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Application note

Simulation of corn yields in the Upper Great Lakes Region of the US using a modeling framework

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ABSTRACT

We examined the utility of a site-based simulation model for corn (MAIZE) applied to the Upper Great Lakes Region (UGLR) of the United States for 1992–1996. To evaluate model outputs, we used a modeling applications system integrative framework (MASIF) to simulate corn yields in the UGLR. We divided the region into two ecological zones (upper UGLR-1 and lower UGLR-2) and compared MAIZE and USDA\National Agriculture Statistics Service (NASS) yield estimates in each zone. There was greater agreement between MAIZE and NASS yields at lower yield values. As NASS yields increased, MAIZE yields also increased, but to a greater extent than did NASS yields. We conducted a mean spatial analysis of maize yield from 1992 to 1996. We also conducted a spatial analysis of 1994, 1995 and 1996. There are both spatial and temporal differences when yields are mapped.

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1. Introduction

Regional analysis using simulation modeling to examine larger scale patterns of change has become common in recent years (Kunkel and Hollinger, 1991; Moen et al., 1994; Burke et al., 1997; Jagtap and Jones, 2002). Current monitoring technologies and computational resources are increasing the spatial and temporal capacity of using large environmental data sets as inputs for regional models. Michigan, Wisconsin, and Minnesota comprise the Upper Great Lakes Region of the US (UGLR) and have a diverse set of agricultural commodities. In spite of this diversity, most of the agricultural acreage is currently planted to corn, soybeans and to a much lesser extent, wheat. In the early 1990s, a corn simulation model (MAIZE), was developed to simulate site specific daily growth and development of corn and to estimate final

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yield (Muchow et al., 1990; Muchow and Sinclair, 1991). Model developers documented its potential for regional application (Muchow et al., 1990) and provided modifications for its use in cold climates (Wilson et al., 1995; Stone et al., 1999). This model was modified and incorporated into MASIF, a modeling framework developed by Gage et al. (2001), to accept inputs from multiple locations to examine regional patterns of crop productivity.

2. Objective

Our objective was to use the modeling applications system integrative framework (MASIF) to examine the use of a site based simulation model (MAIZE), when applied to the Upper Great Lakes Region (UGLR) of the US.

3. Materials and methods

We used MASIF to evaluate outputs from MAIZE on a regional basis. We obtained year-end estimates ($t\,ha^{-1}$) of corn yield by simulating daily growth and development of corn for each of the 266 counties in the UGLR from 1992 to 1996. We used the meteorological inputs of daily maximum and minimum temperature, precipitation and solar radiation for each county provided by the Cooperative State Research, Education and Extension Service (CSREES) NC1018 Regional Research Program as input to MAIZE. We used a threshold of -51° days to initiate planting. The USDA STATSGO database (USDA, 1994) was used to estimate soil characteristics for each county. These soil characteristics were input to the model to account for soil variability. Because of the large genetic variability planted to the region, the variety parameter of the model was set so that it generalized for a common region-wide corn variety. We examined the regional simulated year-end corn yield by comparing simulated corn yield with yield estimates provided by USDA-NASS (2005). In a relational database we associated climate and crop data with county centroids to facilitate regional mapping and county specific data analysis. A digital atlas of static and time series maps and visualizations was developed to assess and analyze regional patterns of change. The relationships between climate, crop data tables, and MASIF are shown in Fig. 1.

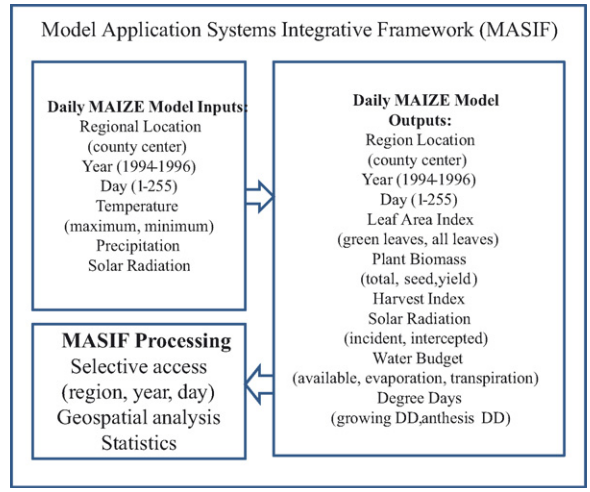

Fig. 1 – The relationship between the MASIF environment and inputs and outputs of the MAIZE model.

4. Results and discussion

4.1. *Ecological regionalization*

We used Bailey's Ecoregions (Bailey, 1995) to divide the Upper Great Lakes Region, into two ecological zones: UGLR 1 (Warm

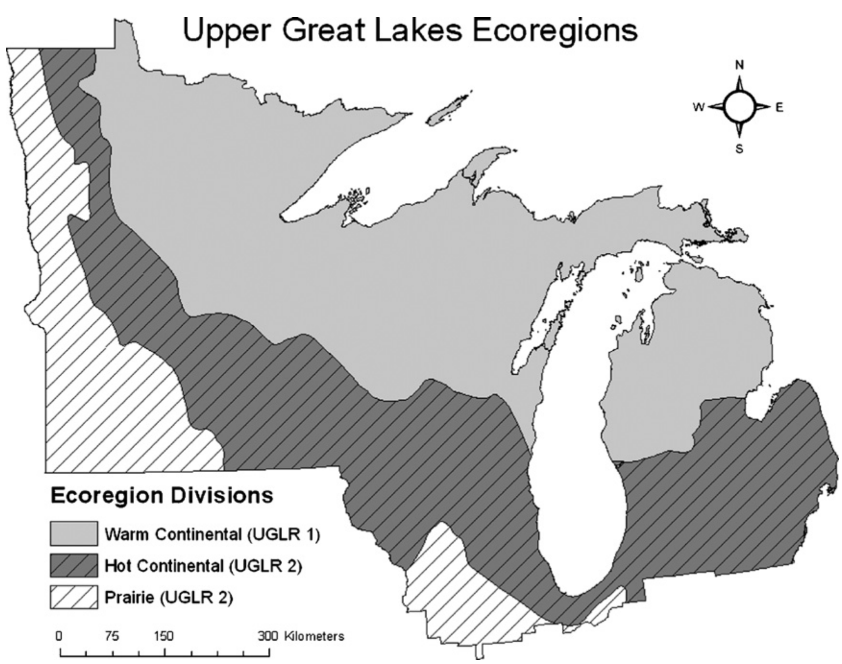

Fig. 2 – Bailey Ecoregions applied to the Upper Great Lakes Region (UGLR).

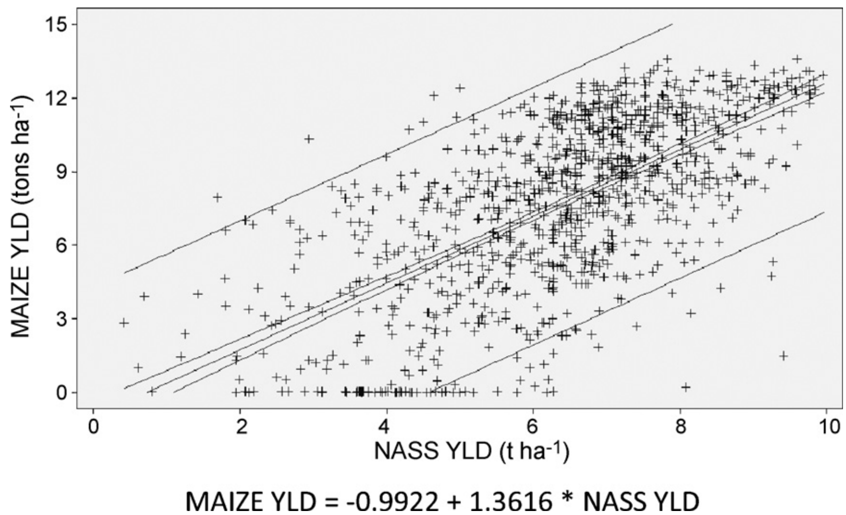

Fig. 3 – Regression plot of simulated yields (MAIZE YLD) and NASS yields (NASS YLD) (metric tonnes per hectare) for 1992–1996. MAIZE YLD = −0.9922 + 1.3616 × NASS YLD (95% conf. and pred. intervals).

continental division) and UGLR 2 (Hot continental and Prairie divisions) (Fig. 2). The majority of the maize is currently planted in UGLR 2.

4.2. *Analysis of corn yields*

MAIZE yields and NASS yield estimates were compared after converting corn yield to metric tonnes per hectare. The relationship between NASS and MAIZE yields for the entire UGLR is presented in Fig. 3. The distribution of data points with respect to the regression line showed greater agreement between MAIZE and NASS yields at lower rather than higher NASS yields. This was likely due to stresses that reduced water availability. Also, as NASS yields increased, MAIZE yields also increased, but to a slightly greater extent than did NASS yields.

Under conditions of high yield and high water availability, stressors other than lack of water, such as disease or insect-induced stress, will play larger roles in reducing simulated corn yields. This is expected since MAIZE was developed and tested under irrigated conditions in the absence of any biological stress. The fact that MAIZE yields are higher than NASS yields agree with results from Kunkel and Hollinger (1991) and Moen et al. (1994). However, it is possible that MAIZE over estimated production under these conditions. The mean corn yield difference and standard deviations for the entire UGLR as well as for UGLR 1 and UGLR 2 for each year are presented in Table 1. The mean difference between MAIZE and NASS yields for the UGLR was positive (i.e. MAIZE yields > NASS yields) from 1993 to 1996, and positive in the UGLR 2 for all years. Results were different in the UGLR 1, where the mean difference between MAIZE and NASS yields were negative (i.e. MAIZE yields < NASS yields). The mean differences between MAIZE and NASS for the UGLR for 1992, 1994, and 1996 were lower than the UGLR 2's yields but higher than those in the UGLR 1. The mean yields for UGLR 2 were the highest of all. The UGLR 2 simulations of mean yields had the lowest overall standard errors and, thus, were more accurate than yield simulations of either the UGLR or the UGLR 1.

Note that corn is not a major crop in the UGLR 1, which is much colder than UGLR 2, but is planted in that region to take advantage of government subsidies. This difference in yields and temperature between UGLR 1 and UGLR 2 leads to the potential use of a temperature adjustment for the ecological zone being studied (Wilson et al., 1995).

The spatial and temporal pattern of corn yield (metric tonnes per hectare) in the UGLR for the years 1992–1996 (Fig. 4) show differences between MAIZE and NASS yields. MAIZE yields were generally higher than NASS yields in the UGLR 2 (Fig. 4). In the UGLR 1, the simulated yields are slightly lower than estimated yields. The UGLR had substantial areas where MAIZE yields occurred in the same class range as NASS yields but the location of agreement differed between

Table 1 – Difference between maize yield (metric tonnes per hectare) simulated using MAIZE and maize yield estimated by NASS (±S.E.) for 1992, 1994, and 1996 in the Upper Great Lakes Region

Year	UGLR	UGLR 2	UGLR 1
1992	−0.89 ± 0.16, N = 223	0.33 ± 0.14, N = 145	−3.17 ± 0.18, N = 78
1994	1.72 ± 0.19, N = 218	3.23 ± 0.13, N = 145	−1.28 ± 0.28, N = 73
1996	0.66 ± 0.19, N = 207	1.77 ± 0.19, N = 145	−1.95 ± 0.27, N = 62

UGLR is the entire region, UGLR 2 is the southern ecological region and UGLR 1 represents counties occurring in northern latitudes. *N* is the number of counties in each regional component.

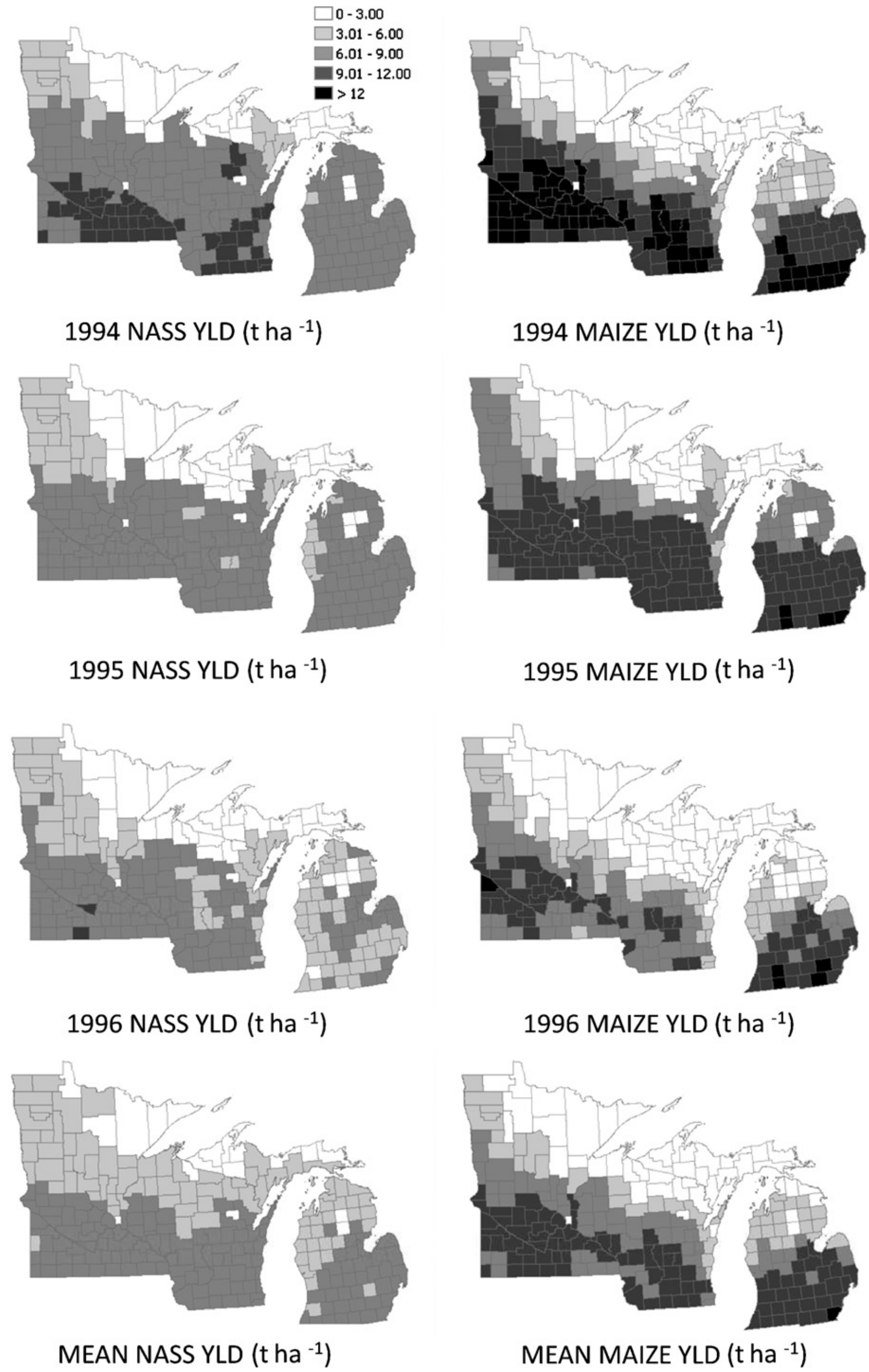

Fig. 4 – Regionalized NASS (NASS YLD) and MAIZE yields (MAIZE YLD) in metric tonnes per hectare for 1994–1996 and the mean regionalized NASS and MAIZE yields (metric tonnes per hectare) for 1992–1996 using MASIF.

years (1994–1996). Thus, both MAIZE and NASS yields differed in amount depending on the temporal and spatial location within the UGLR.

It is not possible for practical and economic reasons to validate this crop model for each field in a region for each year. Therefore, the level of detail is less for regional assessments compared with field level assessments. Additionally, it has been found (Jagtap and Jones, 2002) that a given model will not be as accurate at a regional scale if it was developed for the field level. Regional scale predictions of crop production can be, for example, especially useful for predicting inter-annual yield response (Boote et al., 1997) or used indirectly for carbon sequestration estimates (Grace et al., 2006). Also, the acquisition of regional maize phenology and weather information, at daily time intervals, should enable creation of pest/disease templates (submodels) for determination of the potential presence and extent of plant damage on a county-wide level in the UGLR.

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