# Maize (*Zea mays* L.) productivity as influenced by sowing date and nitrogen fertiliser rate at Melkassa, Ethiopia: parameterisation and evaluation of APSIM-Maize

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## Abstract
Crop modelling can assist in exploring the production risks and the yield uncertainty associated with rainfall variability but requires empirical data suitable for model testing within a specific system and environment. To parameterise the crop simulation model APSIM-Maize, a field experiment examining a medium maturing maize cultivar sown on two dates and grown at two nitrogen (N) fertiliser rates (0 and 100 kg N ha$^{-1}$) was conducted at Melkassa, Ethiopia. Model performance was evaluated against six independent datasets from the same site. APSIM-Maize simulated crop phenology, leaf area index, and biomass well for both sowing dates. The model showed acceptable performance in simulating grain yield in most cases. However, at the late sowing date and high N supply, the model over-estimated yield by 37%. The model realistically captured variation in soil water dynamics as indicated by a RMSE of 0.039 mm mm$^{-1}$. Evaluation of the parametrised model against independent data showed that it was able to reasonably simulate various crop responses including date of silking (RMSE=1 d), date of physiological maturity (RMSE=1.50 d), grain yield (RMSE=0.39 t ha$^{-1}$), and biomass production (RMSE=0.48 t ha$^{-1}$) for maize grown at different sowing dates (between June and July) and N application rates (up to100 kg N ha$^{-1}$).The results showed that APSIM-Maize is credible and can be used for scenario analyses of maize systems in semiarid environments of Ethiopia.

## Key words
Crop simulation modelling, Ethiopia, maize, model evaluation, model parameterisation

## Introduction
In dryland regions of Ethiopia, fluctuations in annual production are high due to large inter- and intra-annual rainfall variability (Kassie et al., 2013). Maize is the major crop, and plays a significant role in the livelihoods of smallholder farmers (Biazin & Stroosnijder, 2012). Maize yield in the region is approximately 1.5 t ha$^{-1}$, compared to the national average yield of around 2.2 t ha$^{-1}$ (Bogale et al., 2012). The uncertainty associated with rainfall variability is a major concern for resource-poor farmers, as management options are severely limited (Kassie et al., 2013).

Crop modelling offers an effective way to understand and analyse the consequences of management options under variable climatic conditions. For example, the Agricultural Production Systems Simulator (APSIM; Keating et al., 2003) has been used successfully to simulate maize growth and development for a wide range of climatic conditions (Robertson et al., 2005; Fosu-Mensah et al., 2012; Archontoulis et al., 2014) and management practices (Fosu-Mensah et al., 2012; Kamanga et al., 2014). However, APSIM has had limited use in Sub-Saharan Africa due to the scarcity of suitable input data for model parameterisation, testing, and application (Whitbread et al., 2010).

Data are required to parameterise the model for a new set of conditions including new cultivars (e.g. photo-thermal response) and environments (local soil and climate), and for subsequent model testing to ensure the credibility of model performance. A field experiment was conducted at Melkassa in the Central Rift Valley of Ethiopia to obtain a comprehensive crop and soil data set for a maize system typical to the study region. The objectives of this study were to (i) parameterise APSIM-Maize using phenology, grain and biomass yield, and soil water data from a field experiment specifically designed for modelling purposes, and to (ii) evaluate the capabilities of APSIM-Maize to simulate maize systems in the semi-arid study environment.

### Methods

Data from the field experiments conducted at the Melkassa Agricultural Research Centre (8º24’ N, 39º12’ E, 1550 m elevation) were used for both parametrising and evaluating APSIM-Maize. The location has a semi-arid, tropical climate with a weakly bi-modal rainfall distribution, an average annual rainfall of 820 mm, and a mean annual temperature of 21.2°C (1977-2012). Daily temperature and rainfall were recorded at a local weather station. Daily solar radiation data were available from the NASA POWER database (Stackhouse, 2010). In 2012, a medium maturing maize cultivar (cv. *Melkassa-2*) was sown on 6 July (SD1) and 20 July (SD2). Nitrogen fertiliser was applied as urea at two rates: 0 kg N $ha^{-1}$ and 100 kg N $ha^{-1}$. Sowing dates were later than the recommended cut-off date of end of June due to late rains. The experiment was irrigated at around silking (i.e. flowering). The dates of key phenological events were recorded, and total above-ground biomass and the leaf area index (LAI) were measured three times during the season. At final harvest, number of grain per head, grain weight and yield was determined. Soil characteristics including bulk density, soil organic carbon, pH, C: N ratio, soil water, and nitrate N ($N\text{-}NO_3$) were determined at six soil depths (0-0.15, 0.15-0.30, 0.30-0.60, 0.60-0.9, and 0.90-1.2 m) prior to the establishment of the experiment. Soil water was measured at one to two week intervals throughout the cropping season from the soil depths as specified above. Following parameterisation, model performance was evaluated against six independent data sets from experiments conducted between 2006 and 2012. These experiments had assessed crop phenology, yield and biomass of cv. *Melkassa-2* at different sowing dates (between June and July) and N application rates (up to 100 kg N $ha^{-1}$).

The APSIM model (version 7.5), which included the APSIM-Maize, SoilWater, SoilN, and SurfaceOM modules, was used in this study. Important parameters for SoilWater and SoilN are presented in Figure 1. With the use of crop, soil, weather and management data obtained from the field experiment, APSIM was used to simulate silking and maturity dates, soil water dynamics, leaf area index (LAI), grain yield, and biomass, which were subsequently compared with observed data. Model accuracy was assessed using the root mean square error (RMSE) and the coefficient of determination ($r^2$).

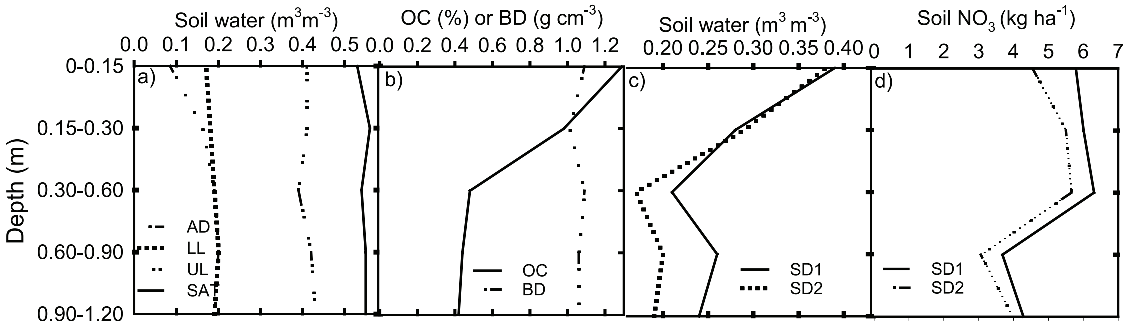


**Fig. 1. Soil characteristics at Melkassa: (a) lower (LL) and upper limit (UL) of plant extractable soil water, saturated (SAT) and air-dry (AD) soil water content; (b) organic carbon content (OC) and bulk density (BD); (c) initial volumetric soil water and (d) initial N-NO3 for the maize sown on 6 July (SD1) and 20 July (SD2), 2012.**

### Results and discussion

*Cultivar specific parameters*

Cultivar parameters (Table 1) were determined using the experimental data of 2012. The combination of parameter values in Table 1 resulted in the best possible fit (less than two days difference between the observed and simulated dates of silking and maturity).

**Table 1. Parameters used to simulate cv. *Melkassa-2.***

| Parameters | Values |
|---|---|
| Thermal time from emergence to end of juvenile stage (°Cd) | 230 |
| Thermal time from end of juvenile to floral initiation (°Cd) | 0 |
| Thermal time from flag leaf to silking (°Cd) | 10 |
| Thermal time from silking to start of grain-filling (°Cd) | 160 |
| Thermal time from silking to physiological maturity (°Cd) | 730 |
| Maximum kernel number per ear | 440 |

*Soil water dynamics*

The model reproduced the temporal variation in soil water contents observed in 2012 well. For example, the large reduction in volumetric soil water due to lack of rainfall at about 100 days after sowing was well captured. The RMSE was 0.039 mm mm$^{-1}$ and $r^2$ was 0.86 (Fig. 2).

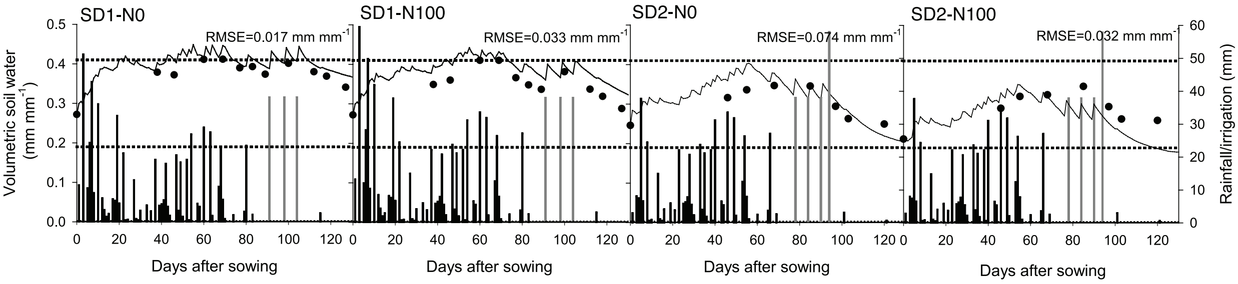


**Fig. 2. Simulated (lines) and observed (symbols) soil water content for the whole soil profile (0-1.2 m) for earlier- (SD1: 6 July 2012) and late-sown (SD2: 20 July 2012) maize grown at two nitrogen rates (N0: 0 kg N ha-1; N100: 100 kg N ha-1), Melkassa. The plant available soil water capacity is given between the dotted lines. Bars represent daily rainfall (black) and supplemental irrigation (grey). The r2 ranged from 0.77 to 0.94.**

*Biomass, grain yield and LAI*

In 2012, late-sown maize had received 42% less cumulative rainfall around silking than the earlier-sown crop. This was associated with an average yield reduction of 42% in the late-sown compared to the earlier-sown crop. There was no yield benefit from adding fertiliser N to late-sown maize. However, when maize was sown earlier the application of 100 kg N ha$^{-1}$ increased the grain yield by 39% and total above-ground biomass by 47% compared with the unfertilised crop. Simulated biomass yields were 12-27% lower than observed except for the late-sown maize fertilised with 100 kg N ha$^{-1}$, where the biomass yield was accurately simulated (Fig. 3). Grain yields were accurately simulated for unfertilised maize, and over-estimated by 11-37% when 100 kg N ha$^{-1}$ were applied. The simulated and observed values for seasonal LAI corresponded reasonably well for both sowing dates. The LAI values increased steadily and approached a peak between 60 and 70 DAS, which is just before flowing. This was well reproduced by the model.

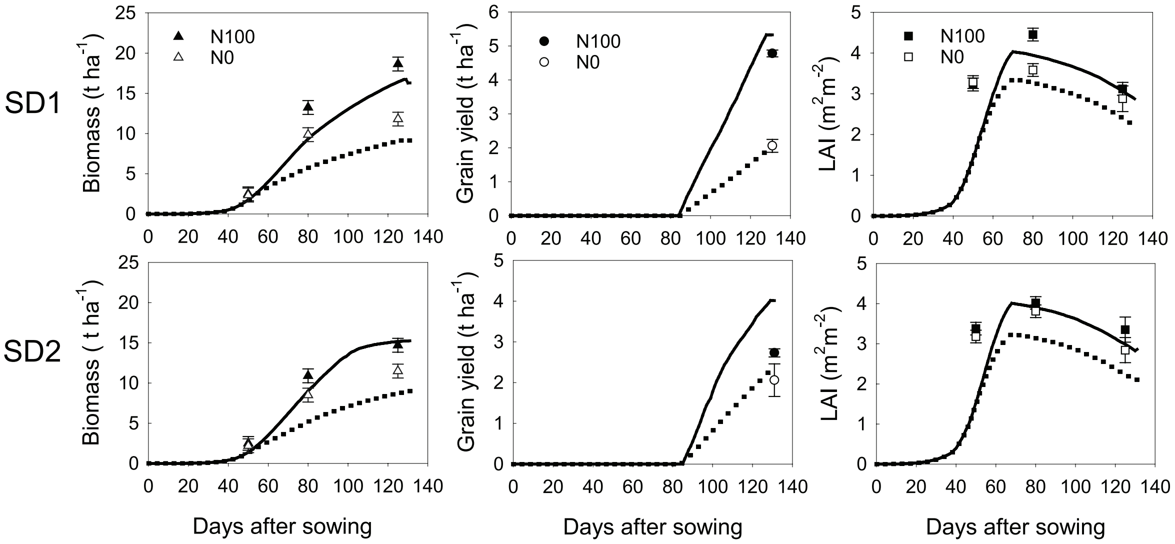


**Fig. 3. Comparison of simulated (lines) and observed (symbols) biomass, grain yield, and LAI of earlier- (SD1: 6 July 2012) and late-sown (SD2: 20 July 2012) maize (cv. *Melkassa-2*) grown under two rates of fertiliser nitrogen (N0: 0 kg N ha-1; N100: 100 kg N ha-1) at Melkassa, Ethiopia. Vertical bars represent the standard error of means.**

*Model evaluation*

When tested against independent data, phenological development of cv. *Melkassa-2* was reasonably well simulated, with a RMSE of less than 2 days and an $r^2$ of 0.89 for days to maturity and 0.80 for days to silking (Fig. 4). Given that these experiments were not designed for model testing, the performance of the model was acceptable in terms of grain yield and biomass production. There was an acceptable to fairly good agreement between the measured data and simulated values, with $r^2$ values of 0.66 for biomass and 0.68 for grain yield.

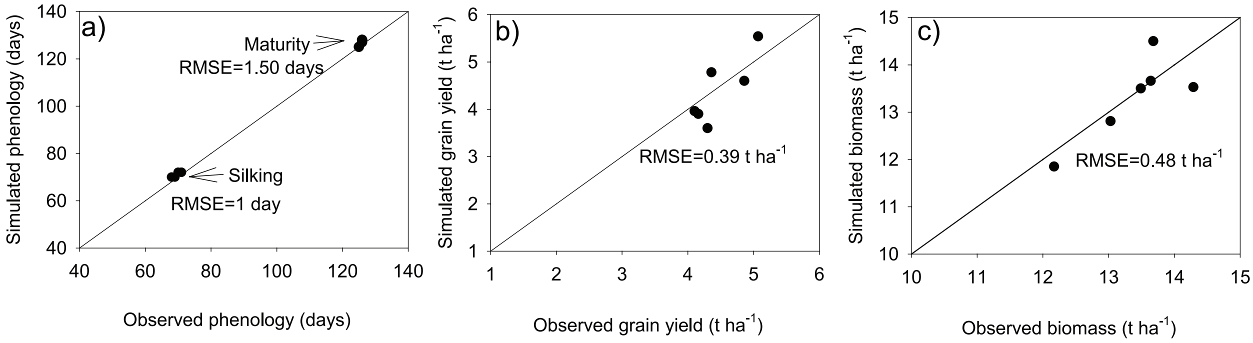


**Fig. 4. Comparison of observed and simulated results for (a) days to silking and physiological maturity; (b) grain yield; and (c) biomass of cv. *Melkassa-2* from experiments conducted in 2006-2012 at Melkassa, Ethiopia. The 1:1 fit (y=x) is represented by diagonal lines.**

## Conclusion

The study showed that APSIM-Maize is able to adequately simulate crop phenology, grain, and biomass yield, as well as the soil water dynamics in the semi-arid study environment. Therefore, APSIM-Maize can be used for scenario analysis to explore management options and resource-use to improve maize productivity in smallholder farming systems of Ethiopia.

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