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Modeling Sorghum yield in response to inorganic fertilizer application in semi-arid Ghana

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Abstract

In semi-arid Ghana, cereals production is characterized by low external inputs. Over the last decades this has resulted in depletion of soil nutrients. The conventional system of restoring moderate soil fertility on bush farms by extensive fallow periods is no longer effective. Hence, the cultivation of cereals like Sorghum (Sorghum bicolor (L.) Moench) is restricted to the compound farms where manure is applied. The demand for Sorghum by far outweighs its production. Thus, there is a need to explore the use of mineral fertilizer in both the compound and bush farms, and also to assess the seasonal fluctuation of grain yield in view of an adaptive risk management, using a crop simulation model – DSSAT. It uses weather, soil, and crop management data as input parameters. The model was calibrated with data collected under optimum growth conditions and evaluated with independent data collected on different rates of mineral N fertilizer application. DSSAT predicted grain yield creditably with a modified un-bias absolute percentage error of 28. A value to cost ratio analysis indicated mineral fertilizer use was profitable in both management systems with the application of 40 and 80 kg N ha^{-1} *yielding the highest benefit in the homestead and bush farms respectively. Yield projections of yield into 2035 on both systems, revealed higher risks in mineral fertilizer use on the bush farms. DSSAT, however at present does not simulate P dynamics, hence not very suitable for simulating yield on P deficient soils.*

Key words: Modelling, Soil productivity, Sorghum yield.

Introduction

In semi arid Ghana, cereal production is characterized by low external inputs in parts because the costs of these inputs are beyond their reach. The conventional system of restoring moderate soil fertility on bush farms by extensive fallow periods is no longer effective due to ever increasing population pressure on the land resources (Braimoh and Vlek, 2004) and the annual bush fires that that has characterized the area. Over the decades this has resulted in depletion of soil nutrients. Hence cultivation of cereals like Sorghum (*Sorghum bicolor* (L) Moench) is restricted to the compound farms where manure is applied. The demand for Sorghum has by far outweighed its production. Thus, there is the need to explore the use of mineral fertilizer in both the compound and bush farms. Additionally, investigate the temporal fluctuations in crop yield due to variation in rainfall onset and amount as it constitutes a major risk to the effectiveness of mineral fertilizer through unavailability of adequate water for plant growth.

Traditional agronomic approaches were experiments are conducted are site, time and space specific with the outcome results being season specific. Current innovations with decision support systems such as DSSAT – CSM provides an approach which integrates knowledge of soils, site information, crops, weather and management practices to estimate crop yield and growth. Crop models can also be used in quantifying the effect of the variability of weather and different management strategies on crop yield (Lagacherie et al., 2000). In order to use the latter approach, following objectives were set out (1) to calibrate and evaluate the DSSAT – CSM for the study area, (ii) Assess the feasibility of mineral fertilizer use, (iii) and also assess the seasonal fluctuation of grain yield in view of an adaptive risk management, using a crop simulation model – DSSAT

Materials and Methods

Data Collection

Experimental data used for the calibration of the DSSAT model, were principally generated from two planting date trials conducted in Pungu, in the Upper East portion of the Volta basin (Ghana). The cultivar used was ICSV III, a pure-line cultivar developed at ICRISAT Asia center, Patancheru, India. Sorghum was cultivated under optimum conditions (no water or N limited growth conditions) for two different planting dates within the growing season (June – September) in the semi- arid region of Ghana. The plants were monitored and phenological data which included planting date, date of flowering, date for grain filling date of maturity and date of flag leaf stage. To evaluate the model, an experiment was set up in a randomized complete block design and four different levels of mineral N fertilizer were applied in the homestead farms as well as the bush farms. Treatments were replicated seven times in the homestead and four times in the bush farms.

Model calibration and evaluation

Based on the phenological data collected, thermal degree times (P1, P5 and PHINT) was calculated from temperature data collected for the study area using algorithms described by Jones and Kiniry (1986). Estimated parameters relating to each of the replicates in each planting date were used to calibrate the CERES – Sorghum (Crop Evaluation through Resource and Environment) model (Jones et al., 1998). The radiation use efficiency of 3.2 g plant dry matter/MJ PAR was adjusted to 3.8 as used for sorghum in DSSAT version 3.5 (Ritchie et al., 1998) as the model was under predicting yield.

The genetic coefficients were calibrated until there were appreciable agreements between measured and observed values for phenology and yield data. The experiments were run with each set of genetic coefficients (associated with each replicate in a planting date) and the simulated and observed yield values used to compute the root mean square error (RMSE). RMSE is defined as;

$$RMSE = [n^{-1} \sum (Yield_{Calc} - Yield_{meas})^{2}]^{0.5}$$

where n is the number of replicates in each planting date experiment, *calc* and *meas* denotes simulated and measured yield for each replicate. Statistical methods were employed in assessing the performance of the crop simulation models in comparison with field measured/observed data. Methods used included Tukey test of pair wise comparison, coefficient of determination (R^2), root mean square error (RMSE) and modified unbiased absolute percentage error (MdUAPE). The MdUAPE is;

$$MdUAPE = 100 * Median\left[\frac{|simulatedi - observedi|}{1/2(observedi + simulatedi)}\right]$$

Results and Discussions

Model calibration and evaluation

Weather and phenological data for each planting date experiments were used to determine two different sets of genetic coefficients. Each set of coefficients were used to simulate grain yield for both planting date and RMSE calculated for each set of coefficients. The set genetic coefficient with the lower RMSE was selected as the more appropriate set of genetic coefficients of the cultivar (Table 1).

Table 1 Comparison of predicted and measured yield from DSSAT model using two data sets.

Parameter set	RMSE
200 C	119
200 D	154

200 C and 200 D: genetic coefficient sets for the first and second planting dates respectively.

Sorghum grain yield in response to different application of mineral fertilizer was reasonably predicted by the DSSAT – CSM with a median unbiased absolute percentage error of 28 and a RMSE of 0.36 t ha^{-1}. Pair-wise comparisons of observed and simulated values indicate no significant difference ($p = 0.05$). The MdUAPE calculated for both management systems were below 30. The RMSE measured were also low, 0.19 and 0.37 t ha^{-1} for the bush farm and homestead respectively. These results are comparable to those of Mavromatis et al., 2001 in their study on developing genetic coefficients for CSM with data set from crop performance trials. Simulations on the Plinthosols in the bush farm were better than those on the homestead were organic manure was applied, a probable indication that the model simulates mineral fertilizer better than organic fertilizer in this region. Figure 1 below illustrates plots of average observed grain yield values with their respective standard deviations and simulated values. Yield were generally well predicted within the standard deviation of measure values, except for the treatment with 40 kg N ha^{-1} were the simulated values were overestimated and out of the range of the standard deviations.

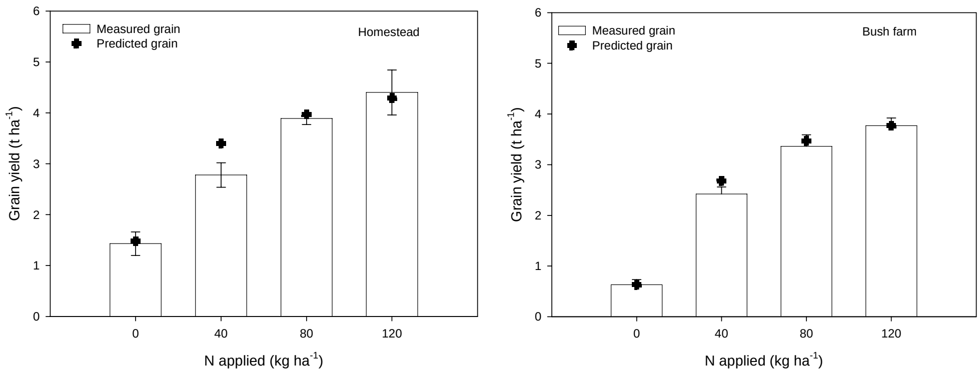

Figure 1 Comparison of measured (mean) grain yield of Sorghum and simulated yield values under different rates of inorganic N applications on the homestead and bush farms (Plinthosol)

Model application

Since farm management has been reported to have much to do with managing risk, with its impact on food security and also reason for low pace in adopting new technologies (Walker and Ryan, 1990), a value to cost analysis was carried out. A value to cost ratio indicate that application of 40 kg N ha^{-1} yielded the highest benefit to farmers on the homestead (Plinthosols) whilst 80 kg N ha^{-1} yielded the highest value to farmer on the bush farm (Plinthosols). Thus mineral fertilizer can be used in both the homestead and bush farms with benefits accrued to farmers.

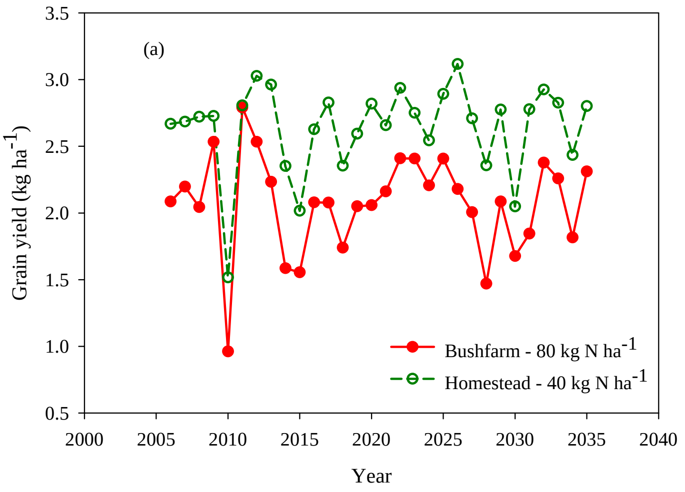

Figure 2 Projection of Sorghum grain yield on different management systems

Sorghum grain yield at 40 kg N ha^{-1} in the homestead were consistently higher than at 80 kg N ha-1 in the bush farm for all projected years (Figure 2). The higher grain yield in the homestead at half the amount of mineral fertilizer applied in the bush farm can be attributed to the multiple benefits provided by the organic manure. Yield projections into 2035, highlighted that, the amount and distribution of rainfall poses a higher risk to efficient use of mineral fertilizer on both management systems, with the risks being higher in the bush farm soil with lower organic matter content as opposed to the homestead soils which are relatively enriched by the application of manure.

Conclusion

The use of mineral fertilizer in Sorghum cultivation is feasible in both management systems with higher returns from the homestead. Also, the risk of lower Sorghum yield due to variability in rainfall is higher in farms with lower soil organic matter content. Smallholder farmers would be well off by investing in organic manure to reduce risk associated with variability in rain fall distribution and amounts. The model thus, provides a sound scientific anticipation into yield variations and can serve as an input to policy and decision making. DSSAT, however, does not simulate P dynamics for Sorghum, hence, limiting its use on P limiting soils.

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