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Impact of Human Waste Management on the Estimation of Ancient Maya Population

Impacto del manejo de residuos humanos en la estimación de la antigua población maya

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ABSTRACT: The population of ancient Maya has been estimated traditionally by multiplying the number of discovered household mounds and the assumed number of persons per household in a given transect of an archaeological site. This approach is foundationally weak as both key parameters are subject to wide variations over the time course of several centuries. The ubiquitous outcome of this approach is that ancient Maya is nearly always construed to have a very large population base, especially during the Classic period. What is largely omitted in prior studies is the proof of sustainability of such calculated population size in commensuration with, among other things, effective management of human wastes. The waste disposal situation in ancient Tikal is aggravated by the generally flat terrain and the lack of natural drainage channels. The only means of waste disposal would have been by manual labourers conveying the wastes collected daily to dump in cesspools at some distance from high-density human settlements. There was a notable absence of draft animals and wheeled machines including transport vehicles, which could have facilitated such means of waste disposal. The problematic issue of human waste management would certainly have limited the practical size of population cluster in ancient Tikal.

KEYWORDS: Maya, Tikal, population, sewage, waste management.

RESUMEN: La población de los antiguos mayas se ha estimado tradicionalmente multiplicando el número de montículos residenciales descubiertos por el número asumido de personas por hogar en un transecto dado de un sitio arqueológico. Este enfoque es fundamentalmente débil ya que ambos parámetros clave están sujetos a grandes variaciones a lo largo del tiempo por varios siglos. El resultado omnipresente de este enfoque es que los antiguos mayas son casi siempre interpretados con una gran base poblacional, especialmente durante el período Clásico. Lo que se omite en estudios previos es la demostración de la sostenibilidad de dicho cálculo teniendo en cuenta, entre otras cosas, el manejo efectivo de los desechos humanos. La eliminación de residuos en la antigua Tikal se agravó por el terreno generalmente llano y la falta de canales naturales de drenaje. Los únicos medios de eliminación de desechos habrían sido mediante transporte a pie de trabajadores manuales, que trasladarían los desechos recolectados diariamente para verterlos en fosas sépticas a cierta distancia de los asentamientos humanos altamente poblados. Hubo una notable ausencia de animales de tiro y vehículos con ruedas, incluidos los medios de

transporte, que podrían haber facilitado tales vías de eliminación. La problemática del manejo de los residuos humanos ciertamente habría limitado el tamaño práctico de los grupos de población en la antigua Tikal.

PALABRAS CLAVE: Maya, Tikal, población, aguas residuales, manejo de desechos.

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Introduction

In the course of the past century of Maya studies, many estimates of ancient population have been made largely on the basis of discovered mounds of household dwellings in excavated areas. Their occupancies through a span of several centuries have been assumed largely to be constant on conjectures through the prism of modern-day practice (see, for example, McAnany and Gallareta, 2010). This approach affords high propensity of systemic errors. There have been little or no independent verifications of this methodology and the resulting conclusions. The validity of the “mound-counting” method has been questioned widely by many researchers in recent years. Other approaches such as water supply have been suggested as alternative means of estimating ancient population. For example, McAnany (1990) had posited that water storage might be used for population estimate in the Puuc region of northwestern Yucatán. French, Duffy and Bhatt (2012) had commented about the implication of discovered hydraulic system of Palenque on population estimation. The topography of the Puuc region and Palenque is notably different from that of Tikal. One critical weakness of the “water supply” approach is its reliance on conjecture of the actual utility of dried-out chultuns and other terrestrial depressions of various sizes more than 1,500 years ago (see, for example, Weiss-Krejci and Sabbas, 2002). Nevertheless, many 21st Century Mayanists are still relying on the “mound-counting” procedure in the absence of any other robust independently-derived alternative methodologies for population estimate (see, for example, Magnoni, 2006; Webster, 2008; Chase *et al.*, 2011; Chase, 2016).

Recently Wong, Ribeiro and Gomes (2017) have proposed the deployment of human nutrition as an independent means to determine the probable sustainable size of population of ancient Maya. This approach is based on the unchanged nutritional requirement for human sustenance through the past few millennia, within the constraint of indigenous stone-age agriculture and wild food supply. In reference to the conclusion reached by Lentz *et al.* (2014), the upper limit of population sustainability in ancient Tikal might be ~45,000 within a land base of 43,000 hectares for agriculture and 67,000 hectares for forest reserve. As noted by Wong, Emerson and Oakley (2017), this estimate of population size of

ancient Tikal could however be reduced to $\sim 15,000$, if the fallowing period was, for example, nine years instead of three years. It may be noted that the shorter fallow period assumed to be practiced in ancient Maya is derived mainly from observations of modern Maya practice under very different circumstances of contemporary market economics. Compare the steadily decreasing fallow period of modern-day “stone age economics” of India (Ranjan and Upadhyay, 1999) and Bangladesh (Hossain *et al.*, 2006), of which shifting cultivation practice is under constant market-economic pressure. In the context of stone-age economics, i.e., in the absence of monetized market forces, the fallow period could be expected reasonably to be long, perhaps without any period consistency. Land availability may not have been a limiting factor, as private land ownership and personal consumerism have essentially no meaning in ancient Tikal. Because of the specific topography of territory, it is not clear if the actual land base used was indeed smaller or larger than that construed variously by different Mayanists. Rice and Culbert (1990: 20) had recognized this important factual deficiency more than 25 years ago. There is certainly no unequivocal evidence of the actual land base of ancient Tikal during the entire Classic Period (from about 250 CE to about 900 CE).

This paper is aimed to explore population size of ancient Maya under the constraint imposed by human waste management. The issue of food supply as a limiting factor has been discussed elsewhere (Wong, Emerson and Oakley, 2017).

Methods

The published literature data and hygiene maintenance guidelines issued by international health agencies have been deployed to assess the quantity of human wastes produced and waste management methods required for a given population size.

Tikal (17.22° N, 89.62° W) in the Late Classic period was chosen as the study example as archaeologists have studied this large ancient Maya site most intensively over the past 50 years. It may be noted that the geographical circumstances of Tikal are somewhat unique as it is not located near any large permanent rivers or lakes. Tikal is located near a large seasonal swamp, viz., bajo de Santa Fe. The northern shore of Lago Petén Itzá is located more than 27 km (straight-line) southeast of Tikal. In comparison, other nearby ancient Maya sites in the Classic period, such as Yaxhá (17.08° N, 89.40° W) overlooking Lake Yaxhá, and Nakum (17.12° N, 89.42° W) situated on the bank of Holmul River, could dispose their human wastes conveniently by natural flow into large perennial bodies of water.

Results and discussion

Waste management in ancient times

In any ancient or contemporary human settlements, adequate water supply is a necessity of life. It is recognized that there have been numerous studies published on water supply in ancient Maya (see, for example, Scarborough and Gallopin, 1991; Crandall, 2009; Isendahl, 2011; Scarborough *et al.*, 2012; French, Duffy and Bhatt, 2013; Lucero *et al.*, 2014; Wyatt, 2014). Although water supply is invariably linked to waste disposal, there has been little or no discourse of waste disposal in ancient Maya settlements to date. Scarborough *et al.* (2012) discussed about the recent discovery of extensive hydraulic works in the core centre of ancient Tikal, without any comments on the human waste-disposal aspect. Chase and Chase (2014: 11) had commented in just one short paragraph about the possible disposal of excrement in portable ceramic vessels in the discussion of “bathrooms” in their analysis of houses and households in ancient Caracol. One well-known outcome of inadequate waste management is the danger of pandemics arising from pathogens present in human wastes (see, for example, Strauch, 1991). There are numerous diseases which could be propagated by the inadvertent contamination of food and water supplies by human fecal matter (see, for example, Cox, 2002; Gonçalves *et al.*, 2003; Nelson and Williams, 2007; Yugo and Meng, 2013). In the extreme case, contamination of potable water (or fresh plant foods) by some of these fecal pathogens could have fatal consequences. In contrast, the importance of urine as a transmission route of pathogens is generally considered to be low (World Health Organization, 2006: 36). Pathogens such as bacteria (e.g., *Escherichia coli* and *Salmonella spp.*), viruses (e.g., norovirus and hepatitis), parasitic protozoa (e.g., *Cryptosporidium parvum* and *Giardia intestinalis*) and helminths (e.g., roundworm and hookworm) are found frequently in feces (World Health Organization, 2006). It is recognized however that not all pathogenic ailments are lethal to humans. With the exception of the “helminths” group (see, for example, Ferreira, de Araújo and Confalonieri, 1983; Araújo, Ferreira, Confalonieri and Chame, 1988; Gonçalves, Araújo and Ferreira, 2003; Leles *et al.*, 2008), it has yet to be ascertain that other pathogens are indigenous to the Neotropics (see, for example, Horne, 1985; Araújo *et al.*, 1988; Simmonds, 2001; Reinhard *et al.*, 2001; Meng, 2011). However, the existence of any of these diseases in Tikal during the Classic period to cause premature mortalities could not be ruled out. Unfortunately, a robust study of these fatal diseases occurring in ancient Maya is very problematic as these “fast-moving” diseases generally do not leave any physical evidence for the detection of their existence through customary paleo-osteologic studies.

In the many thousands of scientific papers, monographs and books on ancient Maya published over the course of the past 100 years, there does not appear to be any archaeological research evidence of human waste management practi-

ces. Houston and Inomata (2009: 118) had noted this rarity. In comparison, Gray (1940) had reported that several ancient civilizations such as Indus and Aegean already had some rudimentary forms of sewage works for the management of human wastes in about the Second Millennium BCE. In ancient Rome (between ~100 BCE and ~100 CE), human wastes were dumped routinely into the Cloaca maxima which flows eventually into the lower reaches of the Tiber River and onwards to the Tyrrhenian Sea (see, for example, Amulree, 1973). During that period, the population of ancient Rome is believed to have ranged from a few hundred thousands to several million (Aldrete, 2004: 21-23). It may be noted that the topography of Rome permits the simple gravitational flow of effluent down the Tiber River. There appear to have been adequate water flow in sewers to flush away human wastes from public latrines. However, solid human wastes and other refuse have been noted to have been thrown largely out of the windows of private households into streets (Casson, 1998: 39-40). Similar practice was also assumed to have occurred in ancient Maya (Houston and Inomata (2009: 118). Beard (2008: 55-57) also provided an insightful account of similar daunting task of waste disposal in the “well preserved” ancient Roman city of Pompeii. In contrast, ways and means deployed by any cluster of households in ancient Tikal to manage human wastes remain almost totally unknown.

Generation of human wastes

The magnitude of human waste management is directly proportional to the size of the population. In other words, normal human body function necessitates the daily discharge of specific amount of urine and feces. The well-known energetics of human life, in accordance to the Laws of Thermodynamics, is illustrated in Figure 1. Only “Energy expended” and “Energy stored” could be changed substantially at will in the disposition of “Energy intake”.

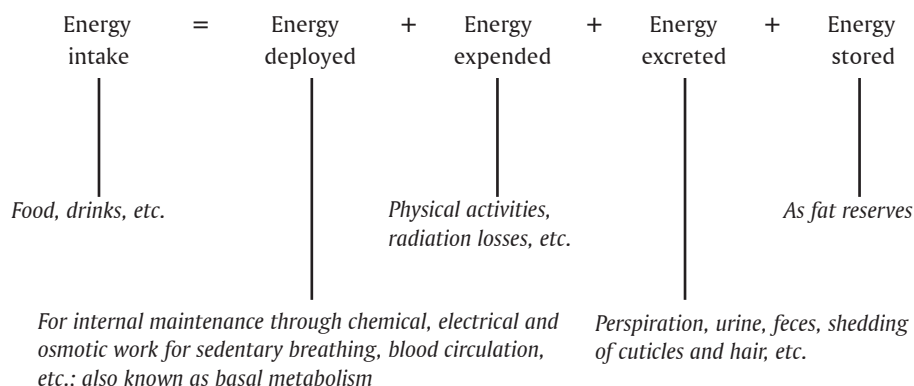


Figure 1. Human energy balance (Source: Wong, Ribeiro and Gomes, 2017: 437).

In general, the average amount of human wastes produced is variable within a narrow range, resulting from such factors as ambient temperature, expenditure of energy through physical work, and quantities of water and energy (food) intake. It can however be safely assumed that per capita amount of human wastes generated has not changed substantially because human physiology has not altered appreciably anywhere in the World over the past two millennia. Even in 21st Century lunar base habitation contemplated by humans, the generation of human wastes under very stringent conditions of regulated intake of food and water is not considered to be insignificant (Hypes and Hall, 1992; Parker and Gallagher, 1992). The discharge of urine and feces by humans is physiologically unavoidable.

As shown in Table 1, the disposal of urine and feces would be an enormous undertaking for the three example sizes of ancient Tikal. A hypothetical urban centre with a population size of 45,000 would have about 1,600 daily loads of urine and feces to be carried away manually. The axiom is that high population density exacerbates the management problem. Due to the lack of veritable data, the daily generation of food wastes for subsequent disposal is assumed to be zero in these calculations. Certainly unlike modern times, there were no packaging materials used in ancient Tikal which must be disposed also.

It is plausible that in ancient Tikal, human wastes and other food rubbish could have been conveyed manually from the urban household by contract labourers. The magnitude and modality of such a human waste management scheme for a core-centre population of 8,300 (from Entry 3 of Table 1) would mean the allocation of about 300 persons for the conveyance of waste alone, everyday of the year!

Where would the human wastes be disposed if they were indeed conveyed manually from a densely-populated residential area? The logistical constraint in ancient Tikal was the absence of draft animals and/or wheeled vehicles. For public health reasons, the disposal site would need to be away from any potable water sources. Figure 2 shows the terrain of the immediate Tikal area to be relatively flat with few intermittent (seasonal) drainage channels (Carr, 2013). Crop irrigation is not known to have been practiced in ancient Tikal. Thus, disposal of urine could not be accomplished by routine dumping into an irrigation or drainage channel. In the absence of draft animals or wheeled machines, lifting water even by a few centimeters to a higher elevation would not have been possible. Flushing human wastes into the nearby Bajo de Santa Fe is not considered practicable as the water level of this swamp is very seasonal in nature (Cowgill and Hutchinson, 1963).

The apparent absence of sewage works (and even distant cesspools) might be a significant clue for explaining the seemingly abrupt decline in population in the Terminal Classic period, after the population peak at the end of Late Classic (see, for example, Santley, Killion and Lycett, 1986; Sharer, 1994; Haviland, 2003; Houston and Inomata, 2009). An alternative explanation of population collapse in ancient Maya might be that successive outbreaks of diseases might have caused

Basis:

Since there are no measured human-waste data from ancient Maya, the Swedish norm as described by Jönsson and Vinnerås (2003), and Pinsem and Vinnerås (2003) was used. Toilet paper has been excluded in this calculation as it is unknown what toilet paper or equivalent might have been used routinely in ancient Maya. For illustration purposes only, the specific per capita discharges were assigned to be as follow:

urine (excluding toilet paper) = 1.370 kg wet mass/day at specific gravity $\approx$ 1.0 kg per litre; this figure could be compared to recommended daily intake of drinking water of about 3 litres per day (Grandjean, 2005).

feces (excluding toilet paper) = 0.141 kg wet mass/day

Identification	Classic Period		Urine		Feces	
	Estimated population	Population density, No./km ²	Total litres produced/day	Calculated loads/day#	Total kg wet produced/day	Calculated loads/day#
Tikal polity (1)	1,520,000	121	2,082,192	52,055	214,466	5,362
Greater Tikal (2)	45,000*	375	61,644	1,541	5,349	159
Tikal Core (3)	8,300	922	11,370	284	1,171	29

Notes:

(1) Turner, 1990

(2) Haviland, 2003

(3) Barnhart, 2002

assuming the maximum tumpline payload is 40 kg; using a baked clay vessel similar in size to the ceramic wine amphorae used in ancient Roman times in which the payload ratio was 4 kg liquid per kg of vessel (Bevan, 2014: 402). Wood stave buckets would have been the only other vessels available for carrying liquids and semi-solids

* Lentz *et al.* (2014) also had cited an ancient Tikal population of 45,000 using a total land base of about 110,000 hectares.

Table 1. Anticipated production and management of human wastes in ancient Tikal.

episodic massive decline in population. Hays (2005) has provided some instructive accounts of panic and hysteria among the general population during ancient epidemics and pandemics. These traumatic events could have caused mass emigration, without widespread deaths. An instructive example of the periodic epidemics of hemorrhagic fevers (also known as *cocoliztli*)¹ in Mexico during the 16th-18th Centuries causing massive population decline (see, for example, Acuna-Soto, Calderon Romero and Maguire, 2000; Acuna-Soto *et al.*, 2002; Acuna-Soto *et al.*, 2004). Acuna-Soto *et al.* (2005) had subsequently speculated that similar drought-associated epidemics might have been the significant cause of massive population decline in ancient Maya in the period of 750-950 CE.

¹ *Cocoliztli* might have been caused by an indigenous virus and carried by a rodent host (Acuna-Soto *et al.*, 2002)

Basis:

Maize and bean crops only.

Regardless of the length of the fallow period, the calculated minimum crop land required to feed a population of 45,000 persons in Greater Tikal would be 12,069 hectares (9,937 ha of maize and 2,133 ha for beans (based on data given in Wong, Emerson and Oakley, 2017). The effective land base in any one crop year would be reduced to 9,937 hectares if co-cropping of maize and beans was practiced. But the total NPK (nitrogen-phosphorus-potassium) demand would remain unchanged.

Maize (9,937 ha)			Beans* (2,133 ha)		Total	Availability from human wastes		
	Application, kg/ha#	Demand, kg	Application, kg/ha#	Demand, kg	Demand, kg	Urine, kg	Feces, kg	Total, kg
N	27	266,671	30	63,981	330,652	180,000	24,751	204,751
P	65	645,890	50	106,636	752,526	14,850	8,227	23,077
K	80	794,942	85	181,280	976,222	40,950	16,431	57,381

* Although beans (*Phaseolus* spp.) are generally recognized to be a N-fixing leguminous crop, its addition of N to the soil might be as low as 45 kg N/ha (Follett *et al.*, 1981: 25). This supplementary source of N fertilizer would be realized only if co-cropping of maize and beans was practiced.

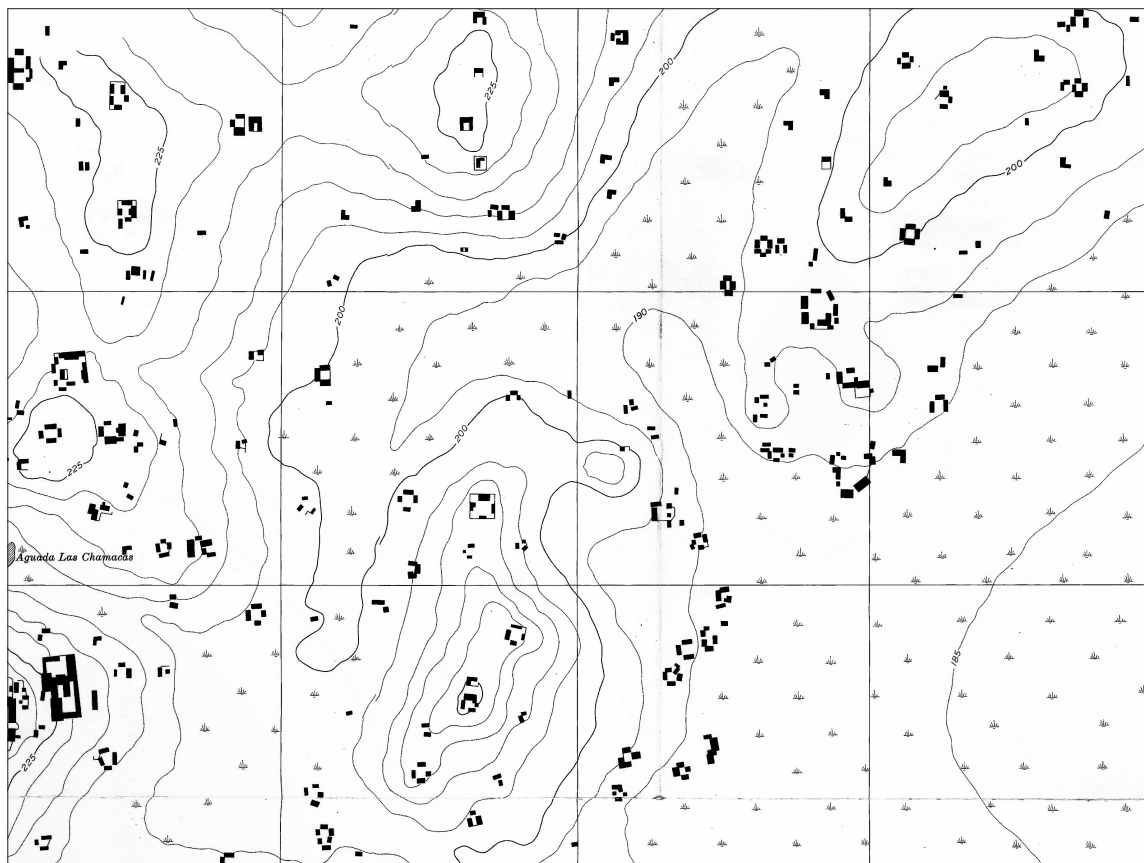
Average recommended NPK demand estimated from data published by FAO (2016). The N demand for maize was estimated from the correlation equation of Ciampitti and Vyn (2014); this figure represents a low N fertilization approach to reflect low yield in present-day Guatemala maize cropping.

Table 2. Disposal of human urine and feces in crop fields.

Dumping of human wastes on cropped fields is an obvious option (see, for example, Palmquist and Jönsson, 2003; Stintzing *et al.*, 2004; El Rafie, Mohamed and Hawash, 2012; Chase and Chase, 2014). The feasibility of disposing human-waste fertilizer on crop land in Greater Tikal polity (Population: 45,000; total land base: 110,000 hectares) is estimated quantitatively in Table 2. This means of disposal might be satisfactory in terms of nitrogen (N), phosphorus (P) and potassium (K) required for minimal fertilization of maize and bean crops. There would be no apparent circumstances of *excessive* plant nutrients provided by human wastes, in relationship to NPK² fertilizer demand of maize-beans crops. The balance requirement of essential nutrients might have been derived from ashes left by the open-field burning of shrubs and grass, and by natural sources from the relatively thin overlaying leptosols³ (Gardi *et al.*, 2015: 47, 55). It may be noted that the actual demand for NPK fertilizers in subsequent crop year could also be affected by the amount of maize stover and other organic residues removed permanently from the field in post-harvesting operations (see, for example, Sawyer and Malarino, 2007). For example, off-field de-husking maize would contribute to the “permanent” loss of NPK nutrients from the soil. The actual post-harvesting operation practiced in ancient Tikal is however unknown.

² NPK = nitrogen-phosphorus-potassium.

³ Leptosols are notably not well endowed with essential nutrients.



Notes:

Discovered building structures (■) scattered along the edge of (present-day) swamps in the acute absence of known drainage channels.

Contour interval is 5 meters; elevation in meters above mean sea level.

Each square grid = 500 meters x 500 meters

Figure 2. Example of relatively flat topography on the immediate region of Tikal, about 1 km northeast of the core archaeological site (Source: adapted from Carr, 2013).

Furthermore, the distance⁴ of conveyance (as much as 15 km in the example case of Greater Tikal in Table 1) and uniform distribution of human-waste fertilizers in fields might present significant logistical difficulties. Moreover, it may be noted that disposal of human wastes in crop land does not guarantee the destruction of many pathogenic micro-organisms (see, for example, Wiley and Westerberg, 1969; Strauch, 1991; Santamaría and Torzanos, 2003; Gerba and Smith, 2005; World Health Organization, 2006: 42-44; Józwiakowski, Korniłowicz-Kowalska and Iglik, 2009). Effective avoidance of fecal contamination of potable water supply might have been very problematic for a large population cluster.

⁴ One day's walking carrying a load would be 10 to 15 km. In the case of Greater Tikal in Table 1, the radial distance would be ~15 km, if the land area was circular.

If the population of ancient Tikal was well dispersed as in the case of hamlets with an example cluster of 10 to 20 persons residing amidst farm land, the daily waste disposal in adjacent cropped fields could have been very practicable. For an example hamlet of 10 persons, the estimated daily waste disposal would be about 14 litres of urine and about 1.5 wet kg of feces. If the cropped land demand was about one hectare per person on a 3-year fallow system (Wong, Emerson and Oakley, 2017), and if the plot of cropped land was circular, then the radial distance traversed daily for conveying wastes for disposal in the field would be less than 200 metres. It is obvious that at high population density, practical management of human wastes might become a critical constraint on sustainable population size.

Concluding remarks

The enigmatic question is whether a large urban centre could have existed in ancient Tikal in view of the significant problematic issue of human waste disposal. Although there has been considerable discourse on water supply in ancient Tikal as well as many other ancient Maya sites, no archaeological evidence of sewage works in any location has been discovered to date. The waste disposal problem was certainly aggravated by the notable absence of usage of draft animals or wheeled vehicles. In particular, large settlement with a high population density as conjecture by many Mayanists would not likely be plausible as such a (large) human settlement unit would have been effectively overwhelmed by wastes, even if the food supply issue could be resolved satisfactorily. There is an acute need for Mayanists to corroborate any projected population size with evidence of, among other things, effective human waste management, and food supply and distribution. There is no basis at this time to link problematic human waste management to the oft-cited Classic Maya Collapse.

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