Characterization of maize environments using crop simulation and GIS

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Abstract

The effectiveness of a product evaluation system largely depends on the genetic correlation between multi-environment trials (MET) and the target population of environments (TPE). Previous characterizations of maize environments based on climate and soil did not quantify their impact on the genetic correlations among environments. Consequently, plant breeders have favoured characterizations based on the similarity of product discrimination in trials. However, these efforts frequently fail to provide adequate assessments of the TPE, due to the cost of collecting long-term performance data. To describe the TPE, we performed crop simulations for each US corn-belt township for the 1952-2002 period, using standard CERES-Maize model inputs. To characterize METs, input data were collected at or near the trial sites. Grain yield and biotic stress data for model validation were collected from 18 hybrids grown in replicated trials in 200 environments in 2000-2002. Based on prevailing conditions during key growth stages, and observed patterns of genotype-by-environment interactions (GEI), six major environment classes (EC) were identified. The relative frequency of each EC varied greatly from year to year. Stratification of grain yield by EC accounted for around 39% of the hybrid-by-environment variance component. Our environmental characterization system provided a useful description of both the TPE and MET. Knowledge of the spatial (locations) and temporal (years) distributions of ECs that influence GEI can be used to improve product performance predictability in the US corn-belt TPE.

Media summary

Characterization of maize production environments enabled investigation of repeatable causes of genotype by environment interactions to improve the predictability of product performance.

Key Words

CERES-Maize, genotype by environment interaction, performance predictability.

Introduction

The effectiveness of a product evaluation system largely depends on the genetic correlation between multi-environment trials (MET) and the target population of environments (TPE, Comstock, 1977). Previous characterizations of maize environments relied mainly on climatic and soil data (e.g. Pollak and Corbett, 1993; Runge, 1968). While useful to describe environmental variables affecting crop productivity, these efforts did not quantify the impact of these variables on the genetic correlations among testing sites. Consequently, plant breeders have more extensively used characterizations of environments based on similarity of product discrimination in product evaluation trials (e.g. Cooper *et al*, 1993). However, these efforts frequently fail to provide a long-term assessment of the TPE, mainly due to the cost and impracticality of collecting empirical performance data for long-term studies. Using a crop simulation model, Chapman *et al* (2000) integrated soils and long-term weather data to classify highly variable sorghum environments in Australia. For a subset of six testing locations, they found that three drought stress environment types had a consistent relationship with simulated yield. The purpose of this study was to investigate the applicability of this approach to the characterization of the milder US maize environments.

Methods

To describe the TPE, we performed crop simulations for each township in the US corn-belt for the 1952-2002 period, using a modified CERES-Maize model and standard model inputs (Ritchie, 1986). Genetic coefficients were developed for all Pioneer commercial hybrids. For this study, average genetic coefficients for hybrids of Commercial Relative Maturity (CRM) 113 were used, and the resulting environmental characterizations assumed that CRM maize was grown across the entire maize region. Precipitation and temperature data from all reporting weather stations for the period of interest were provided by NOAA. Solar radiation was estimated using Bristow and Campbell's (1984) procedure. Data were pre-processed using GIS (MapInfo Co, 1999) so that for each township, model inputs were identified and geo-referenced. METs were characterized using a similar procedure, except that model input data were collected at or near the trial sites, using Doppler radar precipitation data at 2x2 km resolution, and solar radiation estimates based on satellite images. Data on biotic stresses were collected at these sites to supplement the simulated data. Experimental data for validation were collected from 17 maize hybrids planted in 2-row, five m rows in a Randomized Complete Block (RCB) design with 2-4 replicates per site in 57, 66, and 77 sites, respectively, in 2000, 2001, and 2002. Standard data collection protocols used for product advancement trials were applied to this experiment, and grain yield data and corn borer infestation scores were used for our analyses. Statistical analysis was performed using ASREML (Gilmour *et al*, 2002) for the computation of variance components, and Pioneer proprietary software for the generation of GGE biplots (Cooper and DeLacy, 1994; Yan and Kang, 2003)

Additionally, our model simulated four levels of water availability for each of four developmental stages at each 2003 research location in North America.

Results

Based on the prevailing conditions during key simulated growth stages and known patterns of hybrid by environment interaction, environments were characterized as temperate, temperate humid, temperate dry, high latitude, and subtropical. For each of the five environments, modifying biotic conditions were evaluated, and corn borer was identified as having a significant effect. Temperate environments historically occurred in over half of the total maize hectares (Fig 1), but relative frequencies of each environment varied greatly from year to year (Figs 1 and 2). Additional variables can be added to our basic environmental characterization as needed. Fig 3 displays both the regional and trial-site distribution of water stress in North America during the 2003 growing season.

Stratification of grain yield data by environment class accounted for 39% of the hybrid by location variance component measured in 2001-2002. A similar stratification by drought stress did not explain a significant amount of interaction in this dataset.

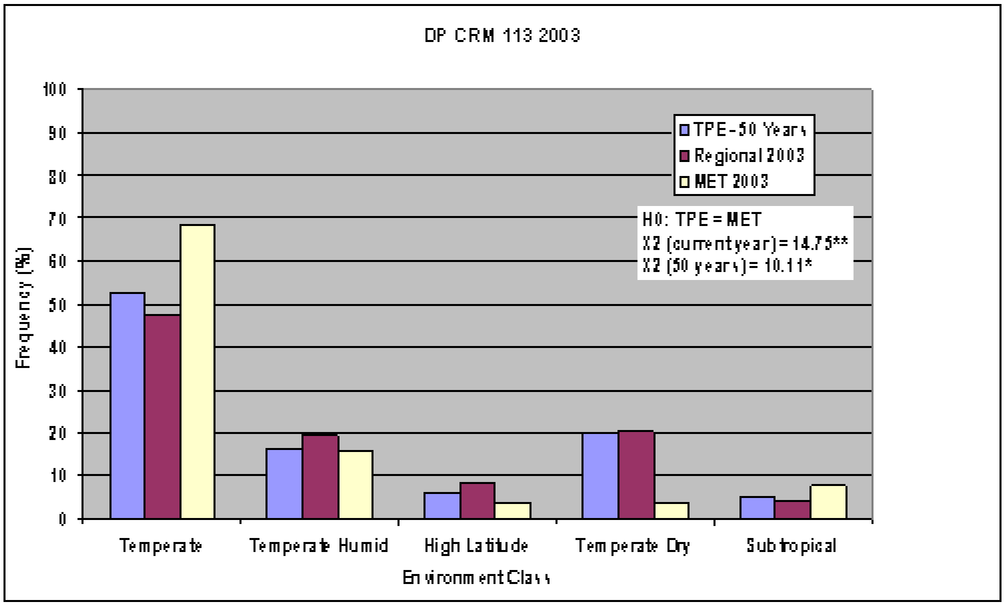

Figure 1. Frequency of maize environments in the USA for 1952-2002, compared to frequencies in 2003.

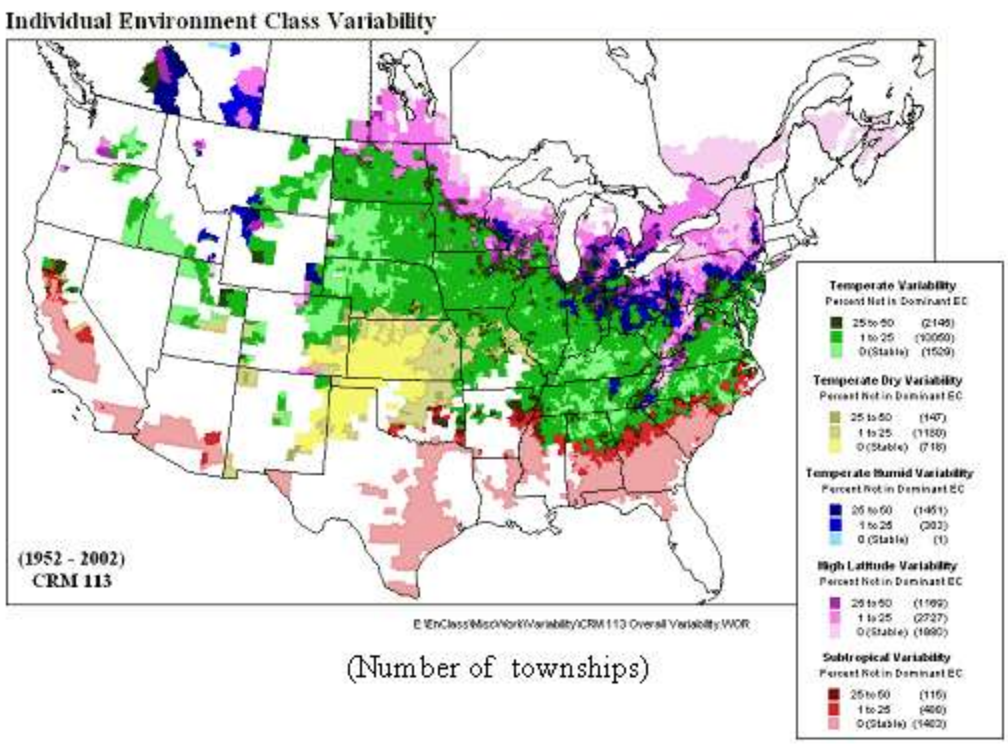

Figure 2. Variability of dominant maize environments in the USA as indicated by the percentage of occasions that a location was not in the dominant environment class for that location.

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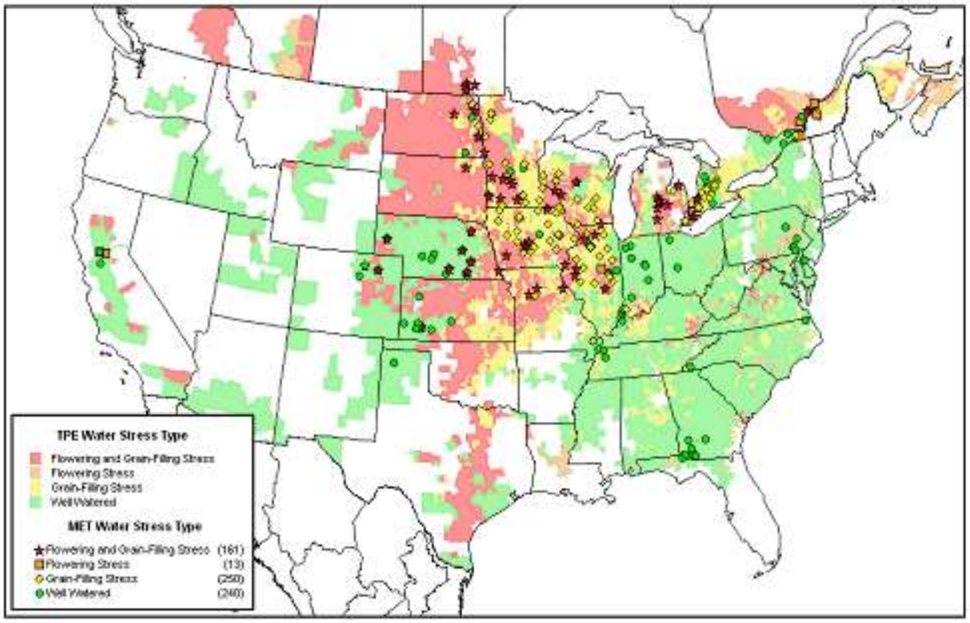

Figure 3. Water Availability for Maize in North America and in Pioneer Research Sites in 2003

Conclusion

Our environmental characterization system provided a useful description of both the TPE and MET environments. It explained a significant portion of the repeatable hybrid by environment interaction for grain yield observed in field trials over a three-year period. Thus, it could help improve product performance predictability.

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