trogen compounds are also generated from the air by nitrogen-fixing bacteria or supplied from manure or rotting vegetable wastes, called humus. The transfer of nutrients from humus and rocks to plants through the action of microorganisms is a slow process. It is most efficient when the soil is porous and well aerated, with a moderate ability to hold moisture. A surprisingly large quantity of soil organisms must be present to maintain a high fertility (see Figure 4-61).

Any process that interferes with soil microorganisms, soil chemistry, or the aeration and water-holding properties of soils is likely to change the soil fertility. There are many such processes, some with a positive influence tending to regenerate soil fertility, and some tending to degrade it. Thus we may think of a continuous competition between the degenerating and regenerating forces, at all times producing some resultant value of the land fertility LFERT:

```
LFERT.K=LFERT.J+(DT)(LFR.JK-LFD.JK)                    121, L
LFERT=LFERTI                                           121.1, N
LFERTI=600                                             121.2, C
   LFERT  - LAND FERTILITY (VEGETABLE-EQUIVALENT
            KILOGRAMS/HECTARE-YEAR)
   DT     - TIME INTERVAL BETWEEN CONSECUTIVE
            CALCULATIONS (YEARS)
   LFR    - LAND FERTILITY REGENERATION (VEGETABLE-
            EQUIVALENT KILOGRAMS/HECTARE-YEAR-YEAR)
   LFD    - LAND FERTILITY DEGRADATION (VEGETABLE-
            EQUIVALENT KILOGRAMS/HECTARE-YEAR-YEAR)
   LFERTI - LAND FERTILITY INITIAL (VEGETABLE-
            EQUIVALENT KILOGRAMS/HECTARE-YEAR)
```

We assumed that the average land fertility LFERT of the arable land AL in 1900 was 600 vegetable-equivalent kilograms per hectare-year, identical to the inherent land fertility ILF of virgin land.

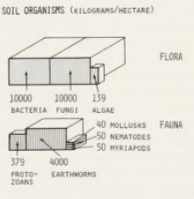

Figure 4-61 Soil organisms in well-cultivated soil

Source: Georg Borgstrom, *Too Many: A Story of Earth's Limitations*, rev. ed. (New York: Macmillan Publishing Co., 1970), p. 94. (Copyright ©1969, 1971 by Georg Borgstrom. Copyright © 1969 by Macmillan Publishing Co., Inc.)

Land Fertility Degradation Rate LFDR The land fertility degradation rate LFDR is the fraction of the current land fertility LFERT that is lost through degradative processes in a year. We made two assumptions about the land fertility degradation rate LFDR: it is increased by the same industrial and agricultural practices that lead to the accumulation of persistent pollution, and its increase appears only after a significant delay.

Chapter 6 contains a definition of persistent pollution and a description of how it is generated in World3. One of the determinants of the persistent pollution generation rate is the total amount of agricultural inputs used each year; another is the total use of nonrenewable resources. Of the many different kinds of persistent pollutants generated by agricultural and industrial activities, we assumed that some feed back to influence human health, and others influence soil fertility. The possible effects of pollutants on soil fertility are many. The soil microorganisms that fix nitrogen and break down humus are sensitive to and sometimes nearly eliminated by a heavy use of nitrogen fertilizers, by pesticides, and by accumulations of heavy metals (lead, mercury) in the soil (see Tyler 1972). The natural mechanisms for pest control by predatory species are almost invariably interrupted by the use of broad-spectrum pesticides. The extensive use of irrigation without proper drainage may eventually cause deposits of salts in the soil at levels that are toxic to plants. In other words, many of the persistent pollutants that are harmful to higher organisms are probably also harmful to the complex system of drainage patterns and to the insects, bacteria, molds, earthworms, and other small but important organisms that create and maintain soil fertility.

We assumed that this interruption of the ecological systems in the soil by pollutants does not create an immediate decrease in soil fertility but instead becomes obvious only after a fairly long delay, as the polluting material works its way through the ecosystem. The delay is contained in the pollution sector of the model, where it is called the persistent pollution transmission delay PPTD and is assigned a value of twenty years.

The assumed relationship between pollution and the land fertility degradation rate LFDR is shown in Figure 4-62. The horizontal axis in this figure shows the persistent pollution index PPOLX, which is equal to the total pollution load of the world's ecosystem at any time, divided by the total load in 1970. This total pollution load is a function of total resource usage and total agricultural inputs, delayed twenty years, as explained in Chapter 6. The graph in Figure 4-62 indicates that with zero pollution we assumed that negligible degradation forces act to reduce the existing land fertility. In other words, the land can be cultivated indefinitely at low intensities because the naturally occurring regeneration forces can keep up with the ongoing degradation—as exemplified by the 2,000-year-long cultivation of England or of the Punjab in India. At any higher intensity, based on the value of modern agricultural inputs per hectare AIPH, the rate of land fertility degradation LFD is higher.

```
LFDR.K=TABHL(LFDRT,PPOLX.K,0,30,10)                    122, A
LFDRT=0/.1/.3/.5                                       122.1, T
   LFDR   - LAND FERTILITY DEGRADATION RATE (1/YEAR)
```