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Crop model and weather data generation evaluation for conservation agriculture in Ethiopia

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ABSTRACT

Crop simulation models offer possibilities to evaluate and target agricultural information for sustainable intensification in countries like Ethiopia with inadequate resources for field research. The objectives of this research were to calibrate and evaluate the CERES-Maize, CROPGRO-Dry bean and CROPGRO-Soybean models for practices associated with conservation agriculture and fertilizer N, and to evaluate five generated weather datasets for Ethiopia. Data from multi-year field experiments and additional data obtained from previously conducted national variety trials were used for model evaluation. Generated weather datasets for six agroecologies were evaluated by comparison with observed data and by use of data in the models. Genetic coefficients used in the models for maize, dry bean and soybean were determined by model parametrization and calibration of phenology and yield. The models acceptably simulated the effects of N rate, maize-legume rotation, and crop residue retention plus tillage with average normalized deviation closer to zero, RMSE less or similar to standard deviation of observed data, and with normalized RMSE (nRMSE) < 15%. Both NASA and Global Yield Gap Atlas (GYGA) daily rainfall showed good agreement with observed weather data (RMSE < 9 mm). Daily maximum and minimum temperature of GYGA and WeatherMan datasets had the lowest RMSE of 1.99 and 3.06, and 2.5 and 3.1 °C, respectively. Between 85–100% of simulated grain yields of maize, dry bean and soybean with GYGA and WeatherMan datasets fell within ± 10% deviation of mean simulated grain yields with observed weather data, and with the lowest inter-annual variability. It was concluded that model calibrations were satisfactory, and either GYGA or WeatherMan datasets alone or combined could be used to run the crop models in sites which lack observed daily weather data in Ethiopia.

1. Introduction

The need for increasing agricultural productivity on a sustainable basis is a primary concern for agricultural research and development in Ethiopia. Cropping system models may be useful in evaluating alternative production practices focused on sustainably increasing land productivity (Grassini et al., 2009; Mupangwa et al., 2011; Gaydon et al., 2017). Such models can provide valuable insights across diverse agroecological and socioeconomic conditions, especially when resources for field research are inadequate to provide sufficient information in space and time to identify appropriate and effective crop and land management practices (Jones et al., 2016). For example, the Agricultural Productivity System sIMulator (APSIM) model was used to develop an understanding of long-term effects of conservation agriculture on the productivity of smallholder systems in Zimbabwe (Mupangwa et al., 2011; Gaydon et al., 2017). Successful application of the Decision Support System for Agrotechnology Transfer (DSSAT) has been reported for sub-Saharan Africa (Singh et al., 2002; Jones et al., 2003; Corbeels et al., 2014). CERES-Maize, CROPGRO-Soybean, and CROPGRO-Dry bean models embedded in DSSAT were used cost-effectively to examine alternative crop and soil management practices such as conservation agriculture, resource use efficiency, and the sustainability of cropping systems (Bidogeza et al., 2012; Corbeels et al., 2014). Such models were used to evaluate alternative crop and soil

Abbreviations: d, the degree of agreement between the predicted and their respective observed values; DSSAT, Decision Support System for Agrotechnology Transfer; EF, model simulation efficiency or Nash–Sutcliff ;e Efficiency coefficient; GLUE, Generalized Likelihood Uncertainty Estimation; GYGA, Global Yield Gap Atlas; LAI, leaf area index; ME, estimated the average generated error; NASA, National Aeronautics and Space Administration; RMSE, root mean square error; nRMSE, normalized RMSE; TED, Technology Extrapolation Domain

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management practices given the environmental conditions (Bidogeza et al., 2012). Application of CERES-Maize, CROPGRO-Dry bean and CROPGRO-Soybean to assess the components of conservation agriculture including crop rotation, crop residue retention, and tillage system, as well as fertilizer N use optimization in different agroecologies of Ethiopia, however, requires model calibration and evaluation.

Using crop models to assess crop management requires a minimum of long-term daily rainfall, maximum (Tmax) and minimum temperature (Tmin), and solar radiation, in addition to soil profile information. Depending on the degree of weather variability among years, at least 10–20 yr of daily weather data are needed for reliable assessment of the effect of a management practice on mean yield potential and inter-annual variability in an agroecological zone (Van Ittersum et al., 2013; Van Wart et al., 2013a; Grassini et al., 2015). However, weather stations are sparse in Ethiopia, and most have only a few years of complete daily weather records available, and often solar radiation was not measured. In addition, because of complex topography, the available weather stations can only represent areas within a 25 km^{-2} radius of a station in the mountainous regions of Ethiopia (Hirpa et al., 2010). Meanwhile, generated weather data (gridded, propagated or generated by weather generators) from different sources are available for use in crop simulation models, but require evaluation to identify the dataset that best represent daily weather variability across agroecologies of Ethiopia.

Stochastic weather generators such as WeatherMan and MarkSim generate daily weather data based on statistical characteristics of historical daily or monthly observed weather data (Jones and Thornton, 2000; Mavromatis and Hansen, 2001). Those weather generators typically generate first daily precipitation, then other weather variables needed by crop models (Jones and Thornton, 2000). Successful generation of weather data with a weather generator depends on the number of years and sites required for their parameterization (Baigorria and Jones, 2010; Rosenzweig et al., 2013). Observed daily Tmax and Tmin data of < 5 yr is often available for most regions in Ethiopia to use in stochastic weather generators (Van Wart et al., 2015). Generated long-term daily data should be evaluated before use, because even when decades of daily observed weather data were used for calibration, simulated crop yields sometimes differed greatly when using generated compared with observed data and inter-annual variation in simulated crop yields were often under-estimated when using generated data (Semenov and Porter, 1995; Hammer et al., 2002; Van Wart et al., 2015). Also, short periods of extreme events, which are of particular importance for crop growth, yield and crop failure, were typically not well represented in generated weather data for some countries for which the data were evaluated (Kysely and Dubrovsky, 2005; Semenov, 2008; Van Wart et al., 2015).

Gridded weather data are typically derived by interpolation of observed weather data over space, or may also be derived from global climate models to estimate daily or monthly weather data for a gridded land area (Kanamitsu et al., 2002; New et al., 2002). The quality of the generated estimates for a given grid cell can have a large degree of uncertainty if the density and distribution of the weather station datasets is inadequate (Van Wart et al., 2015). Even in regions with adequate density of weather stations, poor agreement has been found between simulated crop yields using gridded weather data versus simulations using observed weather data from a location within the same grid cell (Mearns et al., 2001; Baron et al., 2005). Bias in simulated yields using gridded data were unpredictable and inconsistent having different sign and magnitude for temperature and rainfall across locations in Ethiopia and Kenya (Van Wart et al., 2013b, 2015). The Prediction of Worldwide Energy Resource dataset from the National Aeronautics and Space Administration (NASA, 2015) was selected as the gridded weather data source for use in this study due to public accessibility, acceptable agreement with ground data for solar radiation, and previous use in crop growth simulation studies (Bai et al., 2010; Van Wart et al., 2013a, b). The NASA data were derived from satellite observations coupled with the Goddard Earth Observing System climate model to obtain complete terrestrial coverage.

As an alternative to the use of generated or gridded weather data, Van Wart et al. (2015) developed a protocol that uses 3 yr of observed Tmax and Tmin data, combined with long-term gridded solar radiation and precipitation data to generate a long-term daily weather dataset suitable for simulation of crop yield potentials. Such a weather dataset is known as a propagated weather data. The propagated weather data were comprised of uncorrected gridded solar radiation from NASA, rainfall data estimates from the Tropical Rainfall Measuring Mission, and location-specific calibration of NASA maximum and minimum temperature using 3 yr of observed daily temperature data. Use of propagated weather data derived from 3 yr of observed weather data gave median simulated grain yields within ± 10% of yields simulated entirely with observed weather data for 83% of the study sites (Van Wart et al., 2015). Even for locations such as Melkassa in Ethiopia with weak correlation between NASA and observed Tmax and Tmin, mean yield simulated with the propagated weather data fell within ± 10% of mean yield simulated entirely with observed weather data (Van Wart et al., 2015). Hence, the methodology applied to develop propagated weather data was able to correct to some degree the overall temperature bias between NASA and observed weather data for sites in sub-Saharan Africa.

Crop growth simulation models need to be calibrated and evaluated to study the effects of management variables of interest. Quality and suitability of the generated, gridded, and propagated weather data, however, varies from region to region and needs to be evaluated across agroecologies of Ethiopia. These are necessary preparatory steps for use of crop growth simulation models to evaluate conservation agriculture practices and generate N response functions for fertilizer use optimization. Therefore, the objectives of this study were (i) to calibrate and evaluate CERES-Maize, CROPGRO-Soybean and CROPGRO-Dry bean models in Ethiopia and (ii) to evaluate different generated, gridded, and propagated weather datasets for application of crop growth models in Ethiopia.

2. Materials and methods

2.1. Field experiments

2.1.1. Experiment-I

Field experiments were conducted in 2010–2016 and 2015–2016, respectively, at Melkassa and Bako Agricultural Research Centers in Ethiopia, hereafter referred to as Melkassa and Bako, to calibrate CERES-Maize, CROPGRO-Dry bean and CROPGRO-Soybean. These experiments provided data comparing: no-tillage with 100% crop residue retention and plow tillage with complete residue removal; maize (*Zea mays* L.) monoculture, dry bean (*Phaseolus vulgaris* L.) monoculture, maize-dry bean rotation, and maize-dry bean intercropping at Melkassa; and the two-tillage practices with maize monoculture, soybean (*Glycine max* L.) monoculture, maize-soybean rotation, soybean-maize rotation, and maize-soybean intercropping at Bako in a complete factorial split-plot design with tillage assigned to the main plots and cropping systems to the sub-plots. The plot area was 100 m^2 for both maize and legumes.

Tillage was according to the local practice of tilling three times using the oxen drawn “maresha” plow (Melesse, 2007). The first and second tillage were, respectively, done in the first and second week of May at Bako and in the first and second week of June at Melkassa while the third tillage was done at planting time. Planting was from the last week of May to mid-June at Bako for both crops, and in the third and fourth wk of June for maize and in the last week of June and first week of July for dry bean at Melkassa.

The maize cultivars were the hybrid BH546 at Bako and the open pollinated Melkassa-II at Melkassa. Soybean *cv* Dhidhesa and dry bean *cv* Nassir were grown at Bako and Melkassa, respectively. The inter-and