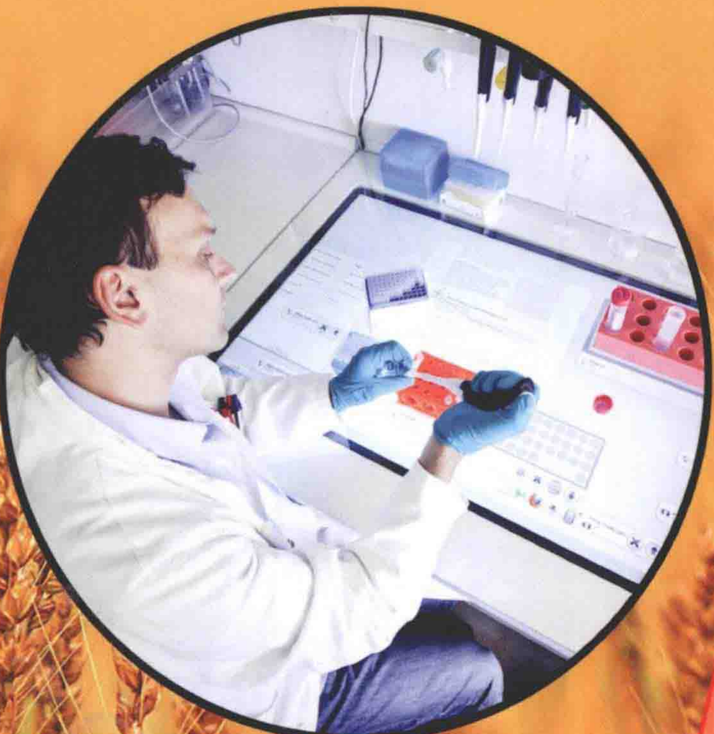
Advances in Statistical Methods in Agriculture and Experimental Biology



Mark Butcher
Editor

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KORO PRESS

KOROS PRESS LIMITED
London, UK

Advances in Statistical Methods in Agriculture and Experimental Biology

© 2013

Revised Edition 2014

Published by
Koros Press Limited
3 The Pines, Rubery B45 9FF, Rednal,
Birmingham, United Kingdom

Tel.: +44-7826-930152
Email: info@korospress.com
www.korospress.com

ISBN: 978-1-78163-262-8

Editor: Mark Butcher

Printed in UK

10 9 8 7 6 5 4 3 2 1

British Library Cataloguing in Publication Data
A CIP record for this book is available from the British Library

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Preface

Agricultural research has played a key role in the development of statistical methods. The presence of wide heterogeneity in the experimental material that is often used in agricultural research, led to the application of statistical tools and consequently many refinements and newer developments in statistics followed. The famous statistician, Sir R.A. Fisher and his colleagues at Rothamsted Experiment Station in United Kingdom and elsewhere, while attempting statistical solutions to agricultural problems, led to the development of design of experiments and analysis of variance techniques which are fundamental to the subject of statistics.

Statistics, in fact, provides scientific tools for representative data collection, appropriate analysis and summarization of data and inferential procedures for drawing conclusions in the face of uncertainty. It is indeed true that statistical tools have wide applicability to almost any branch of science dealing with the study of uncertain phenomena involving aggregates. It has also been established that many apparently deterministic processes, on closer scrutiny, turn out to be inherently stochastic in nature. However, in agricultural research, statistics finds some of the very interesting applications which often led to the development of newer statistical techniques or at least a refinement of existing ones. Consequently, the branch of statistics dealing with agricultural research has been recognised as a separate entity in itself, as agricultural statistics, in view of the growth of the subject particular to this area. Agricultural statistics has three core subject areas, namely, sample surveys, design of experiments and biometrical techniques. Sample surveys in agriculture is primarily concerned with estimation procedures for area under different crops, crop yield and crop production, for various crops over different regions of the country. Besides, the estimation of land use statistics, statistics related to input use in crops such as the varieties, seeds, fertilizer, irrigation, insecticides/pesticides, machines/implements/tools, the supply and demand of various inputs, are often collected through sample surveys. The cost of cultivation/ production needs to be compiled through detailed survey inquiries so as to understand the farm level efficiency. The information about markets, prices, imports/exports is also becoming important now that India has attained food sufficiency leading to surpluses in certain pockets and the fair competitive trade discipline being enforced under World Trade Organisation regime. The household consumption surveys, are important for assessing food security in the country. Biostatistics is the application of statistics to a wide range of topics in biology. The science of biostatistics encompasses the design of biological experiments, especially in medicine, agriculture and fishery; the collection, summarization, and analysis of data from those experiments; and the interpretation of, and inference from, the results. Major branch of this is medical biostatistics, which is exclusively concerned with medicine and health. Biostatistical reasoning and modelling were of critical importance to the foundation theories of modern biology. In the early 1900s, after the rediscovery of Mendel's work, the gaps in understanding between genetics and evolutionary Darwinism led to vigorous debate among biometricians, such as Walter Weldon and Karl Pearson, and Mendelians, such as Charles Davenport, William Bateson and Wilhelm Johannsen. By the 1930s, statisticians and models built on statistical reasoning had helped to resolve these differences and to produce the neo-Darwinian modern evolutionary synthesis. Despite the fundamental importance and frequent necessity of statistical reasoning, there may nonetheless have been a tendency among biologists to distrust or deprecate results which are not qualitatively apparent.

We believe that this book will cater to the immediate needs of all students, researchers and the faculty members of the subject and also serve as a good textbook for the students of agriculture, biology, pharmacy and medicine.

—Editor

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Chapter 1

Global Agricultural Productivity Report

The 2011 GAP Report™ features the latest comparison of the current rate of global agricultural productivity with the rate required to sustainably meet the needs of the more than nine billion people expected to inhabit the Earth by 2050, and four national-level case studies which highlight the impact of key policies on agricultural productivity.

The Task Before Us: Meeting the Needs of a Growing World

Today there are nearly one billion people who do not have access to a safe and adequate food supply. In fact, around 20 percent of the world's population lives on less than $1.25 per day and many of them are children who suffer from severe long-term health problems resulting from inadequate nutrition. Between now and 2050, the global population is projected to grow by more than 30 percent, resulting in an estimated 2.3 billion more people to feed. The May 2011 United Nations population projections show world population growing from about seven billion in 2011 to more than nine billion by 2050.

Most of the population growth is expected in Sub-Saharan Africa (49 percent, an increase of one billion by 2050) and Asia (41 percent, an increase of over 900 million), both of which are low-income areas with relatively low levels of agricultural productivity.

Most of the poor people in these regions obtain their food and earn their meager incomes from farming small plots of land, and spend nearly 80 percent of that income on food. In addition to the challenges presented by a rapidly growing population, the Food and Agricultural Organisation of the United Nations (FAO) analysis highlights the increase in protein-based diets, which causes per capita caloric intake to increase by nearly one-third. Therefore, the total supply of food measured in kilocalories for the region will need to increase by more than 170 percent. However, the basic calculation of caloric requirements oversimplifies the challenge facing Sub-Saharan Africa. While the consumption of staple foods like roots, tubers and cereals will increase at a slower rate than total caloric intake, consumption of meat–currently about 20 pounds per person per year–is expected to nearly double by 2050. Additionally, consumption of vegetable oils, fruits, vegetables and sugar is also projected to rise more rapidly than overall calories.

The above trends indicate the need for a substantial increase in food production, as well as improvements in both domestic agricultural production patterns and trade flows, in order to meet the needs of changing dietary patterns. Changing diets are just one reason why trade is an important food security strategy. By 2050, a larger fraction of agricultural production will need to move through trade because the world's population distribution by region is not the same as the distribution of arable land. Regions like North America, South America, Europe and Oceania have a higher proportion of arable land and will continue to be a source of agricultural output for other regions, including Asia. It is also important to note the continuing population migration to urban areas. Today more than 50 percent of the population lives in urban areas. By 2050, that proportion will increase to 70 percent. In order to reduce the environmental footprint of agriculture, the challenges of meeting the food, feed, fibre, energy and industrial needs of a growing world must be accomplished sustainably, primarily by utilising existing land and natural resources to increase production.

Just as there are constraints on available land, constraints also exist on the availability of water. Globally, agriculture accounts for nearly 70 percent of all water withdrawals. However, this percentage varies greatly by region. In areas such as Asia, where irrigation is vital, water supply will be significantly stressed to keep up with demand. In addition, rainfed agriculture will be important to meeting future production needs.

In the near future, human society will have to make fundamental decisions about food and agricultural policies and how to meet the rising demand for agricultural output. Policies that support agricultural development and productivity improvement are important to meeting aggregate food needs and are also a means of improving nutrition and alleviating poverty; when farmers become more productive, they

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improve the nutrition of their families and are able to move out of poverty.

Rural poverty reduction, in particular, depends on growth in yields and improved agricultural labour productivity, but those links vary widely across countries and regions. In addition, there is strong research evidence that GDP growth originating in agriculture often drives income growth among the poorest rural residents in developing countries. The potential poverty-reducing impact of agriculture-related growth is three times larger than growth originating from other sectors of the economy.

2011 Global Agricultural Productivity Index

The Global Agricultural Productivity Index™ (GAP Index™) was developed by GHI to measure ongoing progress in achieving the goal of sustainably doubling agricultural output by 2050. The GAP Index measures the difference between the current rate of agricultural productivity growth and the pace required to meet future needs. A twofold increase in agricultural output by 2050 will require total factor productivity (TFP) to grow at an annual global rate of 1.75 percent. In 2010, GHI reported that the global TFP growth rate stood at 1.4 percent annually and that a 25 percent increase in the rate of TFP growth was needed to close the gap. This year's GAP Index includes an additional year of data (2008) and incorporates revised FAO data on the inputs and outputs applied. The updated GAP Index shows that the TFP growth rate is now increasing at a 1.74 percent annual rate. As this snapshot indicates, TFP growth rates will fluctuate year to year, just as yields will rise and fall, reflecting changing weather patterns, disease outbreaks and other factors.

While the new evidence of faster productivity growth for this year is welcome, it does not alleviate the concern or urgency about addressing the pace of agricultural development in parts of the world where much of the population increase will take place, especially Sub-Saharan Africa. Currently, TFP growth for Sub-Saharan Africa averages approximately 0.85 percent, in sharp contrast to growth rates well above two percent in Brazil and China. If Sub-Saharan Africa had to meet its expected food needs independently, a twofold increase in TFP growth would be needed. While some of the region's growing demand for food may be met by input intensification, reduction in post-harvest loss and increased imports, the challenge remains daunting and will require other policy changes that will aggressively support agricultural development.

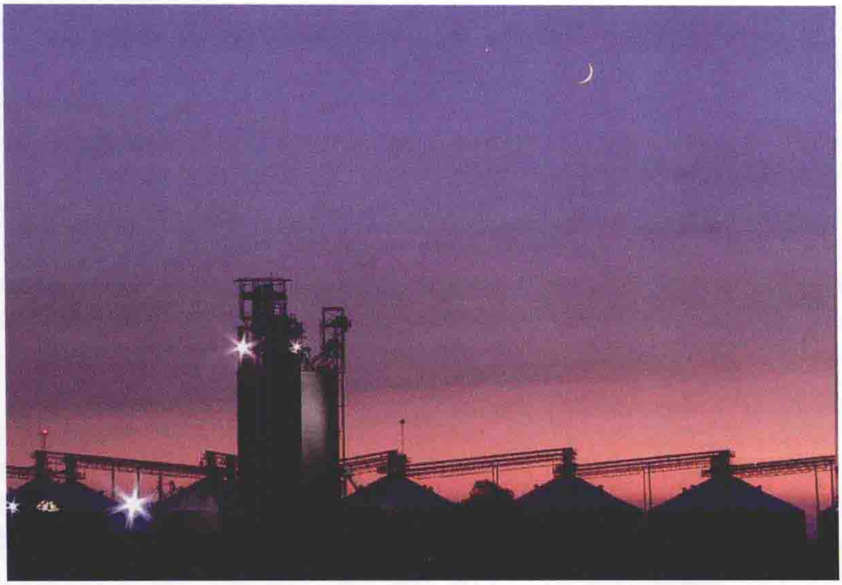

Figure: *Grain production facilities*

Solutions to Close the Gap

The Global Harvest Initiative has identified five policy areas that foster agricultural development to help close the global productivity gap:

- Improving Agricultural Research Funding, Structur]e and Collaboration
- Removing Barriers to Global and Regional Trade in Agriculture
- Strengthening and Streamlining Development Assistance Programs
- Embracing Science-Based Technologies
- Enhancing Private Sector Involvement in Agricultural and Rural Infrastructure Development

The following section features national-level case studies of the emerging market economies of Brazil, China, Indonesia and Ghana, which highlight the impact of GHI's five policy areas on agricultural productivity and development. The case studies seek to provide an understanding of how select policies can be effective in addressing food security and hunger through agricultural development.

Agricultural Case Studies: Four Emerging Market Countries

Productivity growth varies widely among countries and regions, with some having more success than others. Brazil, China, Indonesia and Ghana are examples of four emerging market countries from different parts of the world that have had varying success in agricultural development. Total factor productivity for Brazil and China has outpaced the rest of the emerging market and developing countries, while Indonesia has been closer to the developing country average.

Ghana's TFP, on the other hand, did not begin to improve until nearly a decade after Brazil, China and Indonesia. However, since the early 1980s, Ghana has achieved rates above that of the rest of Sub-Saharan Africa.

While each country's approach has been different, certain fundamental policies exist that are necessary to promote agricultural development. These policies include: supporting research and development (R&D) to create new science-based technologies; supporting the widespread adoption of technologies; investing in critical infrastructure; improving access to domestic and foreign markets and removing trade barriers; and fostering an environment that is conducive to private sector investment in the agriculture and food sectors.

The following sections highlight policies that have contributed to agricultural productivity and development improvements in Brazil, China, Indonesia and Ghana.

Brazil

Brazil is characterized by large and well-developed agricultural, mining, manufacturing and service sectors. It is South America's largest, most populous nation and its leading economic power. Brazil's productivity growth accelerated in the early 1980s and has grown relatively steadily in recent years with significant government support. The government's approach has been unique, focusing heavily on investment in R&D. In 1973, Brazil established a public research company, Embrapa, known as the Brazilian Agricultural Research Corporation, at a time when sharp increases in petroleum prices were making the country's high levels of agricultural subsidies extremely costly. The government pledged to invest $20 in Embrapa for every $50 saved by reducing subsidies, a policy that provided sufficient funds to turn Embrapa into a leading tropical-research institution with broad expertise and projects ranging from plant genetics to livestock breeding. Embrapa has been successful in helping to create effective technologies uniquely suited to the expansion of Brazilian agriculture. Today, Brazil maintains a large and growing public research system. On a purchasing-power parity (PPP) basis, the nation spent more than $1.3 billion on public research in 2005, second to

China, which spent more than $4.2 billion. However, Brazil's total investment in agricultural research represents 1.66 percent of its agricultural GDP, a far greater share than China's research investment, which amounts to 0.53 percent of its agricultural GDP. A longer-term example of Embrapa's R&D success is its role in developing the broad range of efficient crops and production systems in the Cerrado region.

Once regarded as unfit for farming by the father of the Green Revolution and Nobel laureate Dr. Norman Borlaug, today the Cerrado region accounts for a massive 70 percent of Brazil's farm output. Like the United States, China, Argentina, India and Canada, Brazil has embraced science-based technologies, including biotechnology, to accelerate productivity growth. Brazil also has a streamlined and effective regulatory approval process for new technologies, which allows farmers to gain access to the latest technological advancements. Brazilian farmers subsequently invested heavily in mechanization, as well as other more advanced, large-scale farming practices. For example, the number of tractors in Brazil per 100 square kilometres has grown from just over 32 in 1961 to around 130 in 2006.

While R&D and science-based technologies have demonstrated notable results for Brazil, an additional and important stimulus for growth came from macroeconomic stabilization and greater openness to trade, which encouraged more private-sector investment in agriculture. Brazil opened markets by substantially reducing tariff rates from an average of 51 percent to just more than 10 percent currently. Today Brazil is one of the world's largest exporters of agricultural products and continues to seek access to new markets.

The biggest constraint to Brazil's future agricultural growth is a lack of infrastructure. Producers still face competitive bottlenecks arising from internal distance to markets, partly due to the size of the country. For example, parts of the important Mato Grosso agricultural region are 2,000 kilometres away from the main soybean export facility at Paranaguá, which cannot yet handle the largest, most modern ships. In addition, much of the crop marketing chain involves the movement of relatively low-value commodities by truck, the most expensive means of transportation. This problem is exacerbated by the lack of improved roads; only 10 percent of the country's road network is paved, yet more than 60 percent of agricultural production is transported by truck, often for thousands of kilometres. Brazil's rail system, meanwhile, is one-seventh the size of the U.S. system, and consists of several short line railroads that do not connect because of different rail sizes. In Mato Grosso, some farmers have tried to overcome these challenges by building roads that link farms to federal and state highways.

China

China has the largest population in the world and benefits from large land area and sizable domestic markets. However, only 15 percent of China's land is arable. Any review of China's recent development progress must recognise that it was traditionally one of the poorest countries in the world, where most rural people struggled to survive. In 1978, 250 million rural Chinese, or one-third of the entire rural population, did not have access to food or income sufficient to maintain healthy and productive lives.

This changed dramatically beginning in 1978 when rural reforms began, including the introduction of the "household responsibility system," which replaced communal farms. This system allowed households to contract land, machinery and other facilities from collective organisations, to make operating decisions independently and to freely dispose of surplus production over and above national and collective quotas. This greatly improved economic incentives, and productivity on the farms improved significantly, beginning the agricultural productivity growth that continues today.

Mechanization as an indicator of investment in farm-level productivity reveals a dramatic increase in the number of tractors in China per 100 square kilometres since 1961.

A second source of stimulus for productivity growth in China was investment in R&D, starting in 1990. Government spending on agricultural research and extension is generally credited with contributing significantly to agricultural productivity improvements, which has resulted in large benefits for the rural poor.

China's agricultural research system has expanded rapidly during the past four decades and is now one of the largest systems in the world. On a PPP basis, in 2005, China invested more than $4 billion in research, far more than Brazil, Indonesia or Ghana. Research and development spending as a percentage of agricultural GDP was just under 0.6 percent, large in comparison to both developing country standards and the size of the agricultural economy.

Both education and agricultural R&D are seen as highly effective and efficient policies to address China's long-term food security concerns and to simultaneously deal with the need for growth, poverty reduction and equity. Since 1978, China has promoted education through the implementation of nine years of compulsory schooling for all children. The result is an increase in education for the labour force from 4.38 years in 1975 to 6.35 years in 2000, the latest year for which data are available.

The investment in education improved labour quality and reduced illiteracy from 28 percent in 1985 to 10 percent in 1997. These investments have been important in providing farmers with the skills to use modern farming technology and to engage in non-farm activities in both rural township enterprises and urban industrial centres.

Indonesia

Indonesia is the largest economy in Southeast Asia and the world's fourth most populous country, with nearly 246 million people. Fluctuations in government policy that ranged from discrimination against the agricultural sector to support for productivity and technology growth have caused Indonesia's agricultural development to be somewhat erratic. Between 1968 and 1992, agriculture and food security were given priority in economic policy, and producers received large subsidies for agricultural inputs. During this time, Green Revolution crop varieties (especially high-yielding rice varieties) were promoted, and resulted in above average productivity growth. By the mid-1980s, trade and fiscal imbalances led to a gradual shift in economic policies in favour of export-led manufacturing, and agricultural subsidies and investments began to wane, resulting in a period of stagnation after 1993, when productivity growth slowed sharply.

Following the severe economic contraction and political challenges caused by the Asian financial crisis of 1997-1998, a reform government emerged with a more market-oriented agricultural policy. A sharp devaluation of the currency, liberalization of food crop markets and changes in land-use policy shifted comparative advantage in agriculture toward export commodities like tropical perennials, horticulture, animals and aquaculture, as well as food crops. Throughout this period, commodity diversification was an important source of productivity growth.

Research suggests that while agriculturally-focused liberalization efforts and major shifts in monetary policy succeeded in buoying farm technology growth, government-sponsored research has played only a modest role in that improvement. While the government price and trade policies presumably attracted private investment into the agricultural sector and public investment in agricultural and rural infrastructure was important, most of the productivity growth can be

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