

Land Yield Multiplier from Capital LYMC	295
Land Yield LY	307
Land Yield Multiplier from Air Pollution LYMAP	307
Loops 1 and 2: The Investment Allocation Decision	310
Fraction of Investment Allocated to Land Development FIALD	310
Marginal Productivity of Land Development MPLD	311
Marginal Productivity of Agricultural Inputs MPAI	312
Loop 3: Land Erosion and Urban-Industrial Use	314
Average Life of Land ALL	315
Land Life Multiplier from Yield LLMY	316
Land Erosion Rate LER	318
Urban-Industrial Land per Capita UILPC	319
Land Removal for Urban-Industrial Use LRUI	321
Urban-Industrial Land UIL	322
Loop 4: Land Fertility Degradation	322
Land Fertility LFERT	323
Land Fertility Degradation Rate LFDR	325
Loop 5: Land Fertility Regeneration	327
Land Fertility Regeneration LFR	328
Land Fertility Regeneration Time LFRT	328
Loop 6: Discontinuing Land Maintenance	331
4.6 Simulation Runs	333
Historical Run	333
Standard Run	336
Sensitivity Runs—Limits to Food Production	339
Sensitivity Runs—Other Parameter Values	348
Technological Policy Runs	353
Equilibrium Runs	357
Appendix: Program Listing	362
References	365

4.1 INTRODUCTION

The fundamental assumption of the agriculture sector of the world model is that the total amount of food that can be produced on the earth each year has some limit. It is well known that the allocation of more physical resources (land, water, fertilizer, and labor) to food production will increase the annual food output. However, we postulate that the physical resources that can be allocated to food production are limited: in World3 the available agricultural land is limited, the amount of fertilizer is limited by the total global industrial production capacity, and the land fertility is limited by pollution absorption mechanisms. Although technological innovations may lead to higher yields on a given land area, we postulate that there are decreasing returns to technology's ability to increase land yields by diverting other limited resource inputs to the agriculture sector.

The purpose of this chapter is threefold: to propose a structure that relates the land and capital used in agriculture to the food output obtained, to describe the mechanisms by which food output can be increased, and to identify within the chosen structure the forces that can potentially limit total annual food production. We present, in sequence, a set of real-world data illustrating the historical behavior of the elements in this sector, a set of basic concepts underlying the model formulation, the precise causal assumptions of the sector and their exposition in equation form, and simulation runs of the sector as a driven system.

4.2 HISTORICAL BEHAVIOR MODES

The most conspicuous characteristic of the world's food production system is its rather spectacular increase in total output over the last few decades (Figure 4-1). The increase is more impressive in terms of total food production than in per capita food production, since the world population has also increased greatly. The gain in total food output can probably be attributed to two factors: an increase in the cultivated land area, and an increase in the average land yield (Figure 4-2). The observed average land yield has risen sharply within the last hundred years (Figure 4-3), largely because of the advent of modern agricultural inputs such as fertilizer, pesticides, new seed, and farm machinery (Figures 4-4 and 4-5).

There are indications that the recent increases in total global food output cannot continue indefinitely. Opportunities for expanding the amount of arable land are limited (FAO 1970a): some arable land is taken out of cultivation for building cities, roads, and airports; some becomes unsuitable for agricultural use through erosion, laterization, or salinization. Future increases in food production may also be restricted by decreasing returns to the use of modern agricultural inputs (Figure 4-6).

Another trend may be occurring globally: land fertility may be gradually decreasing, although little direct evidence is available to support or refute this hypothesis. Here it is useful to make a distinction between land yield (the actual food output per hectare-year obtained through the use of fertilizer, pesticides, and machinery) and land fertility (the intrinsic ability of the soil to produce food without modern