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A GLOBAL AGRO-CLIMATIC ANALYSIS OF THE DISTRIBUTION AND PRODUCTION OF LIVESTOCK COMMODITIES

David H. White*

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* ASIT Consulting, P.O. Box 328, Hawker, ACT 2614, Australia.

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Acronyms and Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AGA	Animal Production and Health Division of the FAO
AGL	Land and Water Development Division of the FAO
AEZ	Agro-ecological zone
ASIT	Agro-ecological Systems & Information Technology
ANU	Australian National University
AVHRR	Advanced Very High Resolution Radiometer
CGIAR	Consultative Group for International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical, Cali, Colombia.
CIS	Commonwealth of Independent States
CRES	Centre for Resource and Environmental Studies, ANU
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DEM	Digital elevation model
ERGO	Environmental Research Group Oxford, U.K.
FAO	Food and Agricultural Organization of the United Nations
FEWS	Famine Early Warning System (FAO)
FTEs	Full-time equivalents
GIS	Geographic information system
GNP	Gross national product
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis, Vienna
ILRI	International Livestock Research Institute, Nairobi
IRRI	International Rice Research Institute
ISNAR	International Service for National Agricultural Research
LGP	Length of growing period
NARS	National Agricultural Research Systems
NASA	National Aeronautic and Space Administration, USA
NDVI	Normalised difference vegetation index
NOAA	National Oceanic and Atmospheric Administration, USA
OECD	Organization for Economic Cooperation and Development
OIE	Office International des Epizooties
PET	Potential evapotranspiration
SCARM	Standing Committee on Agriculture and Resource Management, Australia
SDRN	Environment and Natural Resources Service of FAO
SPAAR	Special Program for African Agricultural Research
TAC	Technical Advisory Committee of CGIAR
UCLA	University of California, Los Angeles
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USAID	United States Agency for International Development
WAICENT	World Agricultural Information Centre
WHO	World Health Organization
www	World Wide Web

ABSTRACT

Investment in agricultural research in developing countries is being increasingly targeted at those areas and issues where the economic and environmental benefits may be expected to be greatest. However, this in turn requires more accurate estimates of these benefits, in that they are not confined to the immediate area where the research is carried out. In this study it is assumed that benefits are likely to be greater within the agro-climatic zone in which the research was carried out, though estimates are also required of expected technical spillovers, pre- and postharvest, to other agro-climatic zones. This first requires that the zones themselves be defined, along with information on the size and commodity output of livestock industries within agro-climatic zones in different countries. The capacity for undertaking research, and adopting or adapting the results of research undertaken locally or in another country, also needs to be assessed.

Different methods for classifying agro-climatic zones were therefore compared. These included methods based on estimated length of growing period (LGP) using rainfall and temperature data, or the ratio of precipitation to potential evapotranspiration, and on more detailed agronomic models. Remote sensing data and land use information are also being used to help define these zones.

The most appropriate classification method for ACIAR to use at this stage to aid research targeting and prioritisation at the country level would appear to be one based on six agro-climatic zones classified according to LGP. This is primarily because this zonation can be linked to existing livestock data. These zones are designated desert, arid, semi-arid, dry sub-humid, moist sub-humid and humid. However, within each zone it is possible for further subdivision according to the dominant livestock production systems, namely grassland-based, rainfed mixed farming and irrigated mixed farming.

Estimates of livestock production have been constrained in the past because the data have been collected at the country level. However, by defining agro-climatic zones and relating concentrations of livestock populations to those of humans, it is now possible to make realistic estimates of livestock populations and the production of livestock commodities for most developing countries. Cattle density data collected at the subnational level in Africa by ILRI were also made available to this project. A series of 20 spreadsheets was prepared containing estimates of livestock numbers and productivity (meat, wool, milk, eggs) and manure production within different agro-climatic zones in each country. Supplementary spreadsheets containing details of land use in different countries were also prepared.

Quantitative estimates were made of preharvest and postharvest technology spillovers from one agro-climatic zone to another. The distinction was made between agronomic, animal health and animal production technologies with ruminants, and between health and production with pigs and poultry. Postharvest technology spillovers tended to be more independent of agro-climatic zone, so that technology benefits could flow more easily between zones. Perishable livestock products presented greater challenges in terms of

technology spillovers between climatically dissimilar zones than relatively enduring products such as wool.

Estimates were made of the basic and adaptive research capability to assist agriculture in 50 countries and regions, particularly focusing on Asia and Africa. This included summarising details on agricultural research, animal health services, and expenditure on education in most countries around the world.

RECOMMENDATIONS

- That there be increased emphasis on defining agro-climatic and agro-ecological zones throughout the developing countries in which ACIAR commissions research. This would assist in focusing the efforts of research teams on particular issues and problems, and in estimating the likely benefits of research, thereby contributing to improved prioritisation of research programs. Attention needs to be given to the purpose of the zonation, which will often be related to increasing population and socioeconomic issues, to the capacity for future increases in production and productivity, and to environmental concerns about land degradation and other threats to the natural resource base.
- That it be recognised that agro-climatic and agro-ecological zone (AEZ) definition can be facilitated considerably through the use of digital elevation models, climate surfaces, plant growth models such as GROWEST (Nix 1981; Zuo 1996), field and remote sensing data, and geographic information systems. There are several resource issues (staffing, subcontracting, hardware, software) for ACIAR to consider here.
- That the most pragmatic approach for relating livestock density and commodities data to agro-climatic zones is to define these zones on the basis of length of growing season, there being six zones designated as desert, arid, semi-arid, dry sub-humid, moist sub-humid and humid. This classification was used in this study, and is consistent with current work being undertaken by FAO and ERGO (FAO 1996a, 1996b; Slingenbergh and Wint 1997).
- That there be provision for these zones to be further subdivided in future as additional data and computing resources become available. Sixteen zones based on length of growing period have already been identified, but that there should also be provision for further zonation based on land use (pastoral versus dryland mixed farming versus irrigated mixed farming), and for extra discrimination based on the use of agronomic models, remote sensing data, and socio-economic data within a geographic information system (GIS).
- That ACIAR consider providing resources to expedite the publication of the digital elevation model, climate surfaces and agro-ecological zones for mainland East Asia (Zuo 1996) on CD-ROM, including further analysis to determine the actual areas in each country taken up by each AEZ. This work has been funded in part by ACIAR.
- That ACIAR consider a collaborative program involving FAO, ERGO, ILRI, CRES and possibly ASIT Consulting to obtain crop and livestock coverages and land utilisation patterns throughout developing countries with which it is involved. This would help research targeting and prioritisation, and the planning, implementation and evaluation of its research programs. It would also provide the required GIS linkage to overlay the data within a higher resolution of agro-climatic zones, as these become defined.

  ILRI has a global mandate to extend its crop and livestock coverages from Africa to other parts of the world, and is specifically interested in doing so in Asia. AGA, within FAO, has as its goal to relate livestock land utilisation patterns at the national and sub-national level to food and income security and sustainable development. ERGO has been assisting FAO by developing techniques to predict cattle and cultivation levels *within AEZs of countries around the world. CRES has been undertaking agro-ecological analyses of mainland East Asia and Sri Lanka.*

- That ACIAR undertake selected case studies, in consultation with its overseas partners and collaborators, to test a sample of the pre- and postharvest technology transfer and research capacity coefficients estimated during this study.

INTRODUCTION

This project was undertaken to develop a livestock commodities database for use in refining ACIAR's regional commodities priorities table. This is to help ACIAR in its efforts to improve the allocation of research resources to aid livestock production within developing countries (Davis and Lubulwa 1995).

TASK 1. REFINE THE AGRO-CLIMATIC ZONES APPROPRIATE FOR EACH COMMODITY

This included undertaking a feasibility study on this topic (White 1998).

Objectives of task 1

To determine the feasibility, value and limitations of different approaches that can be used, either alone or in combination, to refine agro-climatic zones for different livestock commodities.

To identify where the problems of classification and interpretation are likely to arise.

Definitions

The following definitions are used by Australia's SCARM (Standing Committee on Agriculture and Resource Management) Working Group on Sustainable Agriculture:

Agro-climatic regions
This term is used to denote regions with a characteristic inter-relationship between agronomy/farming systems and climate.

Agro-ecological regions
Similarly, agro-ecological regions are those with a characteristic inter-relationship between agronomy/farming systems and various environmental features, not just climate.

Agro-ecosystems
An agro-ecosystem has been defined as an ecosystem manipulated by frequent, marked anthropogenic modifications of its biotic and abiotic environments (Coleman and Hendrix 1988). Four main types of modification have been recognised. These are, briefly: inputs of energy; reduction in biotic diversity so as to maximise yield of economic products; artificial selection; and external control which is goal-orientated (Odum 1969).

Agro-climatic and agro-ecological regions

Agro-climatic and agro-ecological zonation schemes are standard tools used to target agricultural research and to set research priorities because they provide information about target environments (Corbett 1996). Indeed, this is the major reason for this study. A proper description of the target environment also enables research efforts to be more clearly focused at local issues and needs.

Ways in which these zones are characterised are changing as the reproducibility and flexibility of geographical information systems (GIS) loosen the former restrictions to data integration.

Agro-climatic and agro-ecological GIS have created a new environment to conduct similar research prioritisation and targeting efforts. With GIS, one can greatly refine the methodologies by which 'targets' are defined, while at the same time expanding the opportunities and potential for the accurate targeting of agricultural research efforts.

An accurate spatial (and temporal) database enables the characterisation of agro-ecosystems. This ability is vital in the developing world for efficient resource allocation in agricultural research. Agro-ecosystems are complex entities that span several levels or scales, with different processes dominating each scale. Therefore, a dynamic agro-ecosystem characterisation requires both biophysical and socioeconomic data. Characterisation integrity is maintained by addressing particular objectives with specific information, information which may not aggregate with scaling up or down (e.g. the aggregate description of a complex of soils would not deliver a sensible 'regional' characterisation).

With spatially interpolated climate data, digital elevation models, and low resolution soils data in place, agro-ecosystem characterisation commences with simple models used to differentiate growing season and off season characteristics. These 'climate analog' models serve to describe the initial domain or target area for a range of priority setting steps, from sample design in diagnostic surveys and field trials to the identification of constraints and the number of people affected for institutional priority setting. Socioeconomic information—usually much more difficult to acquire—becomes critical in refining target domains as resource access, land tenure, cropping system, labour availability and so on dominate the land use system at higher resolutions.

Methodology for refining agro-climatic zones

The task of refining agro-climatic zones involved the following:

1. comparing approaches used by different institutions;
2. examining FAO and other livestock population and land-use data, these showing the outcome of a range of biophysical and socioeconomic factors influencing rural production systems;
3. examining climate systems in different parts of the world, and identifying the dominant soils, topography and vegetation;
4. using human population density rather than climate data as the major determinant of livestock population density; and
5. assessing how remote sensing data are being used to monitor vegetation, agro-climatic data and land use around the world.

Major data sources were areas of the different agro-ecological zones within countries, based on agro-ecosystems being subdivided into either 6 or 16 zones according to the estimated length of growing period. Total livestock weight, and livestock weights for individual species, were provided for each of the six zones by Dr William Wint (ERGO) and Dr Jan Slingenbergh (FAO). This information was critical to the success of this project.

ARC/INFO information on cattle distribution and AEZs for Africa was provided by Drs Phil Thornton and Russell Kruska of the International Livestock Research Institute (ILRI), Nairobi, Kenya, and mapped locally by Mr Shawn Laffan, Department of Geography, Australian National University. AEZs used at ILRI were based on length of growing period. The cattle density data provided a check on the model-based estimates.

A comparison of different approaches to defining agro-climatic zones

The number of bioclimatic, agro-climatic, ecoclimatic and biogeographic classifications is very large (Le Houérou et al. 1993). Some are of general use while others are focused towards particular regions.

In choosing which classifications to evaluate and compare, attention was directed to those that have been in or are coming into common use. It was considered appropriate to pay particular attention to the preferred systems used by the Food and Agriculture Organization of the United Nations (FAO), the Consultative Group for International Agricultural Research (CGIAR) including its Technical Advisory Committee (TAC), and the Environmental Research Group Oxford (ERGO) which has been undertaking GIS-based consultancy work for FAO. Other organisations approached included the International Livestock Research Institute (ILRI), CIAT, the Centre for Resource and Environmental Studies (CRES) at the Australian National University, and the CSIRO Division of Forestry and Forest Products.

Köppen climate classification system

Until recently the most widely used system of climate classification has been that of the German climatologist Köppen (1936)—many later classifications are variants of the 'Köppen (or Koeppen) system' (FAO). The classification is based on monthly rainfall and temperatures, including the following five inputs:

- Average temperature of the warmest month
- Average monthly temperature of the coldest month
- Average thermal amplitude between the coldest and warmest months
- Number of months with temperature exceeding 10°C
- Winter and summer rains.

The global map (Figure 1) shows the location and extent of the individual regions. This may also be viewed or downloaded from the FAO WWW site:

< http://www.fao.org/WAICENT/FAOINFO/sustdev/EIdirect/Climate/EIsp0054.htm >

In summary, the Köppen system is a static, empirically based descriptive system that was appropriate for the pre-computer era.

Agro-climatic determination of agro-ecological zones (FAO 1978–81)

Probably the first serious attempt to use computers to help integrate climate, soil and plant information in order to determine agro-ecological zones throughout the world was that reported by FAO (1978–81).

Agro-ecological zones were determined by overlaying climatic inventories for different sites on soils maps, soil characteristics in terms of slope, texture and phase being used to provide an assessment of land suitability for different crops. Crop yields were estimated on the basis of crop phenology and yield potential, with reduction factors in terms of crop yield loss due to water stress, pests, weeds and diseases, and constraints in terms of the 'workability' of the soil.

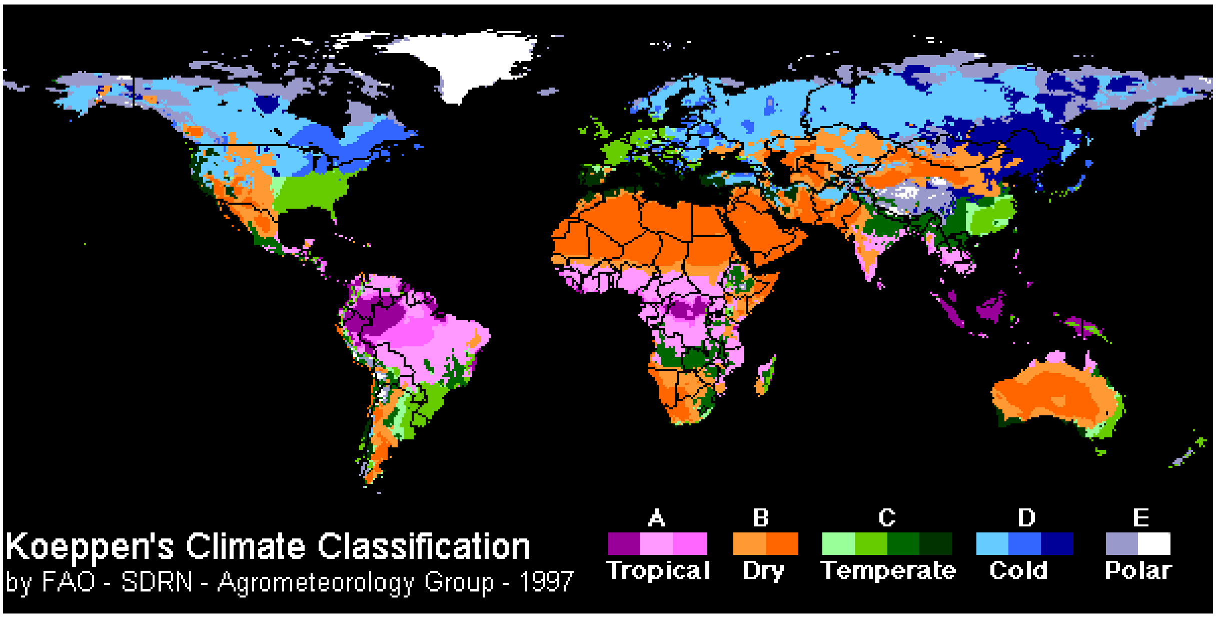

Figure 1. Köppen climate classification system

Climate data were used to estimate the length of the growing period (LGP), the time available when water and temperature permit growth, based on estimates of soil water balance. For a crop to be growing it was assumed that rainfall had to at least equal 50% of potential evapotranspiration (PET) for crop growth to be achieved, and that the mean daily temperature during the growing period had to exceed 5°C. The distinction was made between the humid and non-humid parts of the year, according to when precipitation exceeded PET. Subsequent developments of the LGP concept are reported on in subsequent sections of this report.

Agro-bioclimatic classification of Africa (Le Houérou et al. 1993)

Le Houérou et al. (1993) rejected the Köppen (1936) and similar classifications. This was because they were based on the 'empirical and somewhat obsolete, albeit fairly efficient, relationship between precipitation and temperature as a criterion of water stress/water availability and on mean annual temperature as a criterion of cold or heat stress, which lacks accuracy, sensitivity and efficiency'.

Le Houérou and colleagues tried to identify simple, rational and reliable parameters to represent water and temperature requirements and constraints. The discriminating values of these parameters were selected on the basis of agronomic and ecological criteria of the distribution of native vegetation, wildlife, crops and livestock, in an attempt to make this classification realistic and useable for the continent as a whole, with the aim of producing a framework that could be safely used by agronomists, land managers and planners.

Their classification combined a rather large number of climatic, biological, agronomic and geographic criteria. The actual number of combinations is about 200. Some of these occupy very large areas, such as the hyper-humid equatorial lowlands (some 9 million km^2), or the extra-tropical, winter rainfall, cold hyper-arid lands (some 5 million km^2), whereas other combinations, such as the afro-alpine and mediterraneo-alpine ecozones and the equatorial hyper-arid midland ecozone, cover very small areas

The large number of categories in this classification system is clearly impractical for use in the current ACIAR project aimed at estimating the benefits to agricultural research within and between regions and countries. Furthermore, to use this classification would clearly require a digitised dataset containing the boundaries and details of the wide range of agro-ecosystems. Also, to develop an equivalent system in say Asia or South America would require considerable resources.

Climate classification based on potential crop production (Hutchinson et al. 1992)

This classification of the world's climates is based on monthly climate data from around the world. In addition to the mean and seasonality attributes for rainfall and two attributes based on temperature extremes, the attributes are based on successive 13-week accumulated values of indices calculated by the GROWEST crop growth model (Fitzpatrick and Nix 1970; Nix 1981) for each week of the year for mesotherm plants (temperature optimum = 19ºC) and megatherms (temperature optimum = 28°C). Thirteen standard weeks corresponds to the growing period for the earliest-maturing grain crops grown in very favourable climates, and also provides a measure of the most important period for growth of later maturing and perennial crops. The broadest groupings were based on temperature except for the warm/hot and very dry (desert) climates. This parallels the principal Köppen divisions. The next divisions were principally based on moisture, giving rise to 10 broad groups.

This method was used to classify climates in Africa (Hutchinson et al. 1996). It has since been applied in mainland East Asia by Zuo (1996)and Zuo et al. (1996a,b) to produce a classification and maps of agro-climatic zones throughout the region (Figure 2). A similar classification has been done for Sri Lanka (Kannangara 1998). Zone definition is probably the best of all the available systems. However, no information has been published on area of these zones. One would also have to overlay spatial estimates of livestock distribution on these zones within a GIS to more accurately fulfil the objectives of this study.

Prerequisites of the system include a digital elevation model (DEM) for the area in question, and an adequate density of climate stations. Also needed are software and staff familiar with the models and the Unix platforms no which they run.

Until recently a great deal of digitisation has been required to construct a DEM. However, the American Defence Mapping Agency has recently published a CD-ROM database of the Digital Chart of the World (DCW). This contains all of the information on maps of Operational Navigation Charts (ONC) series throughout the world at a scale of 1:1 million. Digital terrain data can be extracted from this database with ARC/INFO programs.

Climatic mapping programs, such as WORLD (Booth 1990) and GREEN (Hong et al. 1996), have been developed by CSIRO and its collaborators with support from ACIAR and AusAID for several different countries including Australia, Indonesia, Laos, Vietnam, the Philippines, Thailand and Zimbabwe, as well as for major regions such as Africa and Latin America. Emphasis has been on determining appropriate provenances of Australian tree species.

Agro-climatic classification for Mainland East Asia (Zuo 1996; Zuo et al. 1996a,b)

Mainland East Asia, as classified by Zuo (1996), includes China, Vietnam, Laos, Thailand, Kampuchea and Peninsular Malaysia. These are some of the most densely populated areas in the world. With more than one fifth of the world's population living on less than one tenth of the world's land, in areas mostly covered by high mountains, plateaux and deserts, the resource deficiencies are obvious and very serious.

A GIS-based agro-climatic classification was developed for mainland East Asia in this study, based on regular grid data sets at a resolution of 1/20th degree and agro-climatic indices simulated by GROWEST a general plant growth model (Nix 1981). The climatic data sets were developed using climatic surfaces interpolated by ANUSPLIN (Hutchinson 1984, 1991) and a digital elevation model (DEM) calculated using ANUDEM (Hutchinson 1989a,b). The classification attributes were all those simulated using the GROWEST model at a weekly step for each of the grid cells across mainland East Asia. Thirty-nine GROWEST attributes were selected as classificatory variables for each grid cell. Finally 14 agro-climatic zones were developed using PATN, a numerical taxonomy package (Belbin 1987). Each agro-climatic zone represents a particular cropping system or vegetation pattern (Figure 2).

Each agro-climatic zone represents a typical cropping system or vegetation pattern.

Agro-climatic Zone I– the high cold plateau climate of west China;

Agro-climatic Zone II– the dry and hot desert areas in northwest China;

Agro-climatic Zone III– the grazing grasslands of north and west China;

Agro-climatic Zone IV– the single temperate crop area in northeast China;

Agro-climatic Zone V– wheat-dominated double cropping system of north China plain;

Agro-climatic Zone VI– rice-dominated double cropping system in the south of Yangtze;

Agro-climatic Zone VII– the sub-alpine forest area of southern China;

Agro-climatic Zone VIII– the warm highlands of southwest China;

Agro-climatic Zone IX– mountain tops of humid tropical areas of China, Southeast Asia;

Agro-climatic Zone X– the humid tropical highlands;

Agro-climatic Zone XI– triple cropping systems—southern China, northern Vietnam;

Agro-climatic Zone XII– humid tropical lowlands of Southeast Asia;

Agro-climatic Zone XIII– wet tropical highlands of equatorial area; and

Agro-climatic Zone XIV– wet tropical lowlands of equatorial areas.

Although this classification agrees with the main features of previous agro-climatic classifications, differences are evident because of the different philosophy and methodology adopted in this study. The most significant difference occurs in the areas between the Huai River and the Yangtze River. Analyses of this study indicated that the climatic environment of the area is more closely related to the northern adjacent areas than to its southern neighbouring areas as noted in previous classifications (State Meteorological Administration of China 1978; Li 1993). More detail is provided by White (1998).

Revisions to the length-of-growing-period concept (Fischer et al. 1995)

The length-of-growing-period (LGP) has been defined as the period of the year in which agricultural production is possible from the viewpoint of moisture availability and suitable temperatures. The concept has been applied in many continental, regional and country-level studies as the basis for climatic inventories that were used, in combination with soils, terrain and crop information, to assess agricultural potentialities and constraints (e.g. FAO 1978–81; Nachtergaele and Bruggeman 1986). Most of these studies were located in tropical and subtropical areas where temperature constraints were, in general, of less importance than moisture availability in the position and properties of agricultural seasons. Given that the concept was originally developed as a regional water balance approach (Cochemé and Franquin 1967) for tropical areas it is not surprising that the application of the LGP-concept was most successful and extensive in these areas.

In temperate and cold areas temperature becomes more critical in determining the growing season. In addition, variations of day length, negligible at lower latitudes, become sufficiently important at higher latitudes to influence the agricultural productivity of particular seasons. At the same time, moisture constraints remain important determinants.

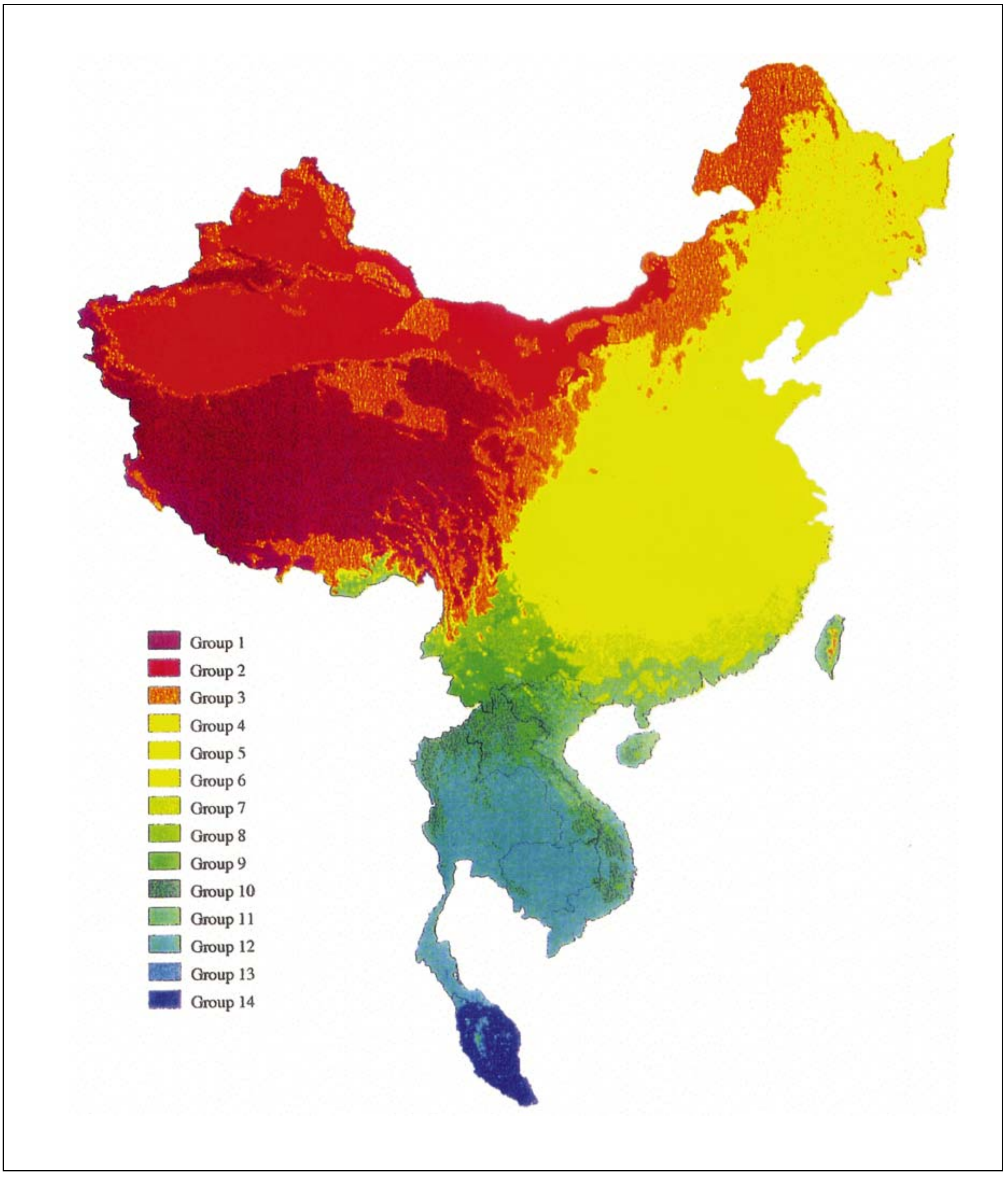

Figure 2. Agro-climatic zones of mainland East Asia (Zuo 1996)

The original LGP approach

In the original length-of-growing-period approach, the operational definition of growing period is (FAO, (1978-81):

> the period (in days) during the year when precipitation (P) exceeds half the potential evapotranspiration (PET) plus a period required to evapotranspire up to 100 mm of water from excess precipitation assumed stored in the soil profile.

The rationale for these operational limits is that they represent empirically validated thresholds for the reliable start and end of the agronomically relevant growing period, which take due account of early, unreliable rains and stored soil moisture, respectively. Different growing periods are recognised according to the portion of the year that rainfall exceeds potential evapotranspiration (humid versus dry) and average mean temperature exceeds 5°C.

To assess the quality of a growing period various types of growing periods were distinguished:

(i) A *normal growing period* contains a subperiod in which rainfall exceeds potential evapotranspiration (the 'humid period'). The occurrence of a humid period within the growing period indicates that (a) the full evapotranspiration demands of rainfed upland crops at maximum canopy cover can be met, and (b) the moisture deficit of the soil is replenished.

(ii) An *intermediate growing period* is defined as a growing period that does not contain a humid subperiod. Within the intermediate growing period monthly rainfall is always below full but above half of monthly potential evapotranspiration. Under those conditions water availability does not meet the full water requirements of major food crops at maximum canopy cover.

(iii) An *all-year-round humid growing period* is a growing period in which the average monthly rainfall exceeds for every month of the year the average potential evapotranspiration.

(iv) An *all-year-round dry period* is characterised by an average monthly rainfall that does not exceed half the potential evapotranspiration for any month of the year.

It is clear that all these definitions and types are based on the moisture characteristics of growing periods. The temperature adequacy of a growing period is implied from the condition that no month can be part of a growing period unless its average mean temperature exceeds 5°C.

Temperature and moisture thresholds

A new approach to LGP-modelling proposed by Fischer et al. (1995) better integrates temperature- and moisture-related constraints, and makes the concept more suitable for a global climatic resources inventory. The temperature threshold for a growing period remains, as in the standard LGP approach, a mean temperature of 5°C, but the temperature and moisture-delimited growing period is defined through both water balance and temperature thresholds.

Water balance

A simple water balance approach was used in the original LGP model. The new approach treats moisture depletion rates as a function of moisture availability. Allowance is also made for the fact that in temperate and cold areas precipitation can be as snow. A third modification of the water balance relates to dormancy periods with temperatures above 0°C but below 5°C.