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JP1.23 DEVELOPMENT OF NEW CLIMATE AND PLANT ADAPTATION MAPS FOR CHINA

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1. INTRODUCTION

With the rapid and continuous economic growth in China, market demands for improved forage-livestock systems, urban beautification, and improved environmental protection - including soil conservation and erosion control - have greatly expanded in the last decade. Specifically, the increased demands for animal products, beautiful turf for roadsides, lawns, and golf courses, and reduced soil erosion in the Yellow (Huang) and Yangtze (Chang Jiang) River watersheds have contributed to increased market demands for high quality grass seeds.

In 1992 the Oregon Seed Council, a consortium of over 50 grass seed companies, partnered with Oregon State University to initiate a USDA Market Access Program (MAP) project for developing the China market for Oregon-grown grass seed. Other cooperators include the Oregon Department of Agriculture, the Chinese Academy of Agricultural Sciences, the Chinese National Meteorological Center, China Agricultural University, Nanjing Agricultural University, Wuhan Technical University of Surveying and Mapping, Jiangsu Academy of Agricultural Sciences, the YiChang Municipality, and the Three Gorges Development Corporation.

Effective marketing of our high quality US-grown seeds requires that we be able to identify all of the areas suitable for using these grasses. Until now that has been impossible on a wide scale. The USDA MAP project has conducted field-based trials in China. However, these have been few in number and located mostly in the populated eastern lowlands, because of the difficulty in finding suitable cooperators, establishing and maintaining test plots, and collecting accurate data on species performance over a period of years.

Fortunately, GIS technology, combined with climate mapping expertise, makes it possible to spatially verify and extrapolate the results of these field trials to all of China. Climate mapping, in combination with spatial soils data and climatic tolerances of grass species, can be used to produce very detailed maps of species adaptation that can be used to accurately identify suitable growing areas for effective marketing.

The objectives of the work described here are to:

- Obtain and quality-check observed climate data from Chinese authorities.
- Prepare detailed draft maps of mean monthly minimum/maximum temperature and precipitation for the People's Republic of China.
- Use the climate maps and expert estimates of species climatic tolerances to prepare adaptation maps for several important Oregon-grown grasses.
- Subject draft climate and adaptation maps to peer review by Chinese climatologists, obtain supplementary climate data, and revise maps as necessary.

This paper describes the methods used to accomplish the first three objectives for eastern China: obtain climate data; create first-draft climate maps; and develop grass adaptation maps.

2. METHODS

2.1 *Collection and quality control of observational data*

In 1998, contact was established with the Chinese Climate Data Center (CDC), which is a part of the Chinese National Meteorological Center in Beijing. The CDC is responsible for the collection, archive, and dissemination of climate data for the national climatic network,

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which consists of approximately 700 stations. In exchange for seminars at CDC by Daly and Hannaway, and a three-week training course for two of their scientists at Spatial Climate Analysis Service offices at Oregon State University, the CDC provided us with mean monthly minimum and maximum temperature and precipitation for 679 stations. These stations have the longest and most complete records available.

Methods used by the CDC to quality-control the station data were unknown. Therefore, we had to assume that errors existed in the data. Two types of checks were made: metadata and monthly data. The location and elevation metadata were checked by plotting each station on a 30-second digital elevation model (DEM) from the ETOPO-30 global elevation dataset. If the station elevation differed substantially from the elevation of DEM pixels in the immediate vicinity, it was assumed that either the DEM was incorrect or of insufficient resolution, or the reported station location or elevation were faulty. Many DEM-station elevation discrepancies were found. In some regions, such as the deeply dissected terrain of the southeastern Tibetan Plateau, the limited precision of the station location (nearest 1 arc-minute) and the inability of the 30-sec DEM to resolve locations at the bottoms of deep canyons were the culprits. An atlas was used in attempts to locate the place names and corroborate station locations. Stations that could not be found on an atlas and had clearly unreasonable elevations were brought to the attention of CDC personnel and attempts made to resolve or correct the discrepancies.

As an additional check, the station metadata were compared to those for the same stations in the Global Historical Climate Network, prepared and maintained by the US National Climatic Data Center (NCDC). After lengthy discussions with NCDC, the most common source of metadata discrepancies was found to be station moves, which caused the GHCN metadata, recorded some time in the past, to differ from the Chinese metadata, which reflects only the current location of the station. No station histories were available from CDC from which to track station moves over time.

The mean monthly station data were checked for reasonableness by applying ASSAY, a version of PRISM (see below) that performs jackknife cross-validation on each station in the dataset. Stations with large observation-prediction errors were flagged. The PRISM Graphical User Interface was used to display climate-elevation scatterplots in the vicinity of the questionable stations to determine if the station “fit in” with the others, or was an obvious outlier. Outliers were removed from the dataset. In general, few monthly outliers were found, giving us confidence that the Chinese climate data were of good quality.

2.2 *Preparation of Climate Maps*

Spatial modeling of the climate data was performed at 2.5-minute (~ 4-km) resolution. A 2.5-minute DEM was derived from the ETOPO-30 DEM series. GIS was used to prepare supplementary grids used in the interpolation. These included a coastal proximity grid, estimates of wintertime temperature inversion heights, and an effective terrain grid.

The PRISM (Parameter-elevation Regressions on Independent Slopes Model) knowledge-based system (Daly et al., 1992, 1994, 1997, in review, Daly and Johnson 1999) was used to grid precipitation and minimum and maximum temperature over China. PRISM technology is being used in several climatic mapping efforts in the US, including a 103-year climate time series (Daly et al., 1999), a major precipitation mapping effort for NRCS (USDA-NRCS, 1998), an updated climate atlas for the NCDC, and others (e.g., Johnson et al., in press). PRISM uses point data, a DEM, and other spatial data sets to generate estimates of climatic elements that are gridded and GIS-compatible.

The strong variation of climate with elevation is the main premise underlying the model formulation. PRISM adopts the assumption that for a localized region, elevation is the most important factor in the distribution of temperature and precipitation. Observations from many parts of the world show the altitudinal variations of temperature and precipitation to approximate a linear form. Available station data often do not span the complete range of elevations in an area, especially in mountainous regions. Therefore, vertical extrapolation is required. This is accomplished in PRISM at each DEM grid cell (termed the target grid cell) through a moving-window simple linear climate-elevation regression. This regression function serves as the main predictive equation in the model.

Upon entering the regression function, each station is assigned a weight that is based on several factors. The combined weight W of a station is a function of the following:

$$W = f\{ W_d, W_z, W_c, W_l, W_f, W_p, W_e \}$$

where W_d, W_z, W_c, W_l, W_f, W_p and W_e are the distance, elevation, cluster, vertical layer, topographic facet, coastal proximity, and effective terrain weights, respectively. A station is down-weighted when it is relatively distant or at a much different elevation than the target grid cell, or when it is clustered with other stations (which leads to over-representation). Vertical layer weighting is used when the atmosphere is layered, such as in temperature inversions or low-level moisture conditions. Topographic facet weighting is used to model rain shadows and other abrupt climatic shifts caused by topographic barriers. Coastal proximity weighting allows the reproduction of sharply-defined coastal strips. Effective terrain weighting accounts for the varying ability of different terrain features to induce orographic precipitation.

PRISM was parameterized to produce to the most physically realistic maps by starting with the settings that gave the lowest cross-validation error in ASSAY, then modifying these settings as experience with China's complex climate patterns increased over time. Experienced was gained by consulting publications on Chinese climate, using the station data themselves (via the PRISM graphical user interface), and by using knowledge from other regions, as applicable. General expectations of climatic patterns in China were formed, and served as a guide for the evaluation of the PRISM modeling runs. Peer review of the draft maps by Chinese climatologists will provide another much needed level of evaluation.

2.3 *Preparation of Species Adaptation Maps*

First drafts of species adaptation maps were prepared for three important Oregon-grown cool-season grasses: tall fescue, orchardgrass, and perennial ryegrass. These first maps accounted only for climatic tolerances and did not include soils considerations. The climatic constraints were also simple as a starting point. Each species was assigned approximate values of mean January minimum temperature, mean July maximum temperature, and mean annual precipitation that corresponded with well-adapted, moderately adapted, marginally adapted, and not adapted conditions, respectively. GIS was used to apply these constraints to the PRISM climate grids to produce maps showing climatic adaptation zones for each species.

3. RESULTS

Maps of all of mainland China and Taiwan are being produced, but only the eastern half of mainland China were available at the time of this writing. Figure 1 shows mean annual precipitation. Mean July and mean January precipitation are shown on the poster only, but are discussed here. Spatial patterns in precipitation are related primarily to elevation and exposure to the southeast monsoon. On an annual basis, the southeastern quarter of the country is the wettest, with amounts in coastal areas and in the mountains exceeding 2000 mm per year. Precipitation gradually decreases as one moves northward and westward. Parts of Inner Mongolia, shielded by several mountain ranges from the East China Sea, receives less than 100 m per year. Mountainous terrain produces local maxima up to about 1000-1500 m in most areas, except the Tibetan Plateau, where precipitation maxima are at much higher elevations.

Summer is the wet season and winter is the dry season across eastern China. Patterns of July precipitation are similar to those of annual precipitation, with some notable differences. High mountains on the island of Taiwan produces a distinct rain shadow on the mainland coast to the northwest, in Fujian Province. The dry zone extends west of this area and well inland into Hunan Province. Further north, there is a precipitation maximum on the coast in

Shaddong and Jiansu Provinces that is not present in the annual map, reflecting a zone of moisture transport during mid-summer. Eastern China is very dry in January, when the region is dominated by cold, dry air from the Asian interior. Most areas receive less than 25 mm, and the maximum is less than 125 mm in the southeastern mountains.

July and January mean daily maximum temperatures are shown on the poster only, but are discussed here. July temperature patterns are dominated by elevation, and show a very strong lapse rate. The coolest temperatures are found at the highest elevations of the eastern Tibetan Plateau, where daily maxima are only 12-16^{o}C. In general, the coastal strip is cooler than adjacent inland areas. This is most easily seen where Shandong Province extends eastward into the Yellow Sea in the vicinity of Qingdao. Maximum July daily temperatures are highest in the inland areas of southeastern China, including the city of Nanchang, Jiangxi Province, known as one of the three "stoves" of China. Here, July temperatures top out at 34-36^{o}C with high humidity. Nearby mountains provide milder summertime temperatures of 24-29^{o}C.

January maximum daily temperature is dominated by latitude, or more specifically, exposure to the air mass associated with the Siberian high pressure center. Maximum daily temperatures in extreme northern China are -20^{o}C and below, which are colder than those found at the highest elevations of the eastern Tibetan Plateau (-5 to -10^{o}C). On the eastern lowlands, temperatures rise steadily as one moves southward, away from the Siberian influence. Hainan Island far to the south and separated from the mainland by water, retains comfortable maximum temperatures of 19-22^{o}C, even in January. The effect of elevation is not as pronounced in winter, due to the tendency of low-level temperature inversions to form in the dry, clear air.

An example of an early draft of a species adaptation map for tall fescue is shown in Figure 2. The patterns of adaptation are caused by different factors in different locations. Low winter temperatures limit the northeastern range of tall fescue, while low precipitation limits is northwestern range. Low summer temperatures limit the range on the Tibetan Plateau. In the southeast interior, it is high summer temperatures that limit the range. The well-adapted zone is extensive; optimum temperatures and rainfall for tall fescue exist across the central lowlands, then extend southwestward, following mild temperatures at moderate elevations all the way to the southern border. In addition, many mountainous and coastal areas in southeastern China show good adaptation, because of mild summer temperatures at higher elevations.

4. CONCLUSIONS

With the rapid and continuous economic growth in China, market demands for grass seed for forage-livestock systems, urban beautification, and improved environmental protection have greatly expanded in the last decade. In 1992 the Oregon Seed Council partnered with Oregon State University to initiate a USDA Market Access Program project for developing the China market for Oregon-grown grass seed. Effective marketing of our high quality US-grown seeds requires that we be able to identify all of the areas suitable for using these grasses. Until now that has been impossible on a wide scale. Fortunately, GIS technology, combined with climate mapping expertise, spatial soils data and climatic tolerances of grass species, can be used to produce very detailed maps of species adaptation that can be used to accurately identify suitable growing areas for effective marketing.

The objectives of the work described here were to: (1) obtain and quality-check observed climate data from Chinese authorities; (2) prepare detailed draft maps of mean monthly minimum/maximum temperature and precipitation; (3) use the climate maps and expert estimates of species climatic tolerances to prepare adaptation maps for several important Oregon-grown grasses; and (4) subject draft climate and adaptation maps to peer review by Chinese scientists, obtain supplementary climate data, and revise maps as necessary. This paper described the methods used to accomplish the first three objectives for eastern China.

Further work in climate mapping will involve expanding the climate mapping to all of China, attempting to obtain more climate data, and subject the maps to peer review. Further activities in species adaptation mapping include using expert opinion to better quantify the climatic tolerances of grass species. The range and types of adaptation maps will also be expanded to include soils tolerances, and management prescriptions such as irrigation, fertilization, and intercropping with other crop species at specified times of the year.

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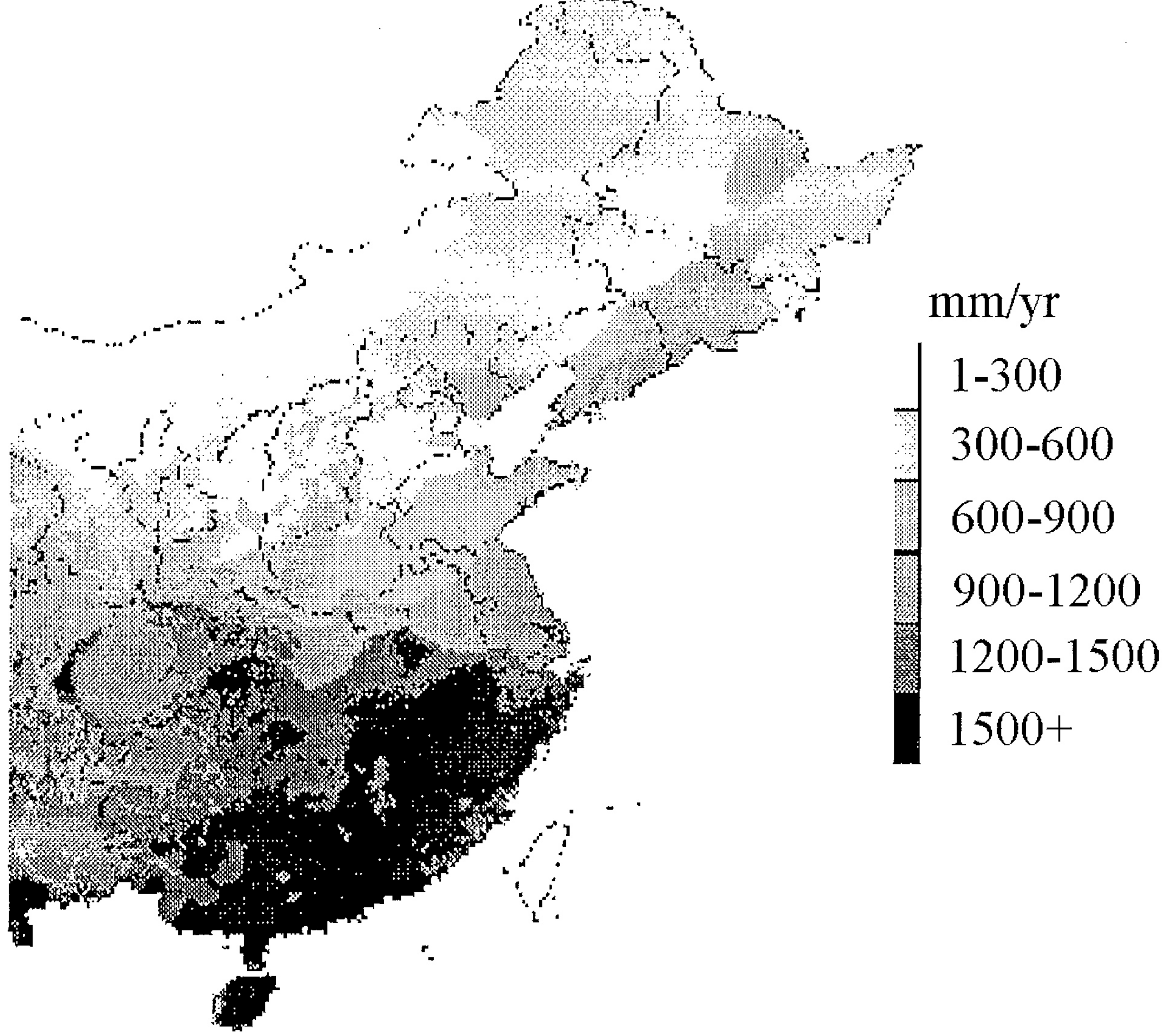

Figure 1. PRISM 1961-90 mean annual precipitation for eastern China.

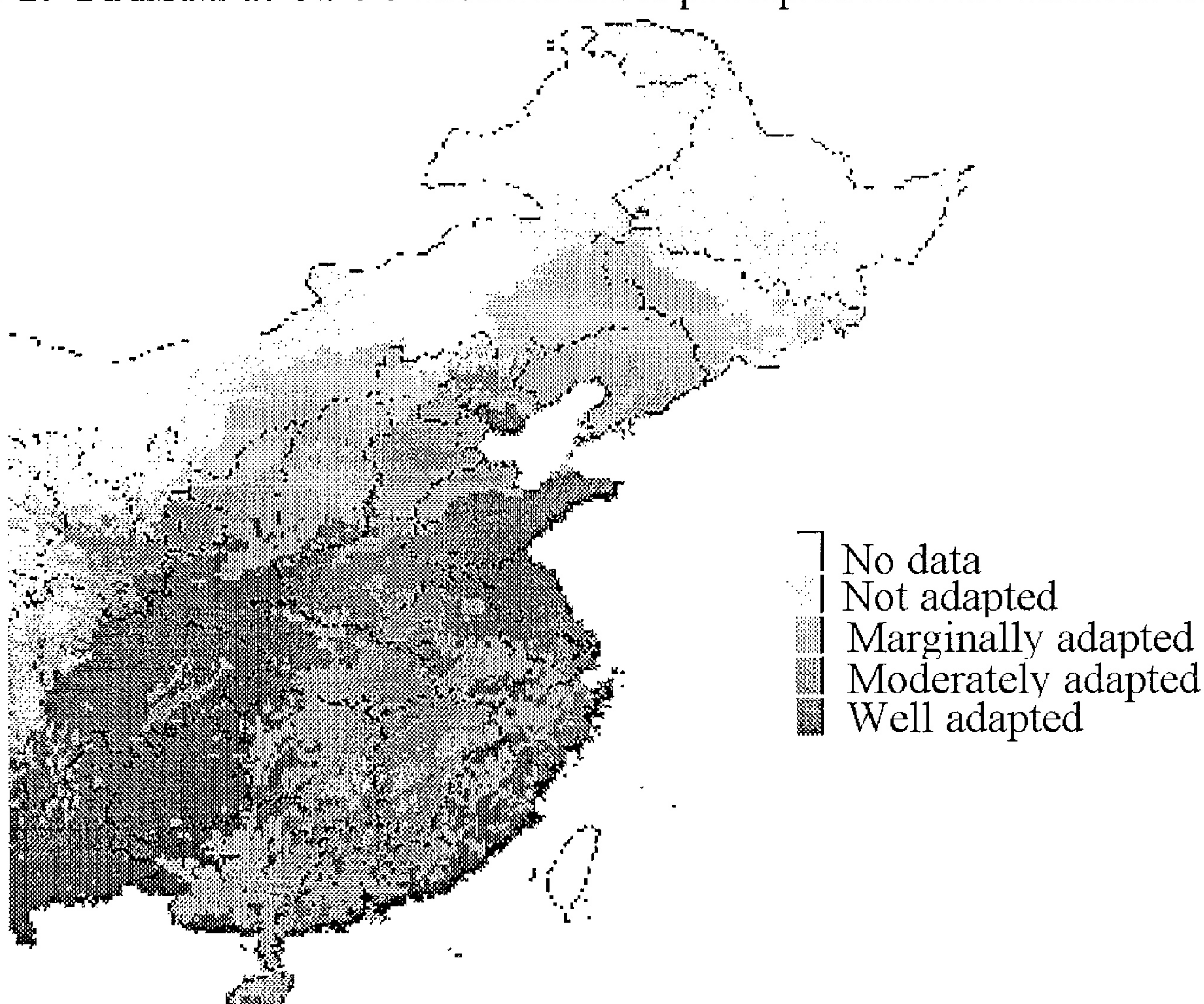

Figure 2. Draft species adaptation map for an Oregon cool-season grass.