Finally, technological advances in the real world might increase both the amount of potentially arable land and the maximum land yield. It is of course impossible to know what extraordinary technological breakthroughs will occur to increase land area or agricultural yields in the future. One could assume that essentially infinite yields might someday be attainable or at least that yields might regularly increase at a rate faster than the rate of increase of the global demand for food. With no way of assessing the total benefits and costs of future technologies, we preferred to study the implications of known technologies; it seemed more useful to develop long-term plans for the global society that take into account the foreseeable problems rather than to assume that problems will never arise.

4.4 CAUSAL STRUCTURE

The major historical trends in world agriculture can be summarized as overall growth in total and per capita food production and in the use of manufactured inputs such as fertilizers and pesticides. To model this behavior, the following set of assumptions were employed:

1. Food is produced from arable land and agricultural inputs (fertilizer, seed, pesticides).
2. Food output increases when the arable land area, the land fertility, or the amount of agricultural inputs are increased.
3. There are decreasing marginal returns to the use of agricultural inputs.
4. The amount of potentially arable land is finite, and development costs per hectare (for clearing, roads, irrigation dams) increase as the stock of potentially arable land decreases; in other words, the best and most accessible land is used first.
5. Newly developed land enters at the current *average* land fertility.
6. Arable land erodes irreversibly on a time scale of centuries when subject to intense cultivation, unless countermeasures are taken.
7. The stock of arable land is decreased by urban-industrial building activity, the rate of decrease depending on both population and industrial growth.
8. Total investment in agriculture increases in the long run with increasing industrial output per capita and in the short run when forced to do so by food shortages.
9. Agricultural investment can be used to develop new land or to increase the amount of agricultural inputs on present land. Investment is allocated on the basis of the relative marginal productivities of the options measured in vegetable-equivalent kilograms per dollar-year.
10. The capital-intensive use of land can lead to persistent pollution of the land (high pesticide concentrations, salinity, heavy-metal poisoning).
11. Land fertility decreases on a time scale of decades when the level of persistent pollutants becomes high.

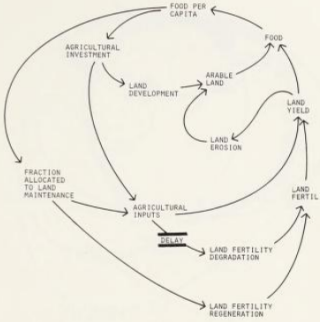

Figure 4-9 The feedback-loop structure of the agriculture sector

12. Land fertility regenerates itself over decades, and the process can be speeded up by proper land maintenance.
13. Farmers tend to maintain soil fertility by the proper use of capital except when pressured by extreme food shortages.
14. Land yield is reduced by air pollution.

The remainder of this section describes how these fourteen assumptions were combined into a feedback-loop structure. Figure 4-9 shows the feedback-loop structure assumed to govern the global aggregate food production in World3.

Loop 1: Food from Investment in Land Development

The output of food can be increased in World3 either by increasing the cultivated land area (the arable land) or by increasing the intensity at which existing arable land is used. Loop 1 (Figure 4-10) represents the process whereby the arable land area is increased.

When the available food per capita decreases, pressures arise to allocate more industrial output to agricultural activities. The resulting agricultural investment is allocated to developing new land or to increasing the intensity of use of existing land, depending on where the marginal productivity is larger.

The allocation of agricultural investments to land development ultimately results in a larger amount of arable land. However, land development is assumed to become increasingly expensive because the cheapest (most accessible, easiest to cultivate with