The second process, which we termed erosion, is of a more serious nature. Erosion in our use of the term includes any process that irreversibly removes the topsoil from arable land, thereby making further cultivation impossible. The actual movement of the soil particles is most commonly caused by wind or water. Laterization, the seemingly irreversible solidification of some tropical soils, is also included in our erosion category.

There will always be some erosion of land. Natural erosion of uncultivated land is caused by the incessant action of rain and water over thousands of years. However, such slow rates of erosion are roughly balanced by equally slow land-creating processes. Man's cultivation activities often lead to an increased rate of erosion, which occurs when land is stripped of its protective cover of forest and grass. But even this higher erosion rate normally requires generations to inflict perceptible damage, and much can be done (for example, terracing, planting of hedges, contour plowing) to keep the erosion rate low while the land is cultivated.

In World3 we hypothesized that in the global agricultural system sufficient resources are not normally allocated to hold the erosion rate as low as its "natural" minimum. This assumption seemed reasonable, since such conservation procedures are time-consuming and costly. The incentive to perform them is low, especially because the costs of neglecting the erosion threat are usually paid only several generations later. In addition, it is difficult for a farmer to judge differential rates of erosion on his land, for the time constants involved may vary from 100 to 1,000 years. As a result, even if erosion prevention is a specific social goal, its practice is not easily carried out.

The harder the land is pressured for higher yields, the more conservation activity is probably needed to maintain a constant erosion rate, even though the increased need is probably not perceived because of the extreme slowness of the erosion process. Thus if one assumes that the same effort is allocated to controlling erosion regardless of cultivation procedures, one is forced to the conclusion that the erosion rate will increase when the intensity of cultivation and the departure from the normal ecological state of the land increase. To the extent that higher land yield accompanies unecological cultivation procedures, higher erosion rates will accompany higher land yields.

Following such reasoning, we assumed in World3 that while increased investment in agricultural inputs does lead to increased land yield, on a longer time scale that increased yield can also result in larger losses of arable land due to erosion (loop 3, Figure 4-12). But it should be stressed that the erosion losses can be reduced if society decides to reduce them and if sufficient resources are allocated to the task.

When most of the potentially arable land in a given area has already been developed, as in Asia today, land erosion can become a serious problem. Food output can be increased only by more intensive use of the existing arable land, as little or no land remains for new development. More intensive land use, if not accompanied by increased efforts to combat erosion, may cause higher erosion rates and ultimately less arable land, less food, and less food per capita. Instead of relieving food shortages as intended, more intensive use of land can lead to a deterioration of the

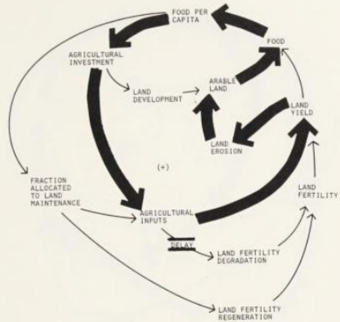

Figure 4-12 Loop 3: land erosion accompanying high yields

situation through the chain of causes and effects represented by loop 3, a positive feedback loop. When loop 3 becomes dominant, it will drive arable land and hence food output toward zero, at a rate that increases with increasing land yields. A reduction in arable land in World3 will cause a need for higher yields on the remaining land, with an even faster erosion of land as a result. The time constant assumed for loop 3 is rather long—of the order of several decades to thousands of years, depending on the land yield—so that the erosion caused by increased high cultivation intensity will not significantly reduce the food output in World3 unless it is allowed to persist for a substantial length of time.

Loop 4: Land Fertility Impairment

We defined "land fertility" as the inherent capability of the arable land to produce crops with the use of traditional inputs only (cow manure, natural irrigation, animal power). It should be distinguished from the land yield, which we defined as the output one can achieve through the use of all modern agricultural inputs. In a society using modern agricultural inputs, land yield is equal to land fertility multiplied by a number larger than one.

The land fertility is a function of the biological and physical characteristics of the soil. It is very sensitive to changes in any of these characteristics and is easily impaired—even by widely used procedures such as fertilizing, irrigation, and the use of farm machinery. In the long run, these three processes can lead to a reduction of