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SUMMARY OF DOCTORAL THESIS

Name: Rui Li

Title: Agricultural drought management in Northeast China and Inner Mongolia
（中国東北部と内モンゴルにおける農業干ばつの管理）

Droughts are the world's costliest weather-related natural hazards, causing an average 6–8 billion USD in global losses annually, and collectively affecting more people than any other type of natural disaster (Wilhite, 2000). Agricultural drought is important because it directly influences food security and therefore poses a grave threat to regional economies and society. In this thesis, agricultural drought is defined as "a period of insufficient moisture to support normal crop production". Three provinces in northeastern China (Heilongjiang, Jilin, and Liaoning) and the Inner Mongolia Autonomous Region were chosen as the study area. Most regions in the mid-temperate climate zone have effective accumulated temperature ≥10 °C 1600–3400 °C and crops can be only harvested once per year. These important regions rely on rainfed cultivation. Owing to a lack of irrigation systems, there is greater drought or flood risk in the rainfed region of the study area.

Agricultural drought is heavily influenced by local factors (e.g., irrigation) and occurs under a certain climate background. Selection of the county is appropriate because it is the basic statistical area for agricultural production in China, and it affects regional food security. Combined with remote sensing and crop model new technologies, this thesis develops multiple methods to understand the relationships of various components with the drought system. I studied agricultural drought management following the logic of drought occurrence monitoring, drought severity assessment, and drought mitigation practice assessment.

The first question regards the determination of agricultural drought occurrence (Chapter 3). A combination of various drought indices has been challenging because there has been a lack of systematic methods for their combination, use, and evaluation. I developed a new decadal time scale (~10 days) conceptual model and evaluated the drought process in a typical rainfed agricultural region, Hailar County in Inner Mongolia. To quantify drought, I used the precipitation-based Standardized Precipitation Index (SPI) and soil moisture-based Crop Moisture Index (CMI), as well as the Normalized Difference Vegetation Index (NDVI). Correlation analysis was done to examine relationships between drought indices during the growing season (May–September) and final yield, using data collected from 2000 to 2010. The results show that:

(1) Yield had positive relationships with the CMI from mid-June to mid-July and with the NDVI anomaly throughout July, but no relationship with the SPI

(2) The relationship between the two drought indices shows that the NDVI anomaly responded to CMI with a lag of one decade, particularly in July.

(3) To examine the feasibility of using these indices for monitoring the drought process at decadal time scale, a detailed drought assessment was carried out for selected drought years. The results confirm that the soil moisture-based and vegetation indices in the late vegetative through early reproductive growth stages can be used to detect agricultural drought in the study area. Therefore, the framework of my conceptual model can be used to support drought monitoring in the rainfed agricultural regions.

The second question regards agricultural drought severity assessment by a crop model (Chapter 4). Conventional assessment methods make it difficult to clarify drought effects on crop yield. Crop models are a good choice for investigating yield, because they can simulate underlying physiological processes of crop growth and their change in response to environmental stress. Drought affects

nearly all climatic regions. To accurately evaluate regional drought intensity, I constructed an assessment framework with three components, namely, crop model calibration and validation, drought index calculation, and index assessment (standard period setting, mean value and agreement assessments with agricultural drought records). I built the assessment based on the Environmental Policy Integrated Climate (EPIC) crop model and tested comparison results by trend analysis. The results show that:

(1) The EPIC model simulated time series of county-level yields well in four spring wheat counties (*RMSE* = 0.556) and five maize counties (*RMSE* = 1.6) in Northeast China and Inner Mongolia.

(2) I calculated a major crop-specific index, i.e. yield reduction caused by water stress (WSYR) within the EPIC crop model, by relating potential and rainfed yields. Using 26 county-level agricultural drought cases, I compared WSYR with two meteorological drought indices, precipitation (P) and aridity index (AI). The results showed that WSYR had better agreement (85%) than either P (65%) or AI (68%).

(3) The temporal trend of the indices over the period 1962–2010 was tested using three approaches. The result from WSYR revealed a significant increase in agricultural drought in drought-prone counties, which was not indicated by P or AI. The increase of average decadal frequency from WSYR of drought years from the 1990s to 2000s was greater than those from P and AI. This study revealed the usefulness of the framework for drought index assessment and possible drought cases for drought classification.

The third question regards the comparison of agricultural drought practices with recovery yield under various drought severities (Chapter 5). Comparing the effects of various agricultural practices on crop yield provides important information related to strategies for mitigating drought. However, quantitative assessment of agricultural practices using common experimental methods requires considerable time and money. I simulated the effects of three practices (supplementary irrigation [SI], sowing date, and crop variety) on wheat and maize yield for dry, normal and wet years in the northeast and Inner Mongolia, based on the EPIC crop model. The results show that:

(1) A single 50-mm SI event was more effective in dry years than wet years for increasing crop yield

(2) A change in sowing date was less effective for increasing yield in dry years than in normal and wet years

(3) For traditional wheat-growing counties, planting the long growing season variety “Yongliang 4” can increase yield more than planting the short growing season variety. For traditional maize-growing counties, the short growing season variety “Dadi” gave better yields than “Zhedan37”. However, none of the tested varieties showed significant yield differences based on variety in dry years. Changes in sowing date and variety altered yield less than a single 50-mm SI event, especially in dry years. This suggests that precipitation expressed as dry/wet years should be considered when growing crops.

In summary, agricultural drought refers to water balance within the complex weather-soil-crop-society system in a given region. The agricultural drought management framework considers agricultural drought demands of these system components at different levels. The new drought monitoring framework in Chapter 3 can integrate timely information for agricultural drought early warning for meteorological, agricultural and water resource government departments. The drought severity assessment method in Chapter 4 can be used to identify regional drought years for long-term drought planning of civil departments. The comparison of practices in Chapter 5 can be used to select effective drought mitigation measures from governmental to farmer levels. This suggests consideration of the aforementioned three questions as a whole for drought management. Northeast China and Inner Mongolia have widespread water resource shortages, and meteorological drought became serious after 2000. Future agricultural drought studies should consider the regional water supply capacity and its relationship with socioeconomic sustainability.