Modelling of agricultural production: weather, soils and crops

H van Keulen and J Wolf

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PREFACE

This book introduces the reader into the quantitative aspects of agricultural production, as influenced by environmental conditions and management practices. The aim is to familiarize the reader with the subjects in such a way that first estimates of agricultural production potentials in situations relevant to him can be made. For that purpose many exercises and examples have been included in the text to facilitate direct application of the theory presented.

The approach presented in this book is developed by the Centre for World Food Studies (SOW), an interdisciplinary research group working on problems related to world food supply and agricultural production potentials and limitations.

The direct motive for publishing this Simulation Monograph was an international course on the same object, organized in Wageningen by dr. J.H. de Ru of the Foundation for Post-Graduate Courses of the Agricultural University in Wageningen. The course was organized in close cooperation with dr. D.A. Rijks of the Applications Program of the World Meteorological Organization in Geneva and was financially supported by the Dutch Directorate General for International Cooperation (DGIS), the European Community (EC), and the Food and Agricultural Organization of the United Nations (FAO). The book has been edited on the basis of the lectures presented during the course with ample cooperation of the authors and invaluable advice of prof. dr. C.T. de Wit. The contributions of ir. D.M. Jansen and Mrs. H.H. van Laar during the course and during the editing stage of the book were of great help. Ing. P.W.J. Uithol is gratefully acknowledged for his accurate work on the list of references. Many thanks are due to Mrs. R. Helder, who skillfully and enthousiastically typed the first versions of most of the contributions, to Mrs. M.A. Boss, who performed the task of finalizing the manuscript and Mr. G.C. Beekhof for his punctual drawings.

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1 INTRODUCTION

1.1 Introduction

C.T. de Wit

Agriculture may be defined as the human activity that produces useful organic material by means of plants and animals, with the sun as the source of energy. The minimum required number of resources is small: labour and land, with some sun and rain. For many soil types and climates, farming systems have been developed that enable subsistence in food, clothing, shelter and fuel, provided sufficient land is available. Unless conditions are very favourable, these farming systems do not produce much more than bare necessities. However, man is an animal species that thrives on brick and concrete and the development of civilisation is very much intertwined with that of urban life. To sustain a substantial non – farming population, the productivity of the farming population has to be much higher than its subsistence level. This is only possible if the non – farm sector produces industrial means of production for the farmers within an economic structure that provides sufficient incentives for their use.

Although a sharp distinction is not possible, these means of production may be classified as labour saving, yield increasing and yield protecting such as machines, fertilizers and pesticides, respectively. Only the yield protecting inputs require little energy for their manufacture and use, although their development would hardly have occurred independently of the chemical industry. With some exaggeration, modern agriculture could therefore be defined as the human activity that transforms inedible fossile energy (mineral oil and natural gas) into edible energy through plants, animals and the sun.

Up to World War II, the emphasis in agriculture in the U.S.A. was on mechanization. Horses were replaced by tractors, so that land that was used to grow food for horses could be used to cultivate crops for other purposes. In this way, the agricultural output of the nation as a whole increased considerably. The yield increases per hectare were, however, small: for wheat only about 3 kg ha^{-1} yr^{-1} as is seen in Figure 1. In Europe in the same period, more emphasis was given to increasing the productivity per unit of land. However, the results were not impressive: ranging from about 4 kg ha^{-1} yr^{-1} in the United Kingdom to 18 kg ha^{-1} yr^{-1} in the Netherlands.

A few years after World War II, the annual yield increase suddenly improved, reaching 50 – 80 kg ha^{-1} yr^{-1} as is illustrated in Figure 1 for the United States and the United Kingdom. In general terms, this persistent yield increase may be attributed to the simultaneous effect of soil amelioration, the use of fertilizers and the control of diseases, as well as to the introduction of varieties that were able to make good use of these increased inputs. In many regions, wheat yields are still so low that an absolute yield increase of 50 – 80 kg ha^{-1}

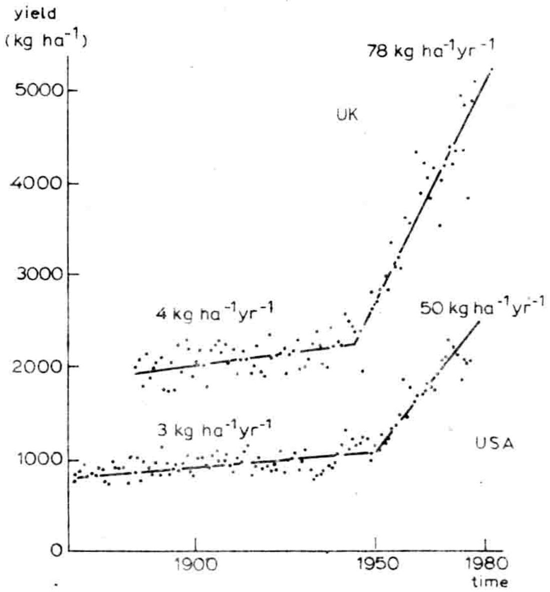

Figure 1. Average wheat yields in the United Kingdom and the United States over the last century.

yr^{-1} represents a relative increase of over 2 percent per year. The situation is not much different for other crops. Such yield increases outstrip the growth of the population in the industrialized countries. Any slack that is created in this way appears to be taken up by increased use of grain and land for milk and meat production and by taking land out of production.

In contrast, the annual yield increases in Africa, South America and Asia appear to be on an average 10, 19 and 25 kg ha^{-1} yr^{-1}, respectively (Figure 2). This is slightly higher than in the industrialized part of the world before World War II, which indicates that some of the knowledge and means of production are trickling down from North to South. However, this occurs at a rate that is too low to prevent hunger and malnutrition. For instance, in Africa with an average grain yield of 1000 kg ha^{-1}, the increase of 10 kg ha^{-1} yr^{-1} amounts to only 1 percent per year and even this may be too high an estimate for the last ten years. This growth in yield is far less than the relative growth rate of the population, which is 2–3 percent per year. Up to now, the difference has been more or less made up for by cultivating larger areas, but land that can be reclaimed by simple means within the social–economic framework of the family or the village is becoming scarce, so that more advanced technology is indispensable for further reclamation. Hence, to improve the food situation,

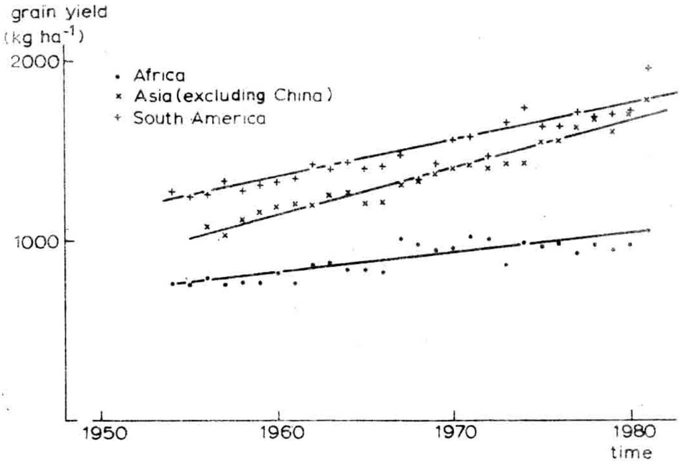

Figure 2. Average grain yields from 1954-1980 for Africa, Asia and South America.

either more machinery has to be used to extend the area under cultivation or more inputs, e.g. fertilizers, to increase the yield per unit area. Both of these paths require an open economy in which the farmer receives sufficient money for his agricultural products to pay for the necessary means of production. Too often the terms of trade are not so favourable, but claims that it is possible to improve substantially the food production in the world without these technical means are not justified in view of what is known about the agricultural production process.

Average yields, as used here for illustration, hide many differences. Some developing countries are reasonably well endowed with resources and have an economic structure that promotes agricultural development. Their price levels are such that it pays, at least for some farmers, to improve the soil, to apply fertilizers, to practise disease control and to use the proper plant varieties. However, policies that enable the poorest segments of the population to purchase the bare necessities may be lacking, so that hunger and malnutrition continue to exist. This is the case even in the richer countries of the world. There are also poor countries with infertile soils and an unfavourable climate, often with few other endowments and landlocked and with a demographic structure that results in rapid population growth. Such countries can only import the necessary agricultural inputs if they can export cash crops. Transport costs for both their import and export are often so high that even this path to increasing production is blocked. Then progress depends on political and economic solidarity that exceeds national boundaries.

The prospects for improvement of the food situation have, therefore, also national and international political and economic dimensions. International policy agreements aimed at stabilization of the prices on the world market at a fair level and at promotion of the opportunities of developing countries to penetrate the markets of the rich countries, may create a more favourable position for developing and poor countries. Such agreements must then be complemented by national development strategies that enable farmers to increase their output and, in particular, to improve the production opportunities for the poor. This broad range of problems has been the focus of research undertaken by the Centre for World Food Studies, which is situated in Amsterdam and Wageningen. For this research, national economic models with emphasis on the agricultural sector are being developed and linked to a global model to analyse and improve the policies of national governments and international agencies. These national economic models contain agricultural production modules that account for the possibilities of production and can distinguish between regions and commodities. That part of the work of the Centre focuses on the physical and agronomic factors that determine agricultural production and is the subject treated in this book.

The main purpose pursued is to familiarize the reader with the processes that govern the technical possibilities for agricultural production in a region in such a way that quantitative estimates can be made of the yield levels of the main crops under various constraints and of the inputs that are needed for their realization. The approach is necessarily simplifying, so the quantitative estimates should not be considered as the final answer, but rather as a framework for further analysis of possibilities and constraints that are based on factual knowledge, which can only be obtained by fieldwork.

For this approach, a hierarchical procedure is adopted which is in a schematic way presented in Figure 3. The rectangles in the second row represent the factors that ultimately determine the production potential. Climate and soil are fixed properties for a given region and, in combination with the level of reclamation, characterize the land quality level. The characteristics of agricultural crops may be changed by breeding, the scope for improvement in this respect being reasonably well – defined. For a given land quality level, the yield potential is therefore fixed for a fairly long period of time, and may, therefore, be calculated with reasonable accuracy.

In the further analysis, the goal is not to define a production function describing the relationship between the yield and all possible combinations of growth factors, because, by the nature of the agricultural production process, no unique solution to such a production function exists. Instead, a reasonable combination of growth factors should be established that will result in the yield level that is in accord with the land quality level. Thus, the yield level is considered concurrently as a dependent variable, determined by crop characteristics and land quality level, and as an independent variable, dictating the required input combination for its realization. This is reflected in the direction of the arrows in Figure 3: towards the yield level as well as away from the yield level.

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