MATCHING MAIZE VARIETIES TO DIFFERENT SOILS AND AGRO-CLIMATIC CONDITIONS OF THE NORTHERN GUINEA AND SUDAN SAVANNAS OF NIGERIA USING CROP SIMULATION MODELS

PROGRESS REPORT OF ACTIVITIES CONDUCTED

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1.0 Detail Report

This write up presents activities conducted for the project titled “Matching maize varieties to different soils and Agro-climatic conditions of Nigerian savannas using crop simulation model”. To achieve the objectives, some major activities were conducted as follows:

1. Calibration trials in 4 locations during the dry season (23rd March to 30th June) and rainy season (1st July to 15th October 2016) using 22 varieties released by IITA and commonly produced in the region. A total of 8 trials were conducted for evaluating the growing pattern and yield of each variety.

2. Validation trials in 60 farmers’ fields across Kano and Kaduna States conducted between 23rd June to 15th October 2016. For validation, the varieties were planted under varying densities to investigate the effect of density on yield.

3. Assembling of weather and soil data for all calibration and validation sites.

4. Assembling of long term weather records (26 years) from Nigerian Meteorological Agency (NIMET) from major airports close to the experimental locations

5. Collection of data for long term evaluation trials of the 22 varieties used for the calibration and validation trials from breeders at IITA.

This report presents findings from activities 1 and 2.

1.1 Calibration trials

The trials were conducted in the rainy and dry seasons of 2016 at Bayero University Kano (BUK), Dambatta, Samaru, and Lere. BUK and Dambatta are located in the Sudan Savanna (SS) Agro-ecological Zone (AEZ); while Samaru and Lere are located in the Northern Guinea Savanna (NGS) zone. The dry season trials were planted on 16-03-2016, 17-03-2016, 18-03-2016 and 22-03-2016 at BUK, Dambatta, Lere and Samaru respectively. Due to varying nature of the varieties, harvesting was done at different periods for the early and late varieties. The early varieties were harvested on 15-06-2016, 19-06-2016, 24-06-2016 and 28-06-2016 at BUK, Lere, Dambatta and Samaru respectively. For the late varieties, BUK was harvested on 01-07-2016, Lere was harvested on 06-07-2016, Samaru was harvested on 10-07-2016 while Dambatta was harvested on 14-07-2016. Growth and phenology data collected from the calibration trials includes: number of days to emergence, number of days to tasselling, number of days to silking, number of days to physiological maturity, plant height, number of leaves and above ground biomass at juvenile, flowering, physiological maturity and harvest maturity. In addition, the plants were monitored daily for days to successive leaf tip appearance. Yield data collected includes: number of cobs per plant, number of seeds per cob, cob yield per hectare, grain yield per hectare, harvest index, shelling percentage and hundred seed weight. The data collected from the trials will be used to calibrate the cultivar files in the CERES-Maize model.

1.2 Validation trials

Validation trials were planted in all the selected locations in the SS and NGS. Following the protocol and experimental design, 10 varieties were planted in the different AEZs. The varieties were planted under 3 different densities (26,666, 53,333 and 66,666 plants/hectare). Sowing started on 8th June 2016 and ended on 19th June 2016. The early varieties were planted in the SS while the intermediate and late varieties were sown in the NGS. In each AEZ, 3 local government areas (LGAs) were selected and in each LGA 10 farmer fields were selected. In each field 10 plots were planted with the 10 varieties under different planting densities. The data collected from the validation trials includes: biomass at anthesis and harvest, number of cobs per plant, number of seeds per cob, grain yield and harvest index. The data from the on-farm trials will be used to validate the calibrated CERES-Maize model.
2.0 Background Information

According to FAO data, the total annual national production of maize in Nigeria has increased from 1.1 million metric tons in 1961, to about 10.4 million metric tons in 2014, thus making the country the 11th largest producer of maize in the world (FAOSTAT, 2014). The recorded increase in production is attributed to expansion in the cultivated area rather than intensification (FAOSTAT, 2015). The area dedicated to maize increased from 1.38 million hectares in 1961 to about 5.2 million hectares in 2014 (FAOSTAT, 2015). Despite the increased area under maize production, yields have remained quite low. For example, the average yield of maize in Nigeria was 1.8 tons ha\(^{-1}\) in 2014 compared to 10.7 tons ha\(^{-1}\) in the USA and the world average of 5.5 tons ha\(^{-1}\) (FAOSTAT, 2014). The major factors limiting the yield of maize in the West African savannas, including Nigeria, include the inherently poor soils (Jibrin et al., 2012), frequent droughts (Kamara et al., 2009), lack of proper adherence to improved agronomic practices and poor use of improved inputs such as fertilizers and seeds (Badu-Apraku et al., 2011).

One of the most common yield-limiting practices in the Savannas of Nigeria is wrong selection of varieties. Farmers in the dryer areas with shorter rainfall tend to select varieties that mature late, this leads to decrease in yield due to end-of-season drought which occurs during the active grain filling stage of the crop. In the wetter areas, farmers also select varieties that mature early and this means physiological maturity occurs during active rainfall, this always reduces yield as a result of diseases and other factors. Research has shown a yield reduction risk from planting early varieties if season length was sufficient for later maturing varieties (Sorensen et al., 2000). Early maturing varieties when planted late will not realize the full yield potential of the growing season and the inputs provided by the grower (Lee and Tollenaar, 2007). Late varieties may fail to mature before the rainfall ceases towards early October, and this will also have a devastating effect on the final grain yield (Lauer, 1998).

Optimum stand density (OSD) selection is an important management practice for maize because yield is maximized at an optimum value (Hernandez et al., 2014). OSD varies across environments, and there are arguments in the literature suggesting that recently cultivated varieties differ in their OSD even if planted in similar environments (Duvick et al., 2004; Lee and Tollenaar, 2007). The recommended planting density for maize in Nigeria is 5.3 plants m\(^{-2}\) which is usually achieved by planting on 75cm \(\times\) 25cm inter and intra-row spacing (Kamara et al., 2009). The majority of farmers do not plant use the recommended density, some plant as low as 2.6 plants m\(^{-2}\) which leads to great yield reduction and fiercer weed competition (Kamara et al., 2009). Also, the recommended planting density has been contested because no consideration is made for varietal differences with respect to tolerance to crowding. Most farmers do not consider the soil type, weather conditions, and fertilizer rates when selecting densities.

Most crop models integrate genetic inputs, (e.g. the concept of genotype coefficients (GCs)) in all DSSAT models. This means that most crop models with such abilities can be used in identifying GxE interactions. Although most of the crop models currently in existence still lack the ability to explain all the complexities associated with variations among genotypes across different environments, they still provide very useful information for understanding mechanisms that determine crop yield in relation to the environment (Bindraban, 1997; Hammer et al. 1999). The CERES-Maize model if properly calibrated and validated can be used to make predictions of varietal performance across different environments and management decisions. Many researchers (Chapman et al., 2002; Tardieu, 2003; Yin et al., 2000; Hammer et al., 2006) believe that the fastest way of reducing difficulties linked to high GxE is by simulating the yields of crops in large sets of environmental scenarios.
3.0 Research Hypotheses

1. The sequential approach method, when optimized, can be used to generate accurate genetic coefficients (GCs) of maize using the GENCALC program of DSSAT.

2. GCs generated by field trials lead to more accurate calibration of CERES-Maize model than GCs generated from yield evaluation trials.

3. CERES-Maize Model can be used as a tool to aid selection of maize varieties and optimization of planting density in the NGS and SS of Nigeria.

4. The planting density adopted for maize in Northern Guinea Savanna and Sudan Savanna of Nigeria is below the optimum.

3.1 Main and Specific Objectives

1. Estimate cultivar coefficients for maize varieties produced in Northern Guinea Savanna and Sudan Savanna of Nigeria.

   a. Optimizing the sequential approach method used in GENCALC by changing the sequence and number of coefficients to be calibrated.

   b. Evaluate differences between maize GCs generated by using data from field measurements and yield evaluation trials.

   c. Optimize the generated coefficients for variations due to soils and seasonal differences by calibrating the soil fertility factor (SLPF) and Radiation Use Efficiency (RUE).

   d. Develop cultivar coefficients for 10 open pollinated and 10 hybrid maize varieties currently produced in the NGS and SS of Nigeria.

2. Evaluate the effect of varying planting densities of maize across the Northern Guinea and Sudan Savannas of Nigeria and validation of CERES-Maize Model for the ability to predict planting density of maize.

   a. To study the response of hybrid and open pollinated maize varieties to varying planting densities in NGS and SS of Nigeria.

   b. To validate the CERES-Maize Model for its ability to simulate effects of plant density using results of the planting density experiments.

3. To carry out scenario analysis (Biophysical, and Economic) under varying soils, environments, and agronomic conditions in NGS and SS of Nigeria.

4. Develop variety suitability maps to be used as decision-support tools for maize varietal selection across the Sudan and Northern Guinea Savannas of Nigeria.

4.0 Materials and Methods

Field trials were carried out in the dry and wet seasons of 2016. The first sets of trials were for the purpose of calibration of maize varieties done in research stations under researcher management. The second set of trials were on-farm trials under researcher, extension agent and farmer management for the purpose of validating the calibrated model.
4.1 Variety Calibration Trials

The variety calibration experiments were conducted in two locations in the Sudan Savanna (Bayero University Kano Teaching and Research Farm, and Irrigation Research farm, Audu Bako College of Agriculture, Dambatta) and two locations in the Northern Guinea Savanna (IAR Farm Samaru Zaria, and Kaduna Agricultural Development Project (KADP) Irrigation Station, Saminaka). Each set of experiments were conducted twice, the first under fully irrigated conditions (Late March to Early June) while a second set was conducted under rainfed conditions with supplementary irrigation (Late June to Early October). The experiments were laid out as a single factor experiment in a randomized complete block design (RCBD) with three replications. The twenty varieties were randomized and assigned to plots, plot sizes were 6 ridges (0.75m between Ridges) each 5 meters in length making each main plot 30 m² ((8x0.75m=6m) x 5m). Planting was done at a spacing of 25cm between stands and 75cm between rows, 2 seeds were planted and later thinned to 1 stand at 2 weeks after sowing. The trials were set in research stations under researcher management in fields with access to irrigation facilities in order to ensure optimal moisture conditions. NPK fertilizers were applied according to soil tests so as to ensure optimum nutrient availability.

Data collections were done in the two inner rows, 50cm from each end of the ridge was ignored and all plants inside were used as net plot, this makes the net plot size to be 6m² and the anticipated number of stands for yield investigation to be 32. Destructive sampling for biomass was done at each plant developmental stage (vegetative, reproductive and ripening stages). All destructive samplings were done in the rows outside the net plot. Profile pits were dug prior to the start of experimentation for soil characterization. Surface soils were taken per plot at 0-30cm for analysis both at the start and end of the experiment. A Time Domain Reflectometer (TDR, FieldScout TDR300, by Spectrum Technologies, Inc) was used to measure soil moisture content throughout the experiment; and supplementary irrigation was given when readily available water (RAW) is fully depleted in order to ensure optimal moisture availability. Twenty maize varieties commonly produced in the maize regions were used as shown in Table 1.

Table 1: List of maize varieties used in calibration and validation trials

<table>
<thead>
<tr>
<th>SN</th>
<th>Variety</th>
<th>Maturity Group</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2000 EVDT-Y STR</td>
<td>Early</td>
<td>OPV*</td>
</tr>
<tr>
<td>2.</td>
<td>99TZEE Y POP STR QPM CO</td>
<td>Extra-Early</td>
<td>OPV</td>
</tr>
<tr>
<td>3.</td>
<td>TZEE I 29 x TZEE I 21</td>
<td>Extra-Early</td>
<td>Hybrid</td>
</tr>
<tr>
<td>4.</td>
<td>2013TZEE-WPOPDSTSTR</td>
<td>Extra-Early</td>
<td>OPV</td>
</tr>
<tr>
<td>5.</td>
<td>2011TZE-WDTSTSTR SYN</td>
<td>Intermediate</td>
<td>OPV</td>
</tr>
<tr>
<td>6.</td>
<td>DTSTR-W SYN 13</td>
<td>Late</td>
<td>OPV</td>
</tr>
<tr>
<td>7.</td>
<td>TZB SR</td>
<td>Late</td>
<td>OPV</td>
</tr>
<tr>
<td>8.</td>
<td>TZE I 124 x TZE I 25</td>
<td>Early</td>
<td>Hybrid</td>
</tr>
<tr>
<td>9.</td>
<td>TZEE-WPOPSTRC5 x TZEE I 6</td>
<td>Extra-Early</td>
<td>Hybrid</td>
</tr>
<tr>
<td>10.</td>
<td>TZL COMP3 C3DTC2</td>
<td>Late</td>
<td>OPV</td>
</tr>
<tr>
<td>11.</td>
<td>2013 STR-Y SYN</td>
<td>Early</td>
<td>OPV</td>
</tr>
</tbody>
</table>
### 4.2 On-Farm Validation Trials

For model validation, 10 trials were set up in 6 Local Government Areas (LGAs) (10 sites per LGA) giving a total of 60 sites. The validation trials were conducted in 2016 rainy season. In each site, the 20 maize varieties were planted under three different planting densities. The experiments for validation were located in six LGAs with three LGAs falling in each of the two agro-ecological zones (AEZ). The varieties to be used will depend on the AEZ, early and extra-early maturing varieties were planted in the SS using the three sowing density treatments while the intermediate and late maturity groups were used in NGS. In each LGA, ten villages were selected i.e. 1 farmer per village. The selection of the farmers was stratified random sampling and based on the grouping of the farmers according to the level of field research experience. Sasakawa Africa Associates (SAA) provides extension services and are partners in this project. SAA farmers are grouped into five distinct classes; two farmers were randomly selected from each group making 10 farmers in each LGA. The selection of the sowing density treatments is based on an unpublished research in the same agro-ecological zones which found that doubling the number of plants/ha in the region relative to the recommendation (5.3 plants m$^{-2}$) led to yield increase of more than 45%. The description of the planting densities is shown below:

- 1 plants/stand @ 0.50cm×0.75cm spacing = 2.6 plants/m$^2$ = 26,666 plants/ha
- 1 plant/stand @ 0.25cm×0.75cm spacing = 5.3 plants m$^2$ = 53,333 plants/ha
- 1 plants/stand @ 0.20cm×0.75cm spacing = 6.6 plants m$^2$ = 66,666 plants/ha

The selected sites and number of trials in each site is shown in Table 2.

Table 2: Selected LGAs for validation trials

<table>
<thead>
<tr>
<th>LGA</th>
<th>State</th>
<th>Zone</th>
<th>Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunkure</td>
<td>Kano</td>
<td>SS*</td>
<td>10</td>
</tr>
<tr>
<td>Garun-Mallam</td>
<td>Kano</td>
<td>SS</td>
<td>10</td>
</tr>
<tr>
<td>Kura</td>
<td>Kano</td>
<td>SS</td>
<td>10</td>
</tr>
<tr>
<td>Doguwa</td>
<td>Kano</td>
<td>NGS</td>
<td>10</td>
</tr>
<tr>
<td>Lere</td>
<td>Kaduna</td>
<td>NGS</td>
<td>10</td>
</tr>
<tr>
<td>Ikara</td>
<td>Kaduna</td>
<td>NGS</td>
<td>10</td>
</tr>
</tbody>
</table>

*SS= Sudan Savanna, NGS= Northern Guinea Savanna
The design of field validation experiments was a fractional factorial design with farmer fields serving as blocks accommodating only 10 treatment combinations. The design was a Custom D-optimal design where all main effects and the interaction between sowing densities and variety will be estimated. The plots sizes for the validation trials are described below:

- Number of ridges = 8
- Length of ridges = 5m
- Plot Size = 30 m²
- Net Plot = 4m x 4 inner ridges = 12 m²

5.0 Results and Discussions

5.1 Calibration Trials

Table 3 shows the combined results of the dry and wet season calibration trials. Results for grain yield, above ground biomass, hundred seed weight and number of kernels per cob are shown. For grain yield and number of kernels, a linear trend was observed across the locations. The highest grain yield and number of kernels was observed in Samaru, followed by Lere, which was significantly higher than B.U.K while Dambatta produced the lowest grain yield and number of kernels per cob across the locations. For above ground biomass and hundred seed weight however, significantly higher values were observed in Samaru for all seasons and variables except for the wet season where statistically similar seed weights were observed for Samaru and Lere. In Dambatta, significantly lower values for all variables across both seasons where reported when compared to all other locations. The variety M0926-8 produced significantly highest values of all measured variables in both seasons, although it produced statistically similar grain yields and number of grains per cob with IWD C2 during the wet season and similar above ground biomass with M1026-10 in both seasons. The variety 2009TZEEWDTSTR produced the lowest grain yield in the dry season, lowest above ground biomass, hundred seed weight, and kernel number during both seasons, while TZEYPOPDTSTRC4 x TZEEi13 produced the lowest grain yield in the wet season. The interaction between location and variety was highly significant for all measured variables. Figure 1 shows the interaction between variety and location on grain yield during the dry season. All the varieties consistently produced the highest grain yields in Samaru except for TZLCOMP4DTC2 and TZLCOMP1SYN. Consistently lowest grain yields were produced in Dambatta by all the varieties except for TZLCOMP4DTC2 and TZLCOMP1SYN. The varieties M0926-8, M1227-12, DTSTRW and IWDC2 produced statistically similar grain yields in Lere and Samaru.

The variable response of the varieties across the planting seasons could be attributed to genetic diversity and stability/adaptive abilities of each individual variety as they interact with the environments. Higher grain yields were recorded in the dry season for all varieties than in the rainy season. This could be attributed to better photosynthesis as a result of higher temperatures/solar radiation in the DS coupled with full irrigation which ensured that all the plots are at field capacity throughout the growing period. Higher yields were recorded in the NGS (Samaru and Lere) than in the SS (BUK and Dambatta). This is due to better soils and the fact that maize is more adapted to the NGS than Sudan Savanna. Lowest amounts of grain yields were reported in Dambatta among all the locations irrespective of seasons, this is due to very high daily maximum temperatures (above 45°C) during the pollination and grain filling stages of the crop as experience in Dambatta. Also, the soils in Dambatta are sandy and degraded and might have leached most of the applied nutrients. The hybrid varieties in all cases produced higher grain yields than the open pollinated varieties due to higher heterotic vigor as well as better photosynthesis, respiration, and more vigorous vegetative growth inherent in the hybrids. The late maturing cultivars yielded more than the earlier varieties irrespective of the varietal type (hybrid or OPV). This could be attributed to the fact that the late maturing varieties spend more time in the field and tool longer to reach physiological maturity which ensured higher assimilate production and partitioning to the grains.
5.2 Validation Trials

Figure 2 shows the mean grain yield produced across farmers’ field in the NGS. Emmanuel Lazarus (3950 Kg/ha) produced the highest grain yield among the farmers while Danbaba Nuhu (1,860 Kg/ha) produced the lowest grain yield among all the farmers. Planting maize under the highest density of 66,666 plants produced the highest mean grain yield (3,120 Kg/ha) when combined across farmers and LGAs. The highest grain yield across LGAs when combined for varieties and density was recorded in Ikara LGA. Figure 4 shows the grain yield for varieties when averaged over farms, density and LGA. The highest yield was reported for M1026-10 although it was statistically similar to IWDC2. The lowest yield was recorded for TZLCOMP1SYN. Interaction between variety and density is shown in figure 5. Planting at higher densities consistently led to higher grain yields for all varieties except for OBA98 where the medium density (53,333 plants/ha) produced the highest yield. Lowest yields were consistently produced when the varieties where planted at densities of 26,666 plants per hectare. Planting M1026-10 under 66,666 plants/ha produced the highest grain yield (4,230 Kg/ha) while the lowest yield was recorded when TZLCOMP1SYN was planted under 26,666 plants/hectare.

Variable response in grain yield across farmers’ fields could be attributed to variation in soil inherent characteristics that differs across all sites. The highest densities produced the most yield because of higher number of stands per area which means more number of cobs and therefore higher densities. Also, the higher densities ensured higher LAI meaning better radiation use efficiency which leads to higher rates of photosynthesis. The variation in grain yield across LGAs could be attributed to variation in rainfall and inherent soil properties.

6.0 Contribution to TAMASA

- The data collected from my trials are currently used to produce the Maize Variety Selector (MVS) for Nigeria which is a direct output of Work-stream 4.
- Availability of variety information and genetic coefficients for 22 varieties is a big step towards bridging data gaps for modelling and other purposes, this is directly linked to work-stream 2.
- Availability of soil and weather data for over 60 locations also bridges data gaps and is directly linked to WS2.

References


FAO (2014), Production Year Book. Food and Agriculture Organization of the United Nations, Rome, Italy.
FAO 2015, Production Year Book. Food and Agriculture Organization of the United Nations, Rome, Italy.


Table 1: Grain Yield, Biomass, 100 seed weight, and Kernel number of Maize Varieties across locations in the dry (DS) and wet (WS) seasons of 2016

<table>
<thead>
<tr>
<th>Location</th>
<th>DS</th>
<th>WS</th>
<th>DS</th>
<th>WS</th>
<th>DS</th>
<th>WS</th>
<th>DS</th>
<th>WS</th>
<th>Kernel Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMR</td>
<td>5675a</td>
<td>3681a</td>
<td>9817a</td>
<td>13360a</td>
<td>26.07a</td>
<td>23.49a</td>
<td>753a</td>
<td>697a</td>
<td></td>
</tr>
<tr>
<td>LERE</td>
<td>5162b</td>
<td>3633a</td>
<td>8979b</td>
<td>9929b</td>
<td>24.22b</td>
<td>23.46a</td>
<td>729b</td>
<td>674b</td>
<td></td>
</tr>
<tr>
<td>BUK</td>
<td>4053c</td>
<td>3148b</td>
<td>8936b</td>
<td>8993c</td>
<td>23.77b</td>
<td>22.46b</td>
<td>609c</td>
<td>649c</td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>2948d</td>
<td>2384c</td>
<td>8135c</td>
<td>7604c</td>
<td>22.37c</td>
<td>20.49c</td>
<td>519d</td>
<td>451d</td>
<td></td>
</tr>
<tr>
<td>SE±</td>
<td>24.83</td>
<td>28.7</td>
<td>206.9</td>
<td>143.1</td>
<td>0.276</td>
<td>0.07</td>
<td>2.2</td>
<td>1.8</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter(s) are not statistically different at 5% level of significance using Fishers’ unprotected LSD

** = Significant at 1% level of significance

DS = Dry Season, WS = Wet Season
Figure 1: Interaction of Variety x Location on grain yield for dry season calibration trials
Figure 2: Grain Yield across Farmers’ Fields in the NGS

Figure 3: Grain Yield across LGAs and planting density in the NGS
Figure 4: Grain yield of Maize Varieties in the Northern Guinea Savanna

Figure 4: Interaction between Variety and Density in NGS