that the trees were untended and in full competition with other non-food-producing species that crowded around them.

As indicated above, maize under the best of conditions and minimal fallowing periods can yield little more than an average of 324 kg/ha/year. The trees then have a demonstrable ability to produce more than five times as much food per unit of land area as maize.

It seems likely that these figures probably fall short of the full potential of this tree. Proper spacing would probably do much to increase the yields of individual trees. In Yucatan and Campeche, where the ramon is grown for its foliage (which is used as a green fodder for dairy cattle), a spacing that would allow 100—125 trees/ha is advocated (Gonzalez 1939:222). This not only allows the trees to produce a broader and denser crown, resulting in a maximum production of leaves and fruit, but further permits intercropping of smaller garden and root crops between the trees. In a good year, such a stand of trees might produce 5,680-9,090 kg of edible seed per ha. Maya families in Yucatan, who depend on a diet that may be 80% maize, consume 1,090-1,727 MT of this staple per year (Steggerda 1941:130; Hester 1954:166; Cowgill 1962:277; Reina 1967). Clearly, under normal conditions, *Vz* — 1 ha of ramon trees would be more than enough to sustain a family on a permanent basis. •

Nutrition

Available studies indicate that the nutritional value of the seeds is high. In several important respects, it appears to be superior to maize. Ramon seed compares favorably with maize in respect to content of protein, calcium, iron, and the vitamins A, B_2, and niacin. Closer investigation reveals that the protein found in ramon is also of higher quality, containing greater amounts of the essential amino acids lysine, arginine, tryptophane, and valine than maize. Particularly significant is the high value for tryptophane since this amino acid is generally deficient in plant proteins. Its low level of availability in maize and beans is responsible for one of the principal deficiencies in modern diets throughout Middle America. All the available evidence suggests that ramon seed is a nutritionally acceptable and probably superior staple in comparison to maize. There is no evidence to suggest that it harbors any harmful properties. It has long been a dietary supplement throughout the Maya area though this fact has not often been recorded. Humans have lived essentially exclusively on the fruit for as long as 15 days without any sign of ill effect (Gonzalez 1939). Experimental work in Campeche has demonstrated that ramon forage actually increases milk production in cattle by 1.5—2.0 liters/day in animals which normally produce 8.0 liters/day on regular forage (Gonzalez 1939:222).

Labor

Slash-and-burn agriculture as practiced in the Maya Lowlands today is essentially a year-round task. As Reina (1967) has noted, the modern maize farmer of the Peten region "just manages to 'break even' all his life by expending a maximum amount of physical energy and by planning carefully." A breakdown of the labor requirements into 15 separate tasks reveals that a typical household invests 2,000—3,000 man-hours in the maintenance of a wet-season maize field alone (Carter 1969:135). When we take into account the comparative inefficiency of stone tools for the felling of bush, this figure must be increased. Experiments carried out by Saraydar and Shimada (1971) indicate that as much as 5.1 times as many calories are needed to cut wood with a stone axe as with a steel one.

Assuming then that 2,000-3,000 man-hours is a minimal figure, what labor is required to produce an equivalent quantity of ramon seed? In an established grove, it is clear that the onerous task of land clearing is completely eliminated. With the elimination of land clearing, weeding becomes unnecessary. Planting, along with the attendant and worrisome questions of timing, disappears. Because the crop is harvested within hailing distance of house transport, labor costs are brought to the absolute minimum. On the basis of experiments carried out in Tikal in 1973, I have determined that a woman and 2—3 children, working at a normal pace, can harvest 455 kg of ramon seed in 25 hours, which means that a total of 60—95 hours would be required to supply a year's worth of food for an average family. Assuming ramon was the staple then, as maize is now, a family's full subsistence complement of 1,364 kg could be collected with an average input of 1 to 1.5 hours/day during the main fruiting season of 7 to 10 weeks.

The significant factor here is that no measurable input is required by males. For reasons that are perhaps unique in the annals of human history, adult males may well have been released from essentially all subsistence activities. It is doubtful that their liberation gave them cause to celebrate, for almost certainly it was this tremendous manpower resource that raised up the architectural monuments which bring visitors to the Maya Lowlands from all over the world „ even today. I suggest that it is unlikely that these were constructed by teams of happy farmers who convened at the great centers in a fit of seasonal religious ecstasy to build temples so their crops would grow. Careful excavation reveals that even the small temples and palaces of Tikal r were methodically put together by skilled (and, by implication, full-time) specialists that included stonecutters, plasterers, masons, lime burners, wood hewers, painters, and vast numbers of porters, attendants, and priests. In view of the harsh and often discouraging struggle that modern steel-wielding *milperos* must sustain in order to survive today, it seems unlikely that their forebears could have accomplished so much more without utilizing some quite dramatically different adaptation.

Settlement Patterns

The distinctiveness of the relationship the ancient Maya had with their environment is revealed nowhere more strongly than in their settlement patterns. In comparison with modern Maya settlements and even those of Postclas-sic times, as at Mayapan, residential settlement is remarkably dispersed. A typical plaza group at Tikal is surrounded by a vacant space of about 1 ha, which works out to an average of 0.6 ha per residential structure (Puleston 1973:197).

Traditionally, the characteristic dispersal of plaza groups has been attributed to the land requirements of slash-and-burn agriculture, but the evidence indicates fairly clearly that 1 ha falls far short of what is needed. Cowgill's data (1962:276) indicate that at least 5.4 ha of good land are needed to provide the 1,735 kg of maize per year necessary for permanent support of a modern family of six persons. This limitation of space makes it far more likely that these areas were used as kitchen gardens. Sanders (1973) has suggested the presence of an infield—outfield situation which would remove maize cultivation to peripheral areas beyond the limits of dense settlement. It was on the basis of this assumption that in 1965 we began what was called the Tikal Sustaining Area Project. The explicit goal of this project was the identification of an agricultural sustaining area that would be recognized by large unoccupied areas that could presumably be devoted entirely to food production. The site limits of Tikal turned out to be easier to recognize than had been anticipated when we discovered the remains of a defensive earthworks system (Puleston and Callender 1967) that encloses an area of approximately 120 km^2. Beyond these limits, however, we were surprised to discover that settlement density, while it did decline significantly, did not reach a level that permitted these settlements to be self-sustaining by slash-and-burn agriculture—much less provide food resources for the estimated 65,000—80,000 occupants of the area within the earthworks. For the "intersite area" outside the earthworks, the total amount of land available per structure in Classic times is calculated to be 3.54 ha. If *tintal* and *escobal bajo* areas are removed, the figure falls to 1.62 ha. Clearly, if these peripheral areas were agricultural sustaining areas, a system a good many more times productive than slash-and-burn agriculture must have been used. This is not to say that maize was not cultivated in these areas—it is very likely that it was—but rather that it contributed little to the caloric intake of the population as a whole.

References

Altschuler, Milton 1958 On the environmental limitations of Mayan cultural development. *Southwestern Journal of Anthropology* 14:189-196.

Bronson, Bennet 1966 Roots and the subsistence of the ancient Maya. *Southwestern Journal of Anthropology* 22:251-279.

Bullard, William R.
1960 Maya settlement pattern in northeastern Peten, Guatemala. *American Antiquity* 25:355-372.

Carter, William E.
1969 *New lands and old traditions: Kekchi cultivator^ in the Guatemalan lowlands. Latin American Monograph No. 6.* Gainesville, Univ. of Florida Press.

Coe, William R. 1957 Environmental limitations on Maya culture: A reexamination. *American Anthropologist* 59:328-335.

Cook, Orator F. 1909 Vegetation affected by agriculture in Central America. *U.S. Department of Agriculture, Bureau of Plant Industry, Bulletin* 145. Washington, D.C.
1921 Milpa agriculture: A primitive tropical system. *Annual Report of the Smithsonian Institution* 1919. Washington, D.C.

Cooke, C. Wythe 1931 Why the Mayan cities of the Peten district, Guatemala were abandoned. Washington *Academy of Sciences* 21(13):283-287. Baltimore.

Cowgill, Ursula, M.
1961 Soil fertility and the ancient Maya. Transactions *of the Connecticut Academy of Arts & Sciences* 42:1-56.
1962 An agricultural study of the southern Maya Lowlands. American *Anthropologist* 64:273-286.
1971 Some comments on *Manihot* subsistence and the ancient Maya. *Southwestern Journal of Anthropology* 27:51-63.

Dumond, Donald E.
1961 Swidden agriculture and the rise of Maya civilization. *Southwestern Journal of Anthropology* 17:301-316.

Gonzalez Perez, Arturo
1939 El ramon o capomo. *Boletin Platanero y Agricola* 2(12):221-222.

Gourou, Pierre
1966 *The Tropical World: Its Social and Economic Conditions and Its Future Status,* 4th ed. translated by S. H. Beaver and E. D. Laborde. New York, Wiley.

Haviland, William A.
1969 A new population estimate for Tikal, Guatemala. *American Antiquity* 34:429—433.
1970 Tikal, Guatemala and Mesoamerican urbanism. *World Archaeology* 2(2): 186-198.
Hester, Joseph A.
1954 *Natural and cultural bases of ancient Maya subsistence economy.* Unpublished Ph.D. dissertation, Department of Anthropology, Univ. of California at Los Angeles.
Higbee, Edward C.
f 1948 Agriculture in the Maya homeland. *Geographical Review* 38:457—464.
Kidder, Alfred V.
1950 Introduction. In *Uaxactun, Guatemala: Excavations of 1931 —1937* by A. Ledyard Smith. *Carnegie Institution of Washington, Publication* 588. Washington, D.C. Leach, Edmund R.
1959 Some economic advantages of shifting cultivation. *Proceedings of the Ninth Pacific Science Congress.* 7:64-66. Pacific Science Association. Likens, Gene E., F. Herbert Bormann, and N. M. Johnson 1969 Nitrification: Importance to nutrient losses from a cut-over forested ecosystem. *Science* 163:1205-1206.
Lowe, Gareth W.
1971 The civilizational consequences of varying degrees of agricultural and ceramic dependency within the basic ecosystems of Mesoamerica. In Observations *on the Emergence of Civiliza tion in Mesoamerica,* edited by Robert F. Heizer, John A. Graham, and Carl W. Clewlow, Jr, pp. 212-248. Contributions *of the University of California Archaeological Research Facility, No.* 11. Berkeley.
Lundell, Cyrus L. 1937 The vegetation of Peten. *Carnegie Institution of Washington, Publication No.* 478. Washington, D.C.
Martinez, Maximo
1936 *Plantas Miles de Mexico,* 2nd ed. Mexico, Ediciones Botas.
Meggers, Betty J.
1954 Environmental limitation on the development of culture. *American Anthropologist* 56:801-824. Meighan, Clement W., David M. Pendergast, B. K. Swartz, and M. D. Wissler
1958 Ecological interpretation in archaeology: Part I. *American Antiquity* 24:131-150. Morley, Sylvanus G. 1920 The inscriptions at Copan. *Carnegie Institution of Washington, Publication* 219. Washington, D.C.
1946 *The Ancient Maya.* Stanford, Stanford Univ. Press.
Puleston, Dennis E.
1973 *Ancient Maya settlement patterns and environment at Tikal, Guatemala: Implications for subsistence models.* Unpublished Ph.D. dissertation, Department of Anthropology, Univ. of Pennsylvania. Puleston, Dennis E., and Donald W. Callender, Jr.
1967 Defensive earthworks at Tikal. *Expedition* 9(3):40-48.
Rathje, William L.
1971 The origin and development of Lowland Classic Maya civilization. *American Antiquity* 36:275-285.
Reina, Ruben E.
1967 Milpas and milperos: Implications for prehistoric times. *American Anthropologist* 69:1 -20.
Ricketson, Oliver G., and Edith B. Ricketson
1937 Uaxactun, Guatemala, Group E, 1926-1931. *Carnegie Institution of Washington, Publica tion* 477. Washington, D.C.
Sabloff, Jeremy A., and Gordon R. Willey
1967 The collapse of Maya civilization in the southern lowlands: A consideration of history and process. *Southwestern Journal of Anthropology* 23:311-336.

Sanders, William T.
1962 Cultural ecology of the Maya Lowlands, part 1. *Estudios de Cultura Maya* 2:79—121.
1973 The cultural ecology of the Lowland Maya: A reevaluation. In *The Classic Maya Collapse,* edited by T. Patrick Culbert, pp. 325-365. Albuquerque, Univ. of New Mexico Press.
Sanders, William T., and Barbara J. Price
1968 *Mesoamerica: The evolution of a civilization.* New York, Random House.
Saraydar, Stephen C, and Izumi Shimada
1971 A quantitative comparison of efficiency between a stone axe and a steel axe. *American Antiquity* 36(2):216-217.
Steggerda, Morris
1941 Maya Indians of Yucatan. *Carnegie Institution of Washington, Publication No.* 531. Washington, D.C.
Thompson, J. Eric S.
1930 Ethnology of the Mayas of southern and central British Honduras. *Field Museum of Natural History, Publication* 274, *Anthropological Series* 17(2). Chicago.
1954 *The rise and fall of Maya civilization.* Norman, Univ. of Oklahoma Press.
Toynbee, Arnold J.
1947 *A study of history.* Abridgment of Vols. I-IV by D. C. Somervell. London, Oxford Univ. Press.
Willey, Gordon R., and Demitri B. Shimkin
1971 The collapse of Classic Maya civilization in the southern lowlands: A symposium summary statement. *Southwestern Journal of Anthropology* 27(1):1 —18.
Wright, A. C. S., D. H. Romney, R. H. Arbuckle, and V. E. Vial
1959 Land in British Honduras: Report of the British Honduras Land Use Survey Team. *Colonial Research Publication* 24. London, Her Majesty's Stationery Office.

*