Human Ecology and Infectious Diseases

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~~MATERIALS ON DEFECATION BEHAVIOUR~~

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Human Ecology and the Distribution and Abundance of Hookworm Populations

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I. Introduction and General Ecological Background

Hookworm infection is largely confined to the moist tropics and subtropics, because the eggs and free-living larvae of *Necator americanus* and *Ancylostoma duodenale* require a warm, moist, external environment in which to embryonate, hatch, and develop. This global generalization has significant exceptions where large-scale manmade ecological changes permit the establishment of infection in areas otherwise unsuitable. For example, ancylostomiasis is an important disease in areas of Egypt which without irrigation would be much too dry for the parasite's survival; it was once well established in several foci in cool temperate areas of northern Europe, where unsanitated mines and the first tunnels through the Alps created habitats that were sufficiently warm and moist for free-living larval development. Such examples demonstrate the major role that human ecology can play in controlling the global distribution and abundance of these parasites.

Natural ecological variation within the normal ranges of these worms will affect their abundance regionally and, consequently, the degree of hookworm infection in the human population. If ecological factors (e.g., moisture and soil type) are generally favorable, the abundance of hookworm larvae in the soil can be significantly influenced by human decisions concerning the environment, such as whether natural vegetation remains or what plants are cultivated in its place. Extensive natural vegetation usually implies a hunter–gatherer culture with sparse, mobile populations; in this situation hookworms are rarely an important problem (Heyneman, 1977).

In contrast, coffee, tea, rubber, and jasmine plantations (but usually not tobacco, pineapple, or cotton) are often sites of heavy hookworm transmission and a high prevalence of disease. Because plants vary in their ability to shade the soil and thus conserve the moisture required for larval survival, they may exacerbate or mitigate the public health problem. Clearly, under conditions of extensive plantations and other one-crop agriculture, the choice of crop can have an important regional influence on the degree of hookworm endemicity.

Water management also affects the occurrence and abundance of hookworm; irrigation generally favors hookworms, but excess water is detrimental because larval development fails in water-logged oxygen-deficient soils. Thus, cultivation of rice and jute in flooded fields limits transmission of these parasites (Cort *et al.*, 1926; Chandler, 1928).

Other agricultural practices, particularly those that contribute to the widespread fecal pollution of crops, also enhance transmission. The use of inadequately composted human feces as fertilizer has long been associated with serious levels of hookworm infection, especially in parts of the Orient. Even when feces are not used deliberately, heavy fecal pollution of crops such as tea, cacao, and coffee occurs when large groups of laborers are in the field from dawn to dusk with few, if any, sanitary facilities available (Chandler, 1925, 1926; Cort *et al.*, 1922a,b; Cort *et al.*, 1923a,b).

Human Ecological Factors Determining the Distribution and Abundance of Hookworms

1. DEFECATION: CUSTOMS, PRACTICES, AND HABITS

Because people are the only important definitive hosts of *Ancylostoma duodenale* and *Necator americanus*, hookworm disease can be an important problem only where they pollute the soil with their feces. Unfortunately, this practice is still common in many rural tropical and subtropical areas, where the prospects for sanitation are limited not only by poverty but also by preference for defecating in the open rather than in latrines.

In traditional Hindu societies, human feces are repugnant not only for the universally accepted reasons but also are considered personally defiling in a ritualistic sense (Kochar, 1975, 1977a, 1979a). Under these circumstances, and in the widespread lack of understanding of the germ theory of disease, it is virtually impossible to maintain latrines in an acceptable condition, and fouled structures rapidly fall into disuse.

On the other hand, very simple structures and naturally occurring squatting places are extensively used as latrines in rural areas of Burma, Bangladesh, and elsewhere in southern Asia, helping to limit the transmission potential of the hookworm eggs entering the environment. In Burma, bamboo platforms, each with a simple superstructure to screen the user from sight, extend over steep banks and adjacent water courses. In the low-lying delta lands of Bangladesh, similar structures keep the small amount of available high ground occupied by villages relatively free of fecal pollution. In the drier, deltaic areas in West Bengal, steep banks are again favored defecation sites, but platforms are rarely built over them; natural overhangs (e.g., trees and roots), over either a steep slope or flat ground, may serve as elevated squatting places. Feces accumulate in heaps, limiting development of hookworms because hookworm eggs within such decomposing fecal accumulations do not yield infective larvae. For this reason, proper composting of human excreta, particularly with the addition of urine, will result in the death of hookworm eggs and will produce a safe fertilizer.

Obviously, defecation habits, important in seeding the environment with hookworm eggs, are also important in the acquisition of infection. Several leading authorities (Chandler, 1929; Cort, 1941; Beaver, 1961) stress that most people become infected when stationary in fecally polluted areas, as during defecation. Thus, the degree of avoidance or nonavoidance of previously fouled sites in selecting a place to defecate becomes a matter of epidemiological significance. The literature abounds with examples from many cultures indicating that little care is taken to avoid polluted areas. Indeed, although clearly identifiable feces are not stepped on, little avoidance occurs after their incorporation into the soil, when they become invisible and odorless. This is particularly so when the people do not associate feces with disease.

There are some areas such as India, however, where a strong desire to avoid human feces exists; successful avoidance depends on knowing where fecal pollution has occurred. The aggregation of feces in socially accepted and generally recognized defecation grounds makes avoidance possible by most people during most activities. In contrast, where defecation is promiscuous, leading to spatially unpredictable pollution, conscious avoidance becomes impossible when individual deposits become visually obliterated.

When feces are aggregated in specific areas set aside for defecation, most members of the population will be at risk of exposure to infection only when they defecate; thus, people can avoid casual and work-related exposure to infection. The few whose work brings them into contact with defecation grounds will at least be aware of the fecal pollution whether or not visible evidence remains.

The daily risk of exposure at defecation can be reduced further by aggregation of feces within the defecation grounds, making it possible to avoid the specific loci where individual fecal masses have been deposited. If a fecal deposit is visible, this avoidance is easily achieved. However, because of the burying action of dung beetles and rain, a deposit disappears rapidly and combines with the soil so that evidence of its presence is subtle (at least to the untrained eye), appearing as a mound of loose earth. If deposited originally on the leaf-covered ground under a grove of trees or bamboo, this fecal locus is defined further by a circular clear area (a plaque) which stands out in the otherwise continuous carpet of leaves and which remains even after rain has compressed the mound of loose earth. Eventually, the mound becomes flattened with one or more holes representing tunnels of dung beetles. These subtle signs persist for several weeks; if the observer knows where the area has been polluted, he/she can even avoid the exact sites of former fecal deposition. Indeed, there is objective evidence that Bengali villagers do avoid these spots (Section II,E). The Bengali terms for a site of dung beetle activity and for a fecal deposit are identical, indicating that the original nature of an obliterated deposit is known.

Although loci of probable soil infestation can be recognized and avoided, individuals refusing to conform to behavioral norms or lacking normal visual acuity may be exposed to frequent and heavy infection from the clustering of soil infestation occurring in defecation grounds. This may explain the increased worm burden observed among the elderly in West Bengal.

2. OCCUPATION

Although many authors have associated hookworm infection with agricultural occupations involving soil contact, it is not necessarily these particular occupations that predispose to infection but rather the rural life style with inadequate facilities for the safe disposal of human excrement. When fecal pollution of the soil is concentrated near homes and around villages, all persons are almost equally at risk; indeed those away from home tilling the land may be protected from heavy infection by their regular, prolonged absence from the areas of maximal soil infestation (Chandler, 1929). Ancylostomiasis may also occur in an urban setting if sanitary facilities are lacking; unpaved streets, alleys, and patches of vacant land provide defecation sites for people with an unsophisticated and essentially rural concept of appropriate behavior.

However, agricultural work can have an important influence on the prevalence and intensity of hookworm infection. We have already described how particular crops are associated with varying intensities of hookworm infection because of the different ecological conditions they create and the specific management practices associated with them.

If ecological conditions permit uniform larval development and survival, the infection to which an agricultural labor force is exposed will depend on (1) the distribution and density of fecal pollution and (2) the timing and duration of contact with infested soil. The fecal input may be planned and narrowly distributed, as when a crop is fertilized with night soil, or it may be caused by incidental defecation on agricultural land, in which case fecal distribution and density will vary with diverse human behavioral factors.

Cort *et al.* emphasized the great danger of housing agricultural laborers along the edge of the plantations where they have to work (Cort, 1941; Cort and Payne, 1922a). This was notable in Trinidad, where feces accumulated between the rows of sugar cane behind the workers' housing so that they were exposed to infection not only during defecation but also when going to and from, and during, work.

Coffee pickers may be exposed to very heavy infection. They remain in the groves for continuous, prolonged periods because picking is a weekly activity for several months; this results in extensive and intensive soil pollution (Cort *et al.*, 1923a,b), and by the end of the harvest season larval populations are uniformly dense and infection correspondingly heavy.

Laborers on tea estates are also subjected to heavy infection (Napier, *et al.*, 1937; Rice, 1927) because they spend long hours far from latrines in the tea gardens where soil pollution is accepted. During the harvest season, every bush is plucked weekly and systematically, precluding avoidance of, and insuring prolonged contact with, polluted ground.

Heavy hookworm infection has been perhaps nowhere more certain than in the districts of China where the mulberry tree is grown to provide leaves for silkworm culture. The epidemiology of hookworm disease in these areas was described dramatically by Cort *et al.* (1926a). Intense transmission is fostered by the need to force leaf growth over a short period of time during the warm, rainy part of the year; human feces are added to freshly cultivated soil around the base of each tree; and the urgent need for fertilizer results in the use of fresh excrement laden with viable eggs after the supply of old, well-composted feces (in which most hookworm eggs have died) has been exhausted. Combining the fresh feces with recently worked soil at precisely the time when weather conditions are ideal creates perfect culture conditions for hookworms, guaranteeing a large population of infective larvae.

When the laborers return and harvest the leaf crop after 2–4 weeks, moving systematically around each tree, prolonged contact with virtually every inch of the heavily infested soils is ensured. Unusually severe cases of hookworm dermatitis occurring precisely at this time provide evidence for massive larval invasion.

In some cultures particular kinds of agricultural work are done by members of one sex. Tea leaves, for example, are most often picked by women, and so they may be more heavily infected than men. In contrast, if infection is likely to occur during plowing or other heavy labor usually done by men, infection is likely to be heavier in males. There is considerable danger in assuming such associations too readily because experimental investigations of the effects of host sex on helminth infections have shown there are also sex-related differences in susceptibility; females are usually more resistant than males. Indeed, our data from India show that females are less heavily infected than males; as this difference is apparent even among young children (Nawalinski *et al.*, 1978a), it is unlikely that it results from infection acquired during agricultural pursuits.

Any occupation that increases contact with fecally polluted soil during warm, moist conditions probably predisposes to infection. We have already indicated that unsanitated mines have been sites of intense transmission, and hookworm disease has been reported from such diverse underground operations as coal mines in Europe, gold mines in California and South Africa (Hodgman, 1934), and phosphate mines in arid parts of North Africa (Becmeur *et al.*, 1950). Troops in combat, living close to the earth and lacking sanitary facilities, are exposed to numerous infections including soil-borne nematodiasis. Even when they are well protected with heavy footwear, contaminated soil and mud contacting unprotected parts of the body can cause hookworm infection.

Hookworm infection associated with recreational activities has been described on a number of occasions. In northern India, a game called *kabaddi*, played on an open field, involves members of one team throwing members of the other to the ground. An outbreak of severe ancylostomiasis followed such a game played

on a muddy field that had been contaminated with feces at some time previously (Koshy *et al.*, 1978).

The possibility of water-borne ancylostomiasis remains in some doubt, but in at least one incident infection seems to have occurred while the subjects were swimming because itching and other symptoms suggestive of hookworm dermatitis began while they were still in the water. This was followed in a few days by a severe, life-threatening, prepatent ancylostomiasis; the diagnosis was confirmed by finding extraordinary numbers of young worms in the feces after anthelmintic treatment. In this instance, torrential rains apparently had carried very large numbers of ancylostome larvae into a small bay from an adjoining, heavily polluted valley (Ashford *et al.*, 1933a,b).

The attending physicians described these incidents and published their findings because the infections were very heavy and the patients had unusual symptoms of special medical interest. Had smaller numbers of parasites been involved, the diagnosis might not have been made; perhaps investigations into the mode of infection would not have been conducted and the information would not have reached the literature. It is possible, therefore, that water-borne infection may not be as rare, and occupational groups associated with water may not be as protected, as is generally assumed. Ghadirian *et al.* (1979), for example, thought that rice farmers in Iran are particularly at risk, acquiring these infections in flooded fields. However, no evidence was provided to support the suggestion.

3. FOOD HABITS

Hookworms are rarely considered to be food-borne parasites. Most textbooks convey the impression that they invariably enter the body percutaneously and in fact *N. americanus* does; *A. duodenale*, however, is able to establish successfully after oral entry, as has been shown in experimental subjects (Kendrick, 1934). Food-borne ancylostomiasis is widely recognized in the Orient, where an allergic response to orally acquired larvae (known as *Wakana* disease in Japan) is associated with eating the small, young leaves of Chinese cabbage and radish (Matsusaki, 1966).

It has also been suggested that human hookworm infection can be meat-borne (Schad *et al.*, 1980); they observed that *A. duodenale* larvae migrated to the somatic musculature of several swine, rabbits, and a calf, where they survived for at least several weeks. Lambs and chickens were partially or totally resistant to infection. These preliminary observations suggest an entirely new route of infection whose significance requires further investigation.

Some foods have anthelmintic properties, although none sufficiently strong to be valuable chemotherapeutically. As we know very little about the long-term effects of weak anthelmintics on hookworms, it is possible that food habits could directly influence worm burden. Certain foods (e.g., onions and garlic) adversely affect the development of the free-living stages in feces (Bastidas, 1969); presumably, diets rich in these foods would have an adverse effect on the parasite's reproductive success.

4. CULTURE AND RELIGION

The degree to which people avoid fecal contact depends on aesthetic, hygienic, and/or cultural considerations. Aesthetic considerations are undoubtedly those which most often inhibit such contact. Hygienic considerations (i.e., associations with disease) also inhibit contact, but how completely and consistently depends on the level of understanding of disease transmission.

In some cultures, human feces are avoided not only for the reasons given but also because contact with them is considered defiling. In Hindu and Muslim cultures of Asia, the act of defecation is considered defiling and elaborate ablution practices are necessary to ritually purify the defiled individual. These beliefs and practices reinforce the abhorrence on aesthetic and hygienic grounds and usually result in almost complete avoidance of fecal contact, even where defecation outdoors causes at least some contact to be inevitable.

Among both Hindus and Muslims in rural India it is essential that one achieve a certain personal sacredness, perceptible by others, to maintain one's social status (Kochar, 1979a). Purity is one aspect of this sacredness, and a cleansing act must be performed after defecation or contact with fecally polluted places. Furthermore, impurity is considered contagious and contact with defiled objects, places, or persons must be avoided. Thus, in traditional Indian society, ablution and a change of clothing follow defecation; food crops are not fouled with human excreta, and contact with fecal pollution is generally avoided.

Additionally, regularity with respect to defecation is considered a virtue, and daily bowel movements at the correct time and place, invariably followed by ablution and often by a bath and change of clothes, is generally expected behavior. In fact, this sequence in whole or part has become a daily ritual. Kochar (1979a) states that a popular Bengali text on the daily rituals of a religious Hindu household begins with detailed instructions concerning defecation, even specifying the direction in which to face. He outlines the typical routine as found in our investigations:

> Defaecation every day early in the morning is considered desirable and in fact about 30% of adults complete the act before 6 A.M. Ablution must be done immediately after defaecation by entering a pond or other water body (since Bengalis do not usually carry water with them like in other parts of North India) and by rubbing the peri-anal skin with water in squatting posture. This is followed by rubbing of hands with soil as [a] purificatory act. The termination of defilement is symbolized by taking by hand a mouthful of water and spitting it out. Many also prefer to take a bath as a continuation of this ritual. In any case, clothes worn during defaecation have to be changed. If bathing is not intended, most adults change from their normal "clean" clothes before going for defaecation. The high castes are required to loop their sacred thread around their right ear (as a sign of defilement) until after they have purified themselves. The ablution must be performed with left hand. Rural Bengalis scrupulously avoid the use of left hand for eating or handling any cooked food material since it is defiled. These norms are followed with high conformity. The ritual norms emphasize early socialization of habits associated with defaecation. Children are reprimanded for not following the correct procedures. Defaecation, contact with faeces, or even a visit to "polluted" defaecation ground, are deemed to pollute a person and would normally require some purificatory ritual. However, these norms are followed with modifications suited to person, time and routine. Polluted fields are not avoided in the same manner as the bamboo groves are.

This culturally based aversion for human feces may not be shared by other groups. Rural Chinese, for example, value feces as fertilizer and conserve them; defecation or work that involves night soil is not perceived as defiling and no purification rituals are required. The Chinese therefore have been at risk of hookworm infection during agricultural work to an extent that is unusual under Indian conditions.

Within India itself, Hindus and Muslims in Bengal show pronounced differences in intensity of hookworm infection (Nawalinski *et al.*, 1978a) as well as in the prevalance of other helminthiases (Chernin, 1954a; Chowdhury *et al.*, 1968a,b). No explanation for this difference is readily apparent, but presumably it is determined by culturally based behavioral differences that control rates of exposure.

II. The Ecology of Interacting Human and Hookworm Populations in Rural West Bengal

A. Parasitological Background

It is thought (W.H.O. 1964) that the prevalence and mean intensity of hookworm infection usually vary directly. Therefore, the epidemiology of ancylostomiasis in gangetic West Bengal, where prevalence exceeds 80% although hookworm burdens are low and disease infrequent, has long held a special fascination for parasitologists (Chandler, 1926, 1928; Chernin, 1954a,b; Chowdhury *et al.*, 1968a,b). Realizing that this enigmatic prevalence/intensity relationship had persisted for at least 40 years in the absence of treatment and sanitation, Schad *et al.* (1971, 1973, 1975), Kochar *et al.* (1976), and Nawalinski *et al.* (1978a,b) suggested that the parasite populations were being regulated by natural factors and initiated a multidisciplinary investigation to determine the epidemiology and population ecology of hookworm infection in this area. A highly quantitative life table approach was adopted, strongly influenced by the well-known investigations of Hairston (1962); it provided information that can be broadly characterized as follows:

1. Density and structure of adult worm populations
2. Number of hookworm eggs entering the environment
3. Time and place of defecation
4. Ecological descriptions of the defecation grounds
5. Hatching, development, and survival of free-living stages
6. Distribution and abundance of infective larvae
7. Human behavior and exposure to infective larvae
8. The dynamics of infection as reflected in fecal egg count

In this chapter, we will present selected parts of the investigation, particularly those that involve human ecology.

B. Physiographic, Climatic, and Demographic Background

The research was conducted in an old delta region of gangetic Bengal lying about 40 miles northwest of Calcutta (Fig. 1). Like Calcutta, this area has sharply demarcated seasons, with the monsoon rains beginning in mid-June, decreasing through September, and ending in early October; March through May is hot and dry (Table I).

The low-lying deltaic plain has a few sluggish rivers, many irrigation ditches, canals, and innumerable man-made ponds (tanks), mostly associated with habitations (Fig. 1). The general flatness is interrupted by excavations for sand and clay and by the mounds of earth dug from ponds, canals, and ditches. The cropland consists of extensive treeless areas divided into small plots by low earthen ridges (bunds) that also serve as dikes for irrigation and as raised pathways. These plots are planted with rice, jute, and sugar cane. In the dry season, irrigated land is planted with vegetables (potatoes, eggplant, cabbage, and okra); land that cannot be irrigated is left in rice stubble that is often grazed by cattle, sheep, or goats. Villages with bamboo and banana groves, palms, and occasional shade trees contrast sharply with the areas of open cropland (Fig. 1).

Our investigations were based on the earlier work of Chowdhury and Schiller (1968b). They chose Bandipur Anchal because it was one of the few areas in Bengal maintaining adequate demographic records. We also used these data to select sample populations for our investigations.

The study area included 12 villages with a total population of 6268. It was

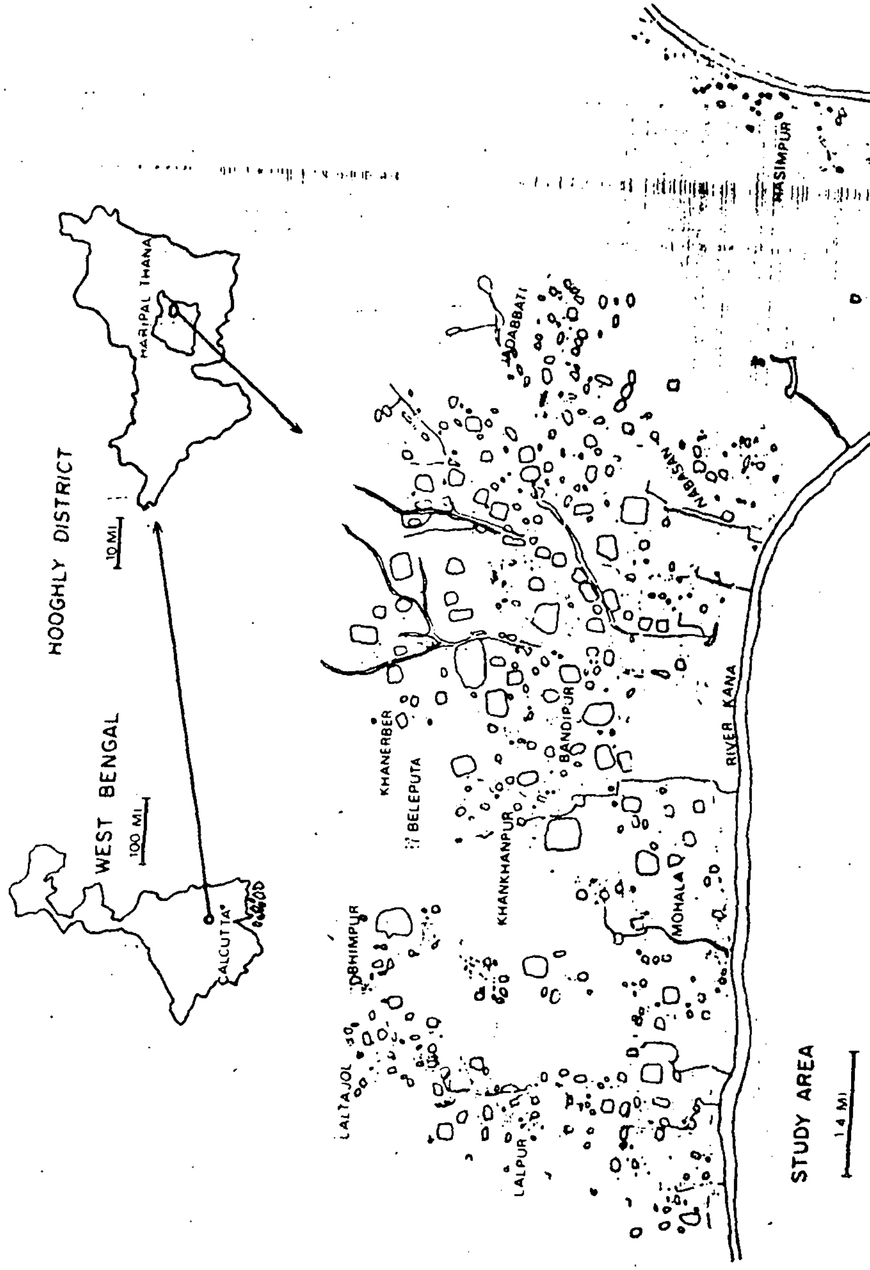

FIG. 1. The study area (88° 8' 27" to 88° 10' 36" East Longitude, 22° 44' 47" to 22° 51' 10" North Latitude) in Bandipur Anchal, Haripal Thana, Hooghly District, West Bengal, India.

TABLE I

Selected Meteorological Data for Calcutta, India, 1881–1940[a]

Month	$\bar{X}$ Daily maximum temperature (°F)	$\bar{X}$ Monthly rainfall (in.)	$\bar{X}$ Days >0.1 (in.)
Jan	80	0.4	0.8
Feb	84	1.2	2
Mar	93	1.4	2
Apr	97	1.7	3
May	96	5.5	7
June	92	11.7	13
July	89	12.8	18
Aug	89	12.9	18
Sept	90	9.9	13
Oct	89	4.5	6
Nov	84	0.8	1
Dec	79	0.2	0.3

[a] From Tables of Temperature, Relative Humidity and Precipitation for the World, Part V. Asia. British Meteorological Office, London, 1966. (Reproduced with the permission of the Controller of Her Britannic Majesty's Stationery Office.)

about ¾ mile in width and extended 3 miles along the north side of the Kana River (Fig. 1). The width of the area was chosen so that we could detect any effect on hookworm transmission caused by distance from the river. This seemed plausible because many of the more distant fields are not irrigated in the dry season, remaining in rice stubble. The study area was selected from the larger areas studied by Chowdhury and Schiller (1968b) so that our field station in Bandipur Village would be centrally situated and so that all villages were generally accessible by jeep or bicycle even during the monsoon season. Of the population about 89% were Hindu and 11% Muslim. A detailed survey of our entire sample population indicated that 22% belonged to households classified as nonagricultural; 35%, owner-agricultural; 19%, part-time agricultural; and 25%, nonowner, full-time agricultural labor.

C. Samples and Methods: Parasitological

Two parallel longitudinal investigations of the prevalence and intensity of hookworm infection were conducted. The first involved persons of all ages and was designed to provide seasonal and group-specific information on parasite burdens and on the number of hookworm eggs entering the environment daily.

Our basic random sample of 750 people in 100 households was weighted to assure adequate representation from each village. This sample, which was thought sufficient to provide 600 regular participants during successive, approximately bimonthly rounds of fecal examination, represented about $\frac{1}{10}$ of the population. It was also used for the anthropological phase described in Section II,D.

During the first round of fecal examinations, treatment was offered to about 16% of those who cooperated; assuming some refusals, about 10% of the sample would be cleared of their infection thus becoming available for longitudinal observation in parallel with those left untreated. The extra work involving the treated group (i.e., extra pretreatment and posttreatment egg counts; treatment per se, and posttreatment worm recovery) extended the first round of fecal examinations through 5 months. As each of the other rounds was completed in about 2 months, the entire sample was examined four times in 1969 and five times in the first 10 months of 1970.

A second independent sample of children through 10 years of age was selected to study the dynamics of hookworm parasitism in a group consisting substantially of uninfected or lightly infected individuals. When 90% of a population is parasitized, most of those who have never been infected will be children; among them, rates of acquisition of worms may be studied without considering acquired immunity. Furthermore, both acquisition and loss are most readily apparent in the uninfected or lightly infected segments of the population. The results of this investigation and details of sample selection have been reported by Nawalinski *et al.* (1978a,b).

In the first year of study, 560 children were examined bimonthly; 320 children were added in the second year. An average of 320 (302–383) were cooperative per round in the first year, and 417 (395–445) in the second, with an average overlap of 63%.

All feces were examined by a quantitative modification of the Kato technique using a 50-mg sample of well-mixed feces (Martin and Beaver, 1968).

D. Sample and Methods: Anthropological

A subsample consisting of half the main sample of 100 households was drawn randomly for detailed anthropological investigations; 49 households with 352 persons actually participated. The anthropological investigations may be categorized as follows.

1. Census: all 100 sample households were covered initially to obtain basic demographic data for both the parasitological and the anthropological investigations.

2. Monthly survey of defecation habits: the time and location of every stool passed by all members of the subsample households during the 24 hr preceding the Interview were recorded monthly. The location of each of 4395 stools from 352 subjects was verified and recorded on enlarged land use maps.

3. Monthly survey of defecation grounds: each month, one person from each subsample household was requested to physically identify his or her stool. Observations of 448 stools included the degree of fecal pollution around the identified stool, its distance from the nearest stool, the average density of pollution within the defecation ground, and a time–motion simulation of the distances covered from house to trail to pond, etc.

4. Direct observation of defecation behavior: from a discreet distance of at least 150 yards, 200 unidentified subjects were observed at 19 sites over a total of 42 hr to document the sequence of activities and movement to and from the defecation grounds. Accurate time records were also obtained from reliable subjects who were taught the use of a stopwatch.

5. Land use and stool distribution studies: enlarged village maps were used for marking the location of all observable human stools during two different seasons in representative villages.

E. Prevalence and Intensity of Hookworm Infection in Rural Gangetic West Bengal

1. PARASITOLOGICAL OBSERVATIONS

Figure 2 (Nawalinski *et al.*, 1978a) shows that the prevalence of infection in rural Bengali children increases rapidly with age so that more than half of all 5-year-old children were infected; by the eleventh year, prevalence reached 90% with a mean fecal egg count of about 3000 EPG among those infected. Both prevalence and intensity of infection were greater in boys than in girls ($p < .025$).

Prevalence of hookworm infection increased much more rapidly among Muslim than among Hindu children, exceeding 90% by age 4 and becoming almost 100% among children older than age 7 (Fig. 3). Among Hindus, prevalence did not approach 90% until the children were 9 years old. There was little difference in the overall mean fecal egg count of the two religious groups, but the difference was significantly greater in Muslims than in Hindus in 9 of the 10 age cohorts (sign. test, $p = .11$). It is interesting that we also found significantly higher prevalences of other soil-borne helminths (i.e., *Ascaris lumbricoides* and *Trichuris trichiura*) in Muslims than in Hindus. These observations suggest that human behavioral factors related to culture or socioeconomic status have a

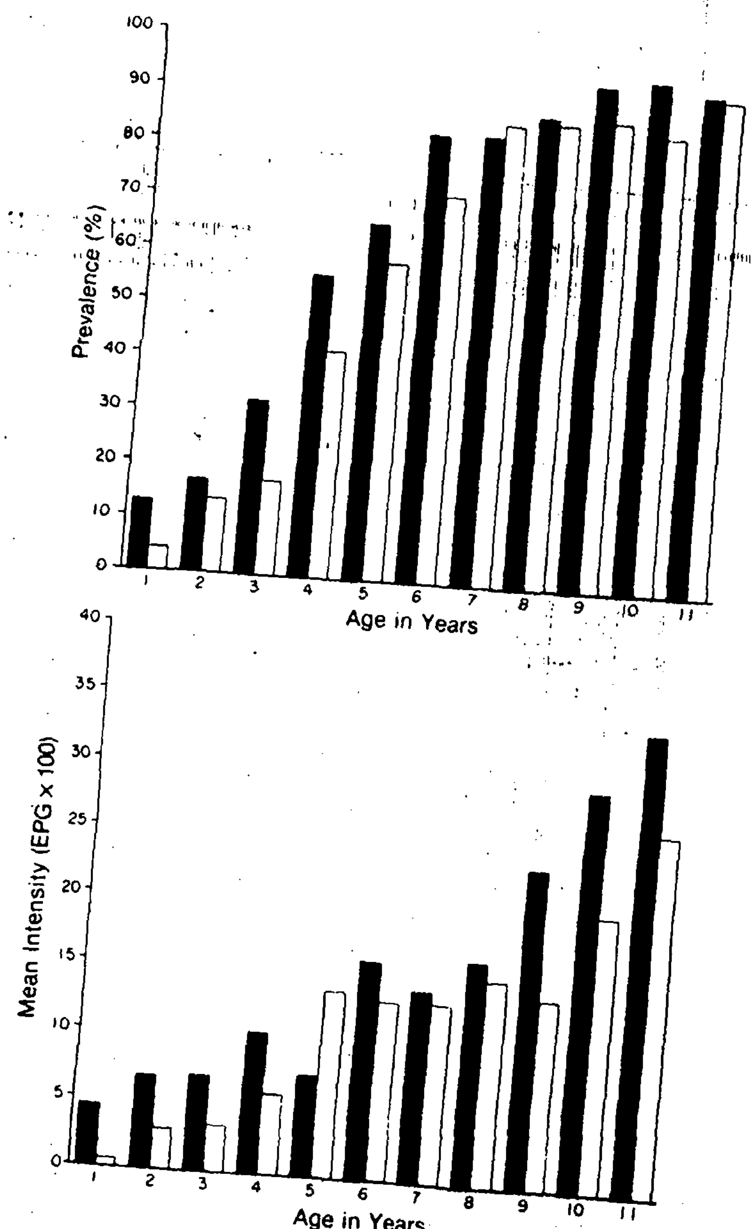

FIG. 2. Prevalence (upper graph) and intensity (lower graph) of hookworm infection among rural Bengali children, by age and sex; mean of 11 bimonthly rounds of stool examination (■ = male, □ female) (from Nawalinski *et al.*, 1978a).

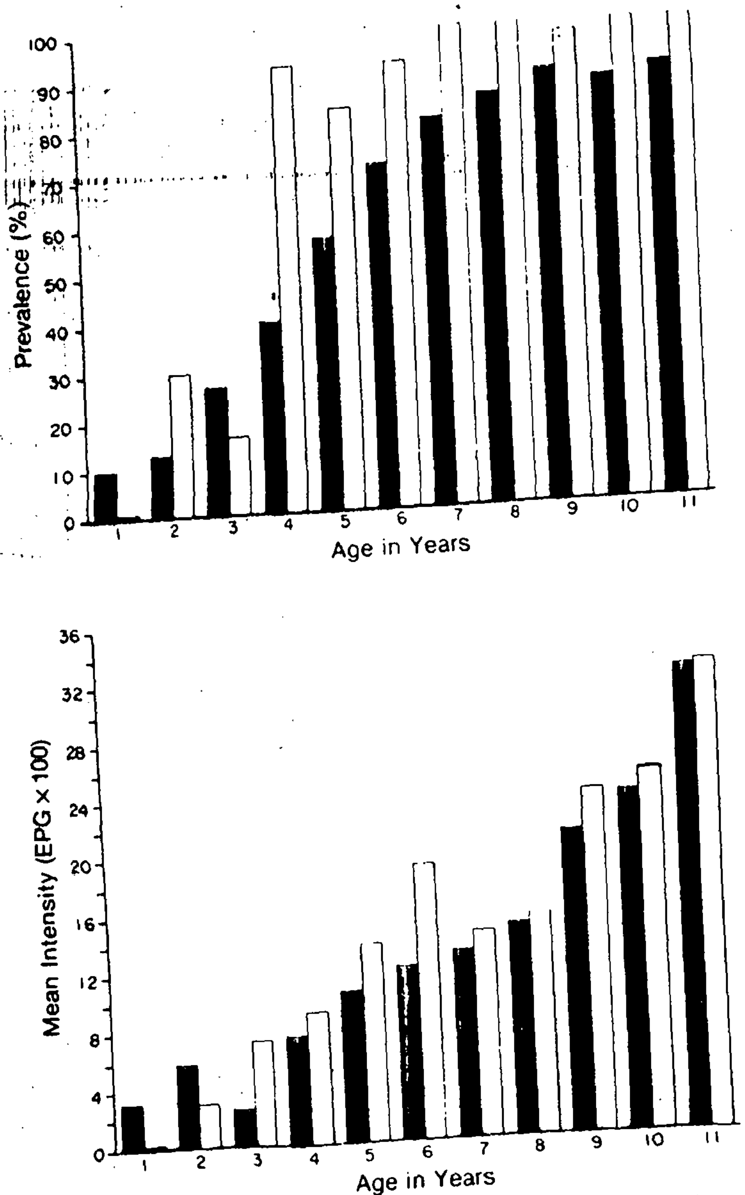

FIG. 3. Prevalence (upper graph) and intensity (lower graph) of hookworm infection among rural Bengali children, by age and religion; mean of 11 bimonthly rounds of stool examination (■ = Hindus, □ = Muslims) (from Nawalinski *et al.*, 1978a).

marked effect on the rate of acquisition of hookworms and other soil-borne helminths.

Data from our basic sample showed that prevalence increased rapidly with age and reached 90–100% among adults (Fig. 4). The rapid rate of worm gain observed in the study of children was not maintained through adulthood. In fact, in men the intensity of infection remained relatively constant from young adulthood through middle age. A similar pattern was seen in women, who may have had a slight net loss of worms. In the oldest age group (over 54) the intensity of infection increased again. Kochar (1975, 1979a) used these same data in evaluating the effect of various human factors on the intensity of infection.

2. ANTHROPOLOGICAL OBSERVATIONS

> It is evident, if the defecation areas are usually the only important sources of infestation, and exposure during the act of defecation the most important time of infestation, that the details of the defecation habits are of very great importance.*

a. Defecation Grounds

About 9% of the sample households had latrines but few people use them; only 0.8% of all stools were passed in latrines. In rural Bengal, certain plots of land are recognized socially as defecation grounds. Households situated in wooded areas often have an adjacent bamboo grove which is used as a site for defecation. Nearly 15% of our subjects had a bamboo grove beside the house; another 10% had another nearby *shaded habitat* (banana, brush, etc.) used for defecation. Of 195 defecation grounds surveyed, 73% were in bamboo and other shaded habitats and 23% were fields. Unlike permanent defecation grounds in shade, those in fields are temporary and transitory. Fallow as well as planted lands are included in the designation "fields," but land planted with a food crop is not considered pollutable and only rarely is a stool deposited in such a site. During the dry season, a special class of defecation ground (*hegomath*) forms in fallow fields. These *hegomaths* are characterized by a very dense concentration of stools.

b. Defecation Behavior

As mentioned earlier, contact with feces or a defecation ground defiles a Hindu. However, when a villager enters a defecation ground for some other purpose, he will not be unduly concerned about feces around him and a purification ritual rarely follows. Regular, early morning defecation is considered desir-

*From Asa Chandler, "Hookworm Disease," p. 195. Macmillan and Co. Ltd., London, 1929.

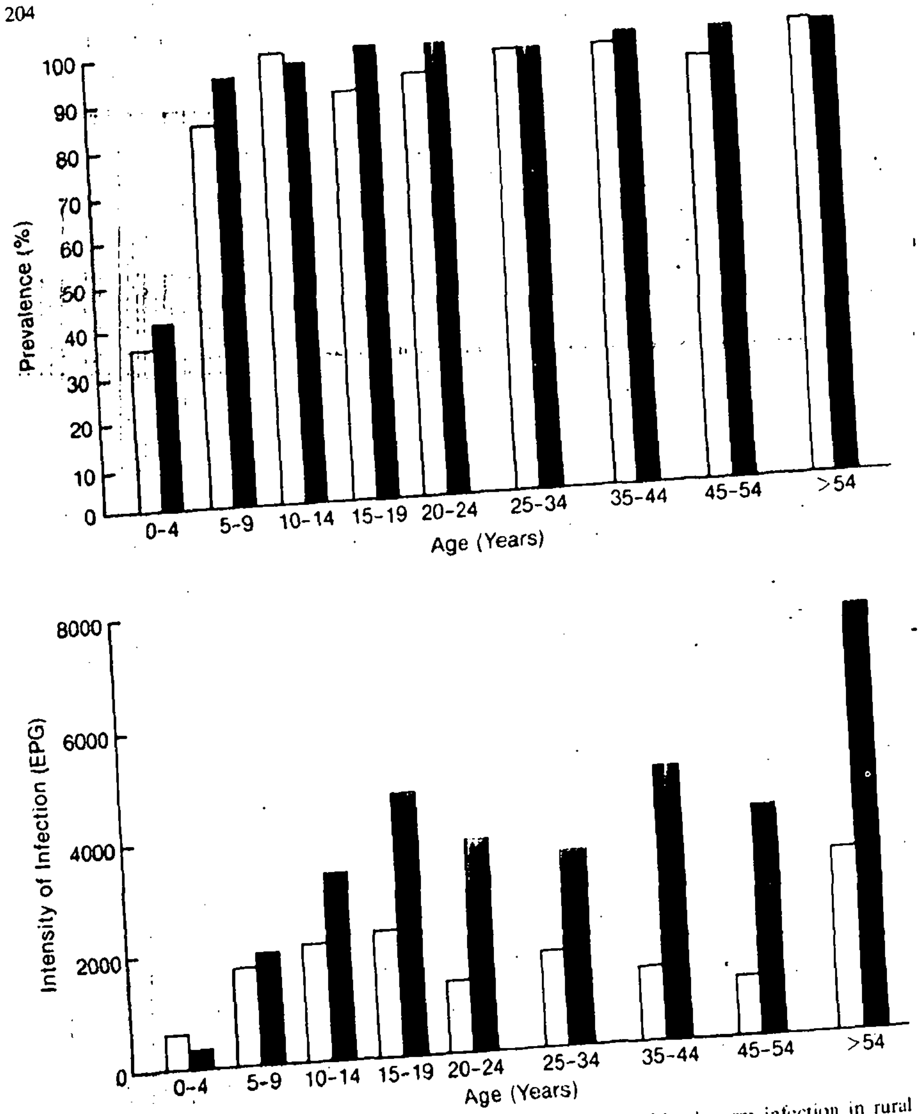

FIG. 4. Prevalence (upper graph) and intensity (lower graph) of hookworm infection in rural Bengali villagers by age and sex; mean of 9 rounds of stool examination (■ = male, □ = female) (from Schad *et al.*, 1975).

able, but this habit is more common among persons of high caste (67%) than among low castes (38%), and more common among Hindus (40%) than among Muslims (24%). In general, 25–30% defecate before 6 AM and 50% before 9 AM.

Fields were used regularly by 80% of agricultural families and 45% of non-agricultural families. Interrogations over 1 year revealed that 43% of all stools are passed in fields, 22% in bamboo, and 39% in all other fully or partly shaded habitats.

On the basis of the time and motion simulation, about 95% of our subjects walked 3 min or less to a defecation ground; 82% walked less than 2 min within the defecation ground; 96% walked less than 4 min (average 1.4 min) in selecting a site, which took about 6 sec to reach from the track; 17% of the subjects took less than 1 min and 72% less than 4 min (average 3 min) to defecate. Ablution is performed immediately after defecation: 41% took less than 1 min and 83% less than 4 min (average 2.5 min) to enter the water. In this part of India with its ubiquitous tanks, canals, and ponds, ablution occurs while standing in water.

c. *Avoidance Behavior*

Table II shows that avoidance of other stools by villagers while defecating was increasingly equivocal as feces became incorporated with the soil with only evidence of dung beetle activity remaining to mark the location. These "traces," which are least likely to be avoided, constitute the real danger, because fresh and partly turned stools would be too recently passed to yield infective larvae. This equivocation was emphasized by Kochar (1979a).

However, the interaction between man and hookworms when examined on the most relevant scale for the interaction of humans and hookworm larvae (i.e., the length of a human foot) shows that human behavior is protective. As seen in Table III, irrespective of age or sex only 2% of stools were deposited within 6 in. of a trace of feces and only 12% within 12 in. Most stools (67%) were deposited 16 in. or more from a fecal trace, indicating that even those loci on which stools per se were no longer visible were repellent. This is consistent with our recoveries of hookworm larvae in which few clusters of larvae were found within an annulus around a fresh stool equivalent to a human foot in width (Table IV).

Furthermore, because it is not precisely known where the feet of the subject were placed during defecation, even traces within 12 in. do not necessarily imply an infective contact; Although Kochar (1975, 1979a) has interpreted these data otherwise, they are consistent with the relatively strict fecal avoidance so thoroughly stressed in Hindu culture.

d. *Use of Defecation Grounds; Hookworm Habitat and Transmission*

Of the stools identified during monthly interviews of persons included in our anthropological subsample, about 75% were deposited in defecation grounds. Of these deposits, 72% were in shaded habitats where transmission most often occurs during activities associated with defecation. Of the remaining 28% identi-

TABLE II

Distance to the Nearest Partly Turned, Fully Turned, and Trace Fecal Deposits from Each of 380 Subject-Identified Stools

	Partly turned		Fully turned		Trace	
Distance	Number	%	Number	%	Number	%
<3 ft	112	30	162	43	225	59
3–6 ft	58	15	80	21	84	22
>6 ft	210	55	138	36	71	19
Total	380	100	380	100	380	100

fied in various nonshaded areas, 80% were in fields where transmission would not necessarily be limited to times of defecation (Kochar, 1975).

Based on this information and on the amount of time villagers spend at various tasks that might expose them to infection, it can be calculated that for persons who plow fields or harvest jute the activity-specific period at risk is about 3 hr per transmission season, or about 45 min per month (June 15–October 15). For persons who cut bamboo or collect fuel (the latter often are the aged), the respective figures are 41 min and 54 min per month. For these occupations, Kochar (1975, 1979a) reasoned that the increased exposure should be reflected in increased worm burdens, and expected this to be reflected in increased fecal egg counts among agriculturalists, particularly the nonowner agriculturalists (i.e., parttime and fulltime agricultural workers) doing the most menial tasks.

Thirty percent of all feces are deposited in shaded sites that provide a more favorable habitat for hookworm transmission than their unshaded counterparts; direct sunlight is ovicidal and larvicidal, and stools are more aggregated in the shaded sites. Only 23% of persons defecating in bamboo encountered low densities of fecal pollution (<5 stools/100 ft²). Open habitats contain 43% of all feces; except during part of July and August, they provide an unfavorable hab-

TABLE III

Percentage of Stools Deposited by Males and Females at Various Distances from Nearest Fecal Trace

Distance (in.)	Males (n = 184)				Females (n = 117)				
	11–19	20–44	≥45	All ages	11–19	20–44	≥45	All ages	Both sexes
<6	2	3	0	2	0	3	4	3	2
6–11	12	10	20	14	6	23	5	10	12
12–15	18	10	24	18	23	10	22	19	19
>16	68	77	56	66	71	64	69	68	67

TABLE IV

Number of Gauze Pads Examined for Hookworm Larvae and Frequency Distribution of Larvae Recovered per Pad[a,b]

Year	Number of gauze pads			Number of infective larvae per sampling pad							
	Total	Negative	Positive	1–2	3–4	5–6	<10	<20	<50	<100	>100
1969	1224	1150	74	37	14	10	1	4	4	3	1
1970	1704	1595	109	75	10	6	5	4	6	1	2
Both years	2928	2745	183	112	24	16	6	8	10	4	3

[a] The soil surface in an annulus 30.54 cm wide was examined for infective larvae. The width was based on the length of the average adult foot. Within each sampling annulus, 10.6% of the surface area (i.e., 516 cm²) was sampled by the damp gauze pad technique developed by Beaver (1953. *Am. J. Trop. Med. Hyg.*, **2**, 102).

[b] From Schad *et al.* (1975).

itat. Additionally, feces are generally less aggregated; 51% of people defecating in fields encountered <5 stools/100 ft².

During the transmission season, 62% of all feces are deposited in fields; about 70% of these stools are passed in jute fields. This increases the risk of infection both for the person defecating and for the laborers who harvest jute. Polluting fields planted with nonfood crops (jute) negates some of the advantage of defecating in the fields. If people changed their defecation habitat from bamboo to open sites just before the transmission season (June–October) as 30–40% do, this would further restrict the abundance of hookworm populations. Most of the hookworm eggs in feces passed in fields before 10 AM (i.e., 56% of feces passed in fields or 24% of all feces) are *not* likely to survive. In fact, the average level of infection in a village (with two exceptions, Bandipur and Beleputa) is inversely correlated with the percentage of feces passed in fields (Fig. 5). Interestingly, these two villages represent polar contrasts with respect to a variety of other factors likely to influence hookworm transmission and resistance to infection (see next section).

C. *Occupation and Intensity of Infection*

Figures 6 and 7 show the relationship between occupation and hookworm infection. It is noteworthy (Fig. 7) that only 113 of 704 subjects in our entire sample population belonged to occupational subclasses that would experience maximal exposure to infection including that due to agricultural work. The occupations having the greatest involvement with the soil had the heaviest infections. This is a normal expectation, and Kochar (1975, 1979a) has interpreted these findings as indicating that epidemiologically important amounts of infection are acquired during agricultural pursuits, thus refuting Chandler's conclu-

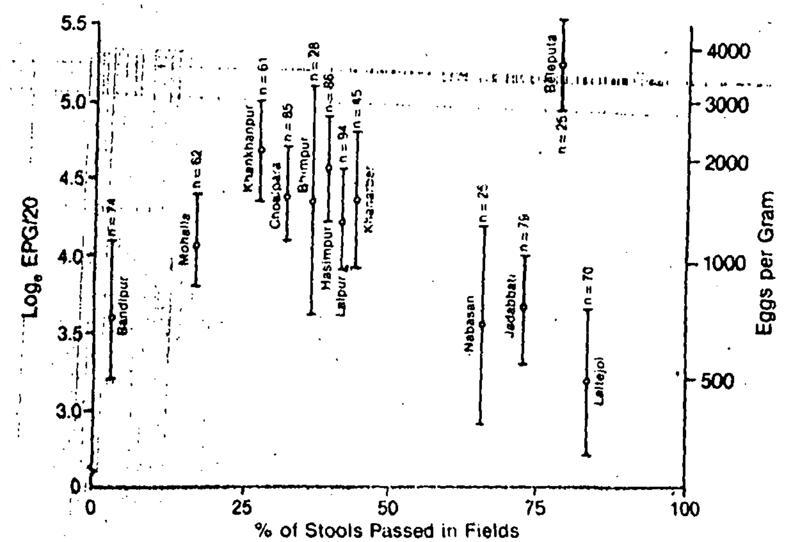

FIG. 5. The intensity of hookworm infection in rural Bengali villagers by village and degree of concentration of stools in fields (from Kochar, 1975).

sion that work in the fields far from the dense fecal pollution around settled areas was, in fact, protective (Chandler, 1929).

Closer examination of the data suggests that a more subtle explanation of the observed differences is required. If exposure to infection in the fields during agricultural activities was largely responsible for the differences between occupational groups, this difference should occur only in groups of working age. Figure 6 shows that the difference is apparent even in young children who are not involved in agricultural work, which suggests that work-related differences in exposure are not the crucial factors determining the between-group differences. If agricultural involvement per se does not provide an explanation, What does? We suggest that a combination of much more subtle factors associated with the overall life style of these groups controls the additional amount of infection observed in the various classes of agriculturalists.

Additional evidence for this interpretation of the data has already been presented: we indicated earlier that two villages did not fit the overall trend showing a decrease in intensity of infection associated with the increasing use of fields for defecation (Fig. 5). Bandipur showed the lower mean level of infection, although a large proportion of the stools was deposited in shaded sites favoring hookworm transmission, whereas Beleputa had the higher mean level of infection although more than 75% of the residents' stools were passed in fields. Of particular relevance to the argument presented is the fact that those villages represent extreme contrasts in education, caste, socioeconomic status, and local ecology as well as in work-related involvement with the soil. Indeed, this unorthodox interpretation of our observations is also suggested by the data for females shown in Fig. 6 (upper graph). Although few females participate in agricultural labor, their mean levels of infection also varied with "family occupation," suggesting that involvement with soil per se does not determine the level of infection.

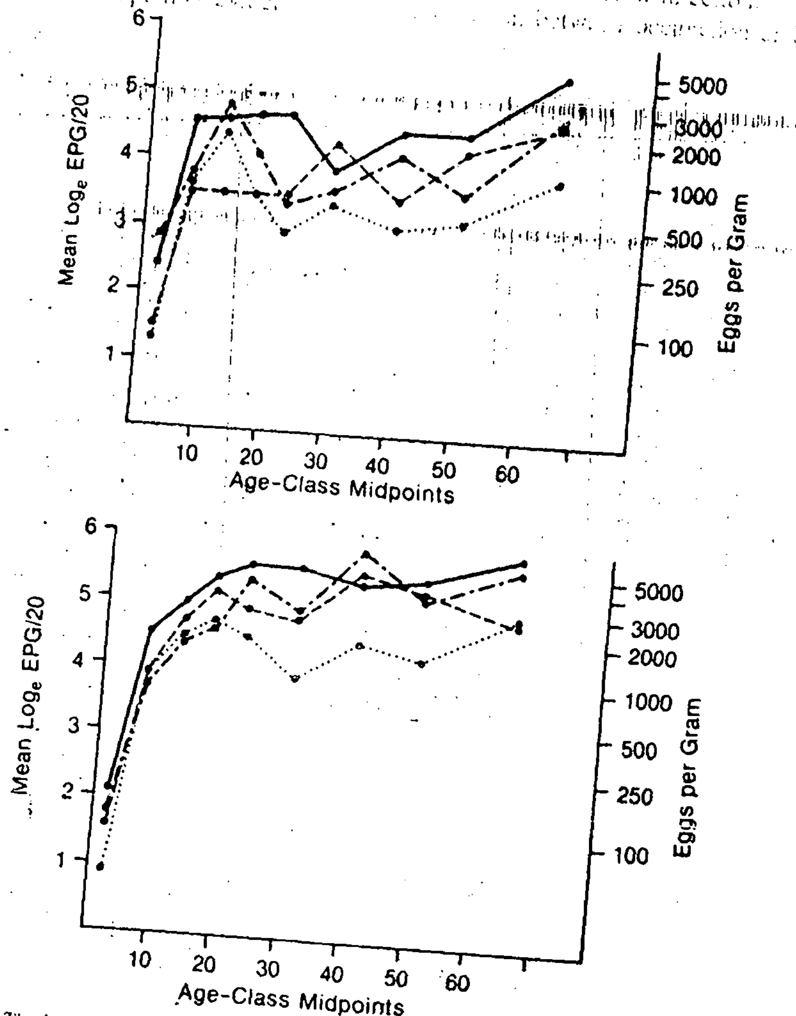

FIG. 6. The intensity of hookworm infection in rural Bengali villagers by sex and occupation of the family head. Upper graph presents data for females, lower graph for males. Family occupation: — = agri-labor; —·—· = part-agri; - - - - = owner-agri; .... = non-agri (from Kochar, 1975).

The most compelling evidence for the association between occupation and

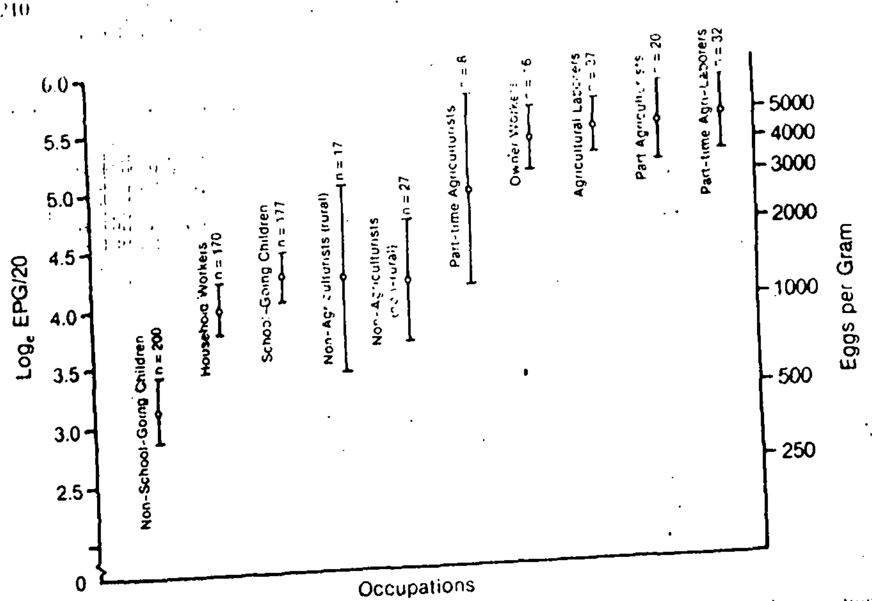

FIG. 7. The intensity of hookworm infection in rural Bengali villagers by individual occupation (from Kochar, 1975).

intensity of infection is presented in Fig. 7, but here too occupation is confounded with other factors. For example, nonschool children have the lowest fecal egg counts, but this category includes many young preschoolchildren whose low egg counts partly reflect insufficient time to have accumulated large numbers of worms. The remaining occupational categories can be combined into two groups, nonagricultural and agricultural workers. Although the former have lower mean egg counts than do the latter, it is also true that the former are largely constituted of children and women, who may well harbor fewer adult worms than do men although exposed to similar levels of transmission. In this connection, the data presented earlier are particularly relevant. As shown in Fig. 2, throughout childhood girls have lower mean egg counts than do boys although it is doubtful that the sexes are differentially exposed to infection as children.

F. Explanations of the Observed Prevalence/Intensity Relationships

It has been suggested that the high prevalence of light infections, so characteristic of much of rural Bengal (Chandler, 1928; Chernin, 1954a,b; Chowdhury

and Schiller, 1968b), might be determined largely by transmission and be explicable in ecological terms.

1. ECOLOGICAL EXPLANATION (SCHAD, 1966)

The abundance of available, infective larvae approaches zero for most of the year. During the long dry period (October to mid-June), the few larvae which develop after an occasional rain are aggregated, but are rarely on the surface where contact with man is probable. During the monsoon, conditions for larval development and survival are somewhat better, but the soil becomes and remains waterlogged. This water-logging, however, permits formation of sheets of surface water in which larvae, eggs, or both can be carried passively or move actively, to be redeposited when the surface water drains. Redeposition yields a non-aggregated pattern of distribution. Thus, human contact with a few larvae becomes highly probable, but contact with many larvae remains very improbable.

In the brief moist period after the monsoon when soil moisture conditions may be ideal, it is probable that aggregated larval populations form within the immediate area adjoining fecal deposits. If larval dispersal on the surface of the soil cannot take place, it is possible that man escapes infective contact because he deliberately avoids visible (evidence of) pollution.

Subsequent efforts to explain the enigmatic prevalence/intensity relationship by Schad *et al.* (1975) and by Kochar (1975, 1979a) are firmly rooted in this original purely ecological hypothesis.

2. THE ECOLOGICAL–SOCIOCULTURAL–IMMUNOLOGIC SYNTHESIS (SCHAD *ET AL.*, 1975)

This synthesis is based on our multidisciplinary investigations in India, some of which have been reported previously in greater detail (Schad *et al.*, 1973, 1975; Kochar, 1975, 1977a,b, 1979a,b; Kochar *et al.*, 1976; Nawalinski *et al.*, 1978a,b).

a. The Distribution and Abundance of Infective Larvae

Infective larvae were consistently recovered from the soil surface during the monsoon period, June to October, but not after the soil became dry in November or December (Schad *et al.*, 1973). Experimentally seeded plots also failed to yield infective larvae during the dry intermonsoon period (Schad, 1965, 1966). These observations indicate that for 6–7 months annually larvae rarely, if ever, survive on the soil surface where they would be in a position to infect man.

Because our monthly soil surface samples were taken within an annulus around a freshly passed stool used as a reference point, they indicate actual larval contact with the feet while our subjects defecated. A frequency distribution of the

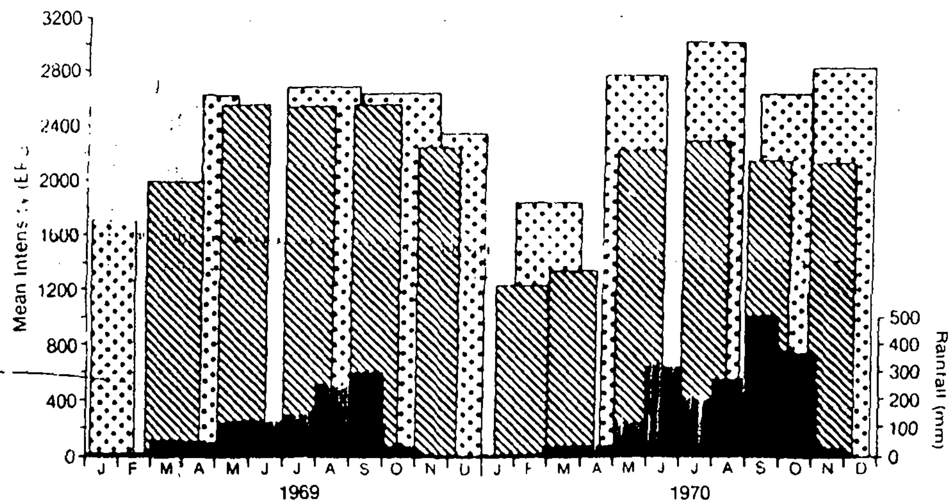

FIG. 8. Seasonal variation in the intensity of hookworm infection in two sample populations of Bengali villagers. One sample was constituted of children only whereas the other was constituted of persons of all ages. The figure also shows the seasonal distribution of rainfall (⊡ = EPG, all ages (n = 734); ▨ = EPG, children (n = 560, 1969; 880, 1970); ■ = rain fall) (from Schad *et al.*, 1975).

recoveries of infective larvae based on this focal method of sampling (Table IV) shows that 86% of the positive samples contained 10 or fewer larvae, and only very rarely were dense populations (>100 larvae) found.

From these sets of data, we deduce that (1) the villagers rarely, if ever, encounter hookworm larvae during the dry season; (2) they encounter them frequently during the monsoon; and (3) at any single encounter, the average person will contact only a few infective larvae.

b. The Dynamics of Infection as Reflected in Fecal Egg Counts

A marked seasonal variation in worm burden as judged by fecal egg counts was observed (Fig. 8). The mean egg count varied significantly ($p < .005$) from a midmonsoon peak (2700 epg) to an intermonsoon nadir (1850 epg), then to a second peak (3050 epg) during the following monsoon season. The concurrent investigation of children showed a similar seasonal pattern, with some age-cohorts being net losers of worms year to year (Fig. 9). This annual loss of adult worms must act as a major regulatory mechanism of the hookworm population.

Data from the investigation involving villagers of all ages also showed that the intensity of infection did not increase with age from 15–19 through 45–54 years and, in fact, it may have declined slightly among females (Fig. 4); it increased again in the aged.

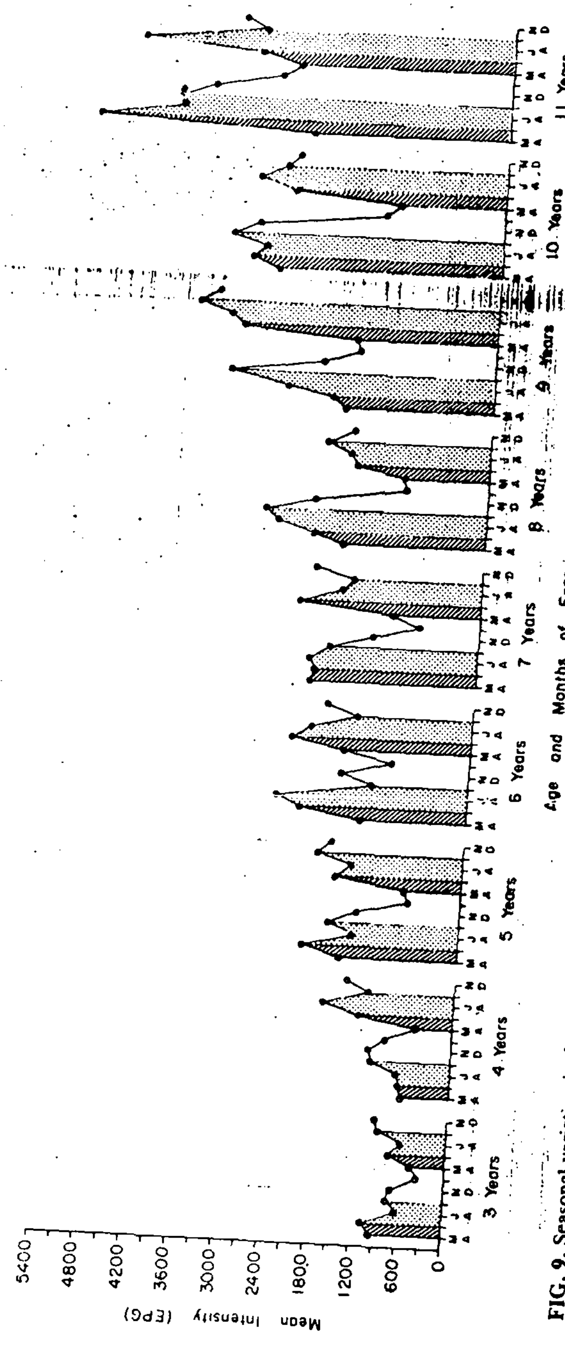

FIG. 9. Seasonal variation in the intensity of hookworm infection among age cohorts of rural Bengali children. Each curve shows the mean fecal egg count by 11 bimonthly rounds of stool examination, beginning in March/April, 1969 and ending November/December, 1970 (▨ = hot dry season; ⊡ = rainy season) (from Nawalinski *et al.*, 1978b).

Anthropological investigations of the time and place of defecation and of human behavior in fecally polluted habitats indicated that there was no increase in the use of footwear or decrease in contact with fecally polluted soil that could account for this decrease in worm gain, nor was there a decrease in the frequency of bowel movements that might reduce the number of infective contacts. A study of the distribution of human feces showed that fecal pollution is restricted largely to areas recognized as defecation grounds and that most of the population has little contact with these areas except during activities related to defecation. Therefore, we cannot account for the failure of worm burdens to increase after young adulthood by a change in the rate of exposure, although the increase in the aged may be explained in these ways: they are traditionally given tasks that could bring them into more frequent contact with fecally polluted soils, or there may be a decreased ability or desire among the aged to avoid fecally polluted soils.

c. *Proposed Explanation of the High Prevalence of Light Infections*

Our data suggest that the hookworm populations of man in West Bengal are regulated by a seasonal loss of worms in all age groups and by a failure to gain worms from one year to the next during adulthood. A constellation of ecological and human behavioral factors interacts so that man is exposed frequently to low-grade invasions. This rate of infection, known as "trickle infection," probably provokes an effective host resistance so that the average villager sustains a low worm burden. In laboratory investigations of the related hookworm *Ancylostoma caninum*, frequent exposure to small doses of hookworm larvae was very effective in protecting dogs against a heavy challenge infection (Miller, 1965).

The concentration of feces in recognized defecation grounds and the culturally-based avoidance of these areas limits frequent, casual contact with larvae; consequently, most exposure to infection occurs at the time and place of defecation. Even then, there is little or no risk for 6–7 months during the dry part of the year. After the onset of the monsoon, contact with larvae is frequent, but, as we showed, larvae will usually be encountered as individuals or in small aggregates (Table IV). Dense populations of infective larvae must occur directly on the sites of old stools, and unpublished data (Schad, 1965, 1966) indicate that they do; however, human behavior is again protective as such sites are recognized as fecally polluted even after the stools per se have disappeared. This presumably explains why our samples only rarely contained large numbers of larvae. Furthermore, should they contact such a site after repeated low-grade exposures, most individuals may be resistant.

We suggest that the postmonsoon loss of worms is caused by increased host resistance following several low-grade invasions during the monsoon season, and the failure to gain worms during most of adult life may be attributable to

increased resistance following repeated infections during childhood and adolescence.

3. THE SOCIOCULTURAL MODEL (KOCHAR 1975, 1979A)

In his most recent statement concerning the regulation of hookworm populations in Bengal, Kochar (1979a) states that

The existing epidemiological pattern of high prevalence and low intensity can be partly explained by the following concurrent factors:

1. A uniformly high probability of contacting some hookworm larvae because of localized soil infestation, absence of latrines, nonuse of shoes at the time of defecation, and equivocal avoidance of stools.
2. A uniformly low probability of contact with larvae through nonlocalized infestation and dispersion of stools in clusters of low to moderate densities, and restricted activities in defecation grounds.
3. A uniformly low probability of larval development and penetration success due to climatic conditions limiting the development of hookworm eggs and larvae (in open fields particularly), squatting time, and short duration between defecation and ablution in water bodies.
4. Other common factors enhancing the probability of hookworm success by small degrees, such as adverse foot conditions during wet season, use of shaded habitats for defecation, and agricultural activities in polluted fields.
5. A relatively high risk among agricultural laborers and their families due to a combination of social and ecological conditions under which they live and work.
6. Relative prevalence (sic) of a variety of "protective factors" vis-a-vis hookworm infection (Table V).
7. A demographic preponderance of low risk population (children and non-working females).
8. A high awareness of, and anxiety about, subclinical ailments leading to early positive health action within the folk culture context (including popular anthelmintics of unknown efficacy).

Kochar reasons that if sociocultural factors (Table V) are important in regulating hookworm populations, much of the variation in the intensity of hookworm infection should be accounted for by the proper model. In his general socioepidemiological model (Fig. 10), 18 variables included in a binary multiple regression analysis were found to account for 62.7% of the variance in the intensity of hookworm infection among our villagers (Table VI). Because a large fraction of the variance had been accounted for, he concluded that sociobehavioral factors are important in regulating hookworm infection. Kochar also concluded that transmission in defecation areas is not as important as others had suggested (Chandler, 1929; Cort, 1941; Beaver, 1961; Schad *et al.*, 1975) because the parameters defined as "defecation factors" accounted for only 18% of the variance. Although he agrees with the authors cited that focal transmission in defecation grounds is the most important single mode of infection, as already

TABLE V

Sociocultural Factors Predisposing Bengali Villagers toward, and Protecting Them from, the Risk of Hookworm Infection[a]

Risk factors	Protective factors
Universal practice of soil pollution	Latrines and "simple latrines"
Universal equivocal avoidance of stools in selecting a squatting place	Strict avoidance of stools in selecting a squatting place
Universal practice of going barefoot	Use of footwear during activity in infested areas
Prolonged or frequent activities in defecation areas	Restricted frequency or duration of activities in defecation areas
Soil pollution restricted to localized defecation areas increasing the larval populations per unit area	Diffused soil pollution decreasing the larval populations per unit area
Defecation in shaded habitats increasing the chances of survival of larval populations	Defecation in open habitats decreasing the chances of survival of larval population
Pollution of fields under jute crop	Universal avoidance of pollution of fields under crops
Fewer defecation grounds (small area per person)	Many defecation grounds (large area per person)
Absence of trails or pollution on trails	Presence of trails and avoidance of pollution on trails
Poor socialization of defecation habits	Strict socialization of defecation habits
Irregular ablution or delayed ablution	Universal practice of ablution soon after defecation
Nonrecognition of risks; nonrecognition of early symptoms of high infection	Recognition of risks of infection and recognition of early symptoms of high infection

[a]From Kochar (1979a).

noted he sees the observed correlation as a matter of increasing mobility and interaction with fields with a substantial amount of transmission attributable to diffuse soil infestation in the fields.

4. COMPARISONS WITH OTHER AREAS

The literature suggests that in many areas where there are, or were, high prevalences of heavy infection, ecological and behavioral factors interact so that many infective larvae are contacted at individual exposures. It is noteworthy that heavy infections have often been associated with particular kinds of agriculture that favor abnormally high numbers of larvae, and with human behavior that increases the risk of massive exposure (Cort, 1942). The exchange of worms between indigenous and nonindigenous peoples in some areas of the world where heavy infections have been prevalent also merits consideration. In the southern

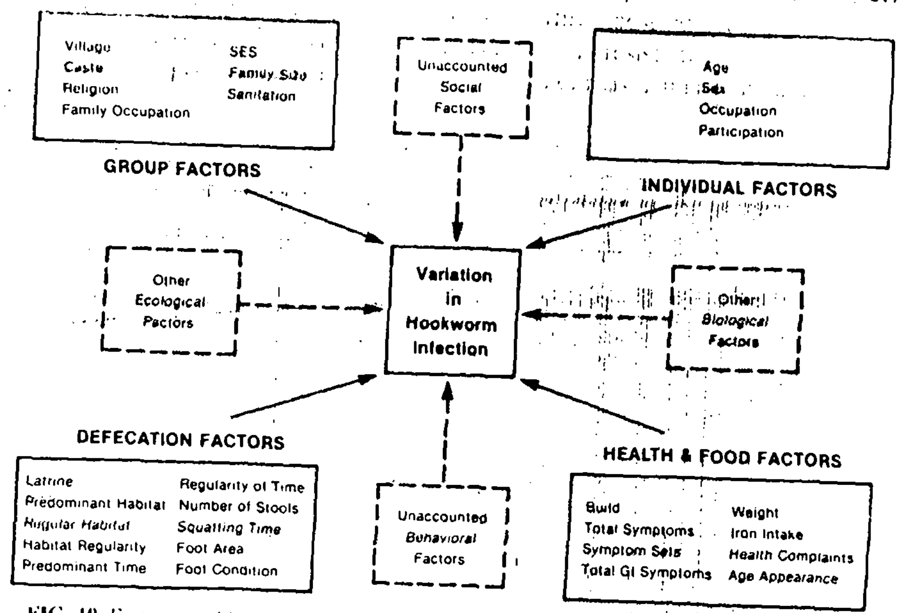

FIG. 10. Factors considered in a socioepidemiological model proposed to account for the variation in the intensity of hookworm infection in a population of rural Bengali villagers (SES = socioeconomic status; ■→ = factors examined in the present analysis; [ ]→ = factors not examined in the present analysis) (Kochar, 1975).

United States, the European immigrant controlled hookworm infection less effectively than did the African (Henderson, 1957; Andrews, 1942a,b). It is less clear whether a cross-susceptibility to infection occurs when two human populations, both presumably originally harboring their own strains of hookworm, come to reside in areas favorable for the propagation of larvae; in the Caribbean both Asians and Africans introduced regional strains of hookworms and both failed to muster adequate host resistance.

III. Implications for Control

It is probable that in the coevolution of host–parasite relationships, a parasite's life history parameters and pathogenic characteristics evolve so that in particular ecological contexts host populations are only rarely exposed to overwhelming parasitism (Hoagland and Schad, 1978). Meanwhile, host populations will be adapting so as to limit the parasite's abundance and to resist the effects of levels of infection expected under average ecological conditions. Human cultural adap-

TABLE VI

Contribution of 18 Selected Sociobehavioral Factors to the Level of Hookworm Infection Observed in Bengali Villagers, as Determined by a Binary Multiple Regression Analysis

Variables	Reduction in r^2 ($r^2 \times 100$)	Rank
Group factors		
Village	12.7	1
Family occupation	5.9	4
Caste	7.9	2
Religion	3.6	8
Socioeconomic status (SES)	0.5	14
Subtotal	30.6	
Individual factors		
Age	4.5	5
Occupation	1.9	9
Sex	1.2	11
Subtotal	7.6	
Defecation factors		
Squatting time	6.1	3
Stools (number per day)	4.3	6
Foot conditions	4.3	6
Regular habitat	1.8	10
Habitat regularity	1.1	12
Defecation time (time of day)	0.2	16
Other variables	0.3	15
Subtotal	18.1	
Health factors		
Total symptoms	3.9	7
G.I. symptoms	0.7	13
Iron intake	1.8	10
Subtotal	6.4	
Total (all variables)	62.7	

tations will enhance biological mechanisms of resistance, and patterns of behavior perceived as protecting against disease will become part of the cultural heritage passed on to succeeding generations.

In rural Bengali culture we have observed human behavioral characteristics that protect against the acquisition of heavy hookworm infection, and others that increase exposure to infection (Table V) (Kochar, 1975, 1979a).

The established protective characteristics that are already part of Bengali culture should be emphasized, at least initially, in any organized program of health education directed against hookworms. The authors have difficulty reaching a consensus regarding the degree with which Bengalis actually avoid fecal pollution once the stool per se becomes invisible (the soil at the point of pollution

remains infective). However, we do agree that traditional Hindus would desire in principle, if not in practice, to avoid such a "defiled" locus. This, then, provides a point of attack for the health educator; these traditional views can be reinforced by stressing the traditional basis for avoidance of fecal pollution as well as the health benefits.

The dense accumulation of feces in fallow fields during the dry season (forming *hegomaths* or fouled land) is highly desirable for hookworm control, since the temperatures attained within stools exposed to direct sunlight are rapidly lethal to hookworm eggs. In the absence of more sanitary methods for fecal disposal, the use of *hegomaths* should not be discouraged, although to the health administrator with a sophisticated urban orientation this may seem less than satisfactory. In our study area, latrine programs, desirable as they might seem to the outsider, would be of little immediate use. Some households have latrines but people do not use them, and without maintenance they rapidly become repugnant. In Hindu societies the problem of maintenance can be particularly difficult, because such work can only be done by members of certain castes; in our study area, suitable people were already fully occupied in other menial but more acceptable forms of labor and were not available for latrine maintenance. This illustrates the unexpected and sometimes largely incomprehensible difficulties associated with introducing new concepts and technologies in traditional social settings, and supports the suggestion that one should try initially at least to work within those settings and reinforce their positive characteristics.

Schad (1979) has suggested that until widespread eradication of helminths such as hookworms is possible in undeveloped countries, it may be desirable to encourage persistence of low-grade, well-tolerated infections which stimulate acquired resistance to superinfection. If a parasite is reintroduced into an area from which it was eradicated, local populations could be particularly vulnerable to previously nonpathogenic levels of infection. Thus, disease rather than mere infection could occur and an important new focus of clinical parasitism would be established where none existed before.

IV. Relevance for Socioeconomic Development

Hookworm infection is the second most prevalent human helminthiasis. More than 900 million people harbor these worms, which in common with the other geohelminths *Ascaris lumbricoides* and *Trichuris trichiura* are often associated with malnutrition and chronic ill health throughout vast areas of the tropical world. Little precise information exists concerning the socioeconomic costs of gastrointestinal parasitism and malnutrition, but there can be little doubt that such parasitisms represent an important burden for rural tropical and subtropical populations.

We have already indicated that major ecological changes such as widespread irrigation of arid lands, or extensive changes in vegetative cover such as in plantation agriculture, can greatly increase the prevalence of hookworm infection. Thus, although malaria and schistosomiasis have received virtually all the recent attention, ancylostomiasis has undoubtedly increased and will continue to increase as more land is brought under irrigation and cultivation in undeveloped countries lacking sanitary facilities.

Rural crowding in the absence of needed changes will also increase the prevalence of hookworm disease through both an increase in the density of fecal pollution and a probable decrease of iron intake, so that light or moderate infections presently well tolerated will be sufficient to produce hookworm anemia (Ball, 1966). Crowding and rural development without health education could exacerbate any tolerable hookworm problem by fostering social changes which tend either to minimize the effects of indigenous protective factors or to maximize the effects of indigenous risk factors. With little understanding of hookworms and the factors favoring their transmission, poorly educated people could easily abandon taboos which have provided protection against infection, seeing them only as discredited or outmoded customs and beliefs. Indeed, the growing belts of unsanitated squatter habitation surrounding most tropical cities are rife with infection, including hookworm.

The costs of hookworm infection to tropical and subtropical societies, which cannot be stated precisely, urgently need careful investigation. Although good anthelmintics are available and hookworms can be easily controlled, the fact that 900 million people harbor them indicates that we have not controlled them and that new investigations directed to new or improved methods are urgently required. The omission of hookworms from the World Health Organization list of the six most important tropical diseases has severely limited hookworm research. Urgent new work must be done to quantify the burden of ancylostomiasis and then to provide cost–benefit data for the range of strategies already available for controlling hookworms. In traditional societies, health education techniques which use and encourage established protective social practices and customs will prove among the most cost effective.

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