Evaluation of Yield Advantage and Water Productivity of Maize-Groundnut Inter-Cropping Systems in the Dry Zone of Sri Lanka using Agricultural Production Systems sIMulator (APSIM)

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Abstract—**The APSIM (Agriculture Productions Systems SImulator)–Maize & Groundnut model has been utilized on a global scale to assess the effects of various farming practices on the growth of maize and groundnut intercropping. However, limited attention has been given to modeling the crop productivity (t/ha) and water productivity (t/ha/m^3) of maize and groundnut intercropping under conditions such as rainfed or rainfed with supplementary irrigation, in tropical SouthAsia. To address this gap, we tailored and assessed the APSIM–Maize & Groundnut intercropping model for two widely cultivated Sri Lankan varieties: *Pacific* (Maize) and *Lanka Jumbo* (Groundnut). The APSIM model was introduced to simulate the growth, development, and yields of maize-groundnut intercropping in the Dry Zone of Sri Lanka, utilizing field experimental data. The model calibration process involved utilizing the first set of data to determine varietal parameters. The simulation results demonstrated a high level of agreement between the simulated values and the actual measurements during the growing periods as RMSE and RRMSE values for maize yield were 0.89 t/ha and 11.37% while that for groundnut was 0.108 t/ha and 7.7%. RMSE (Root Mean Square Error) quantifies the average prediction error in the same units as the target variable. RRMSE (Relative RMSE) normalizes RMSE by the range of observed values, providing a percentage-based measure for better comparison across datasets with different scales. The model accurately predicted grain yield for maize and groundnut under moisture-limited field conditions, showcasing a strong fit with the observed data. This fit was consistent across various factors, including cultivation year, season, time of planting (i.e., with rainfall or based on specific planting dates), variety, and water management practice (e.g., completely rainfed or rainfed with supplementary irrigation). Traditionally, many maize farmers grow this crop as a standalone crop. However, introducing groundnut as a secondary crop alongside maize offers advantages such as additional income and enhanced soil fertility. It was evident from the results that maize-groundnut intercropping can be used to get a high yield with a limited amount of water during periods of low rainfall such as the *yala* season and it is a very good solution to water scarcity. In situations where rainfall or other essential factors are delayed, employing crop modeling with APSIM becomes crucial to augment reliance on supplemental water resources and meet the specific requirements for maize and groundnut crops.**

Keywords—Maize, groundnut, intercropping Water productivity, APSIM, yield advantage

I. INTRODUCTION

APSIM is well-known for its capacity to model diverse facets of agricultural systems, encompassing crop growth and development, soil processes, water balance, nutrient cycling, and the effects of climate variability. By integrating these elements into a cohesive simulation framework, APSIM offers valuable insights into how various factors affect agricultural productivity and sustainability [1].

Maize (*Zea mays L.*), is a cereal crop globally, serving as a staple food, animal fodder, and a crucial raw material for diverse industrial applications [1]. Maize holds significant importance in Sri Lanka due to its versatile applications and economic contributions. As a staple crop, maize plays a vital role in the country's food security, providing a source of nutrition for the population. Additionally, maize cultivation supports the livelihoods of many farmers, strengthening the agricultural sector. Maize is a key ingredient in livestock feed production, supporting the poultry and dairy industries. Moreover, the crop serves as a vital raw material for various industries, including food processing, starch production, and biofuel manufacturing. Its multifaceted role underscores its pivotal position in Sri Lanka's agriculture and economy.

Groundnut (*Arachis hypogaea L.*), commonly known as peanut, holds significant economic and nutritional importance in Sri Lanka as a vital oilseed crop. Tracing its origins back to South America, this leguminous plant has become a fundamental aspect of the country's agriculture, contributing to both subsistence and commercial farming. Groundnut is highly valued for its versatility, ranging from being a source of edible consumption to the extraction of high-quality oil, making it a crucial commodity in the domestic market and a potential contender in the global market.

Intercropping, the concurrent cultivation of two or more crops in close proximity, is a practice deeply ingrained in traditional agriculture worldwide. In Sri Lanka's agricultural landscape, primarily dominated by smallholder farmers, intercropping systems hold significant promise for enhancing productivity, ensuring food security, and promoting sustainable agricultural practices. Maize and groundnut intercropping has gained attention recently as a promising intercropping system, in the Dry Zone (DZ) of Sri Lanka.

Sri Lanka's DZ, known for its limited and unpredictable rainfall, poses unique challenges for agriculture. Within this region, optimizing water usage is crucial to ensure agricultural productivity and livelihood sustainability. Intercropping, a practice involving the simultaneous cultivation of two or more crops on the same piece of land, offers a potential solution Therefore, the aim of the study was to evaluate the performance of a locally adapted APSIM Maize - Groundnut model for simulating crop and water productivity of Maize-Groundnut intercropping system.

II. METHODOLOGY

A. Field Experiment

The field experiment was conducted from November 2022 to September 2023 in consecutive *Maha* and *Yala* seasons at Field Crop Research and Development Institute (FCRDI), Mahailuppallama. (8.0729° N, 80.8743° E) located in the DZ Mahailluppallama, Anuradhapura, Sri Lanka. The Experiment was designed as a Randomized Complete Block Design (RCBD) in triplicates. Maize variety *Pacific* and groundnut variety *Lanka Jambo* were used as crop varieties. Each block was comprised of a randomly assigned maize monocrop plot (spacing: 0.6 x 0.3 m), a groundnut monocrop (spacing: 0.45 x 0.15 m) plot, and a maize-groundnut intercropping plot (spacing maize; 0.45 x 0.3 m; spacing groundnut: 0.3 x 0.25 m). Each plot size was 12 x 4.05 m. All management practices were carried out according to the recommendations of the Department of Agriculture, Sri Lanka.

Crop phenology and growth data were collected as seedling emergence, number of days to reach 50% flowering, Leaf Area Index (LAI), and total above ground dry weights. Dry weights were measured using a one-square-meter sampling area at 50% flowering for both maize (silking) and groundnut and, during the harvest.

B. Modelling Experiment

The APSIM 7.10 version was used for the modelling exercise.

Input data: Climate data were collected from a local weather station in the Mahailluppallama study area from 2003 - 2023. Physical and chemical parameters of soil data gathered from laboratory analysis and as secondary data. The crop and management data were fed according to department recommendations, as they had been implemented in a field experiment.

Parametrization and validation: Model parameterization was done using the field experimental data and the validation was done by using the previous experimental data conducted by FCRDI in previous years and seasons. The performance of the model was evaluated by comparing simulated data such as crop yield and growth parameters with field measurements and also used a 1:1 graph for qualitative (graphical) validation and RMSE “(1)” value and RRMSE “(2)” value for quantitative (statistical) validation.

(1) $RMSE = \{\sqrt{\sum_{i=1}^{n}(Y_i - \hat{Y_i})^2}/n$
(2) $RRMSE = RMSE/\max(Y) - \min(Y)$

Yield advantage and water productivity: The yield advantage was evaluated by calculating the Land Equivalent Ration (LER) and the water productivity was calculated as follows.

$$Water\ Productivity = \frac{Yiled\ (t/ha)}{water\ requirement\ (mm)}$$

Scenario Analysis: Scenario analysis for maize-groundnut intercropping was done using APSIM with 20 years of past weather data to evaluate the yield stability of the intercropping system across long-term climate variations.

III. RESULTS

A. Yield Advantage of Maize-Groundnut Intercropping

According to the results, the Land Equivalent ratio (LER) calculated from experimental data for maize-groundnut intercropping was 1.74±0.2 indicating the yield advantage of the intercropping system. In validation, it was found that RMSE and RRMSE values for maize yield where was 0.89 t/ha and 11.37% while that for groundnut were 0.108 t/ha and 7.7% indicating good model performance [3].

Figure 1, 1:1 graph shows a visual representation of the fitness of simulated and observed yields. Data points of both maize and groundnut yields of the intercropping system were fitted well close to 1:1 line indicating the good fitness.

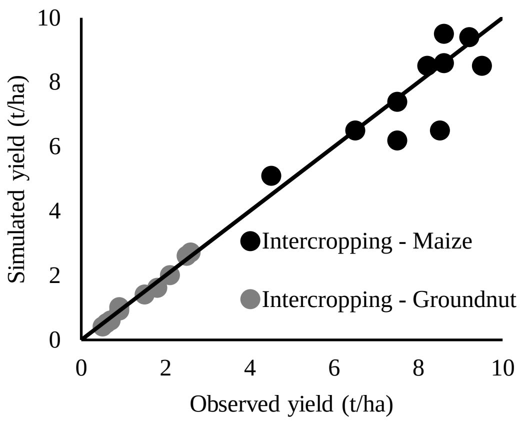

Fig. 1. Observed and Simulated Yield of Maize-Groundnut Intercropping in MI

B. *Maximum Water Productivity*

As shown in Figure 02, it was found that simulated and observed water productivities for monocrop and intercrop were in good agreement indicating APSIM model's capability of simulating water productivity in both monocropping and intercropping systems. The observed results indicated that Maize in intercropping system gave a higher water productivity than its monocropping.

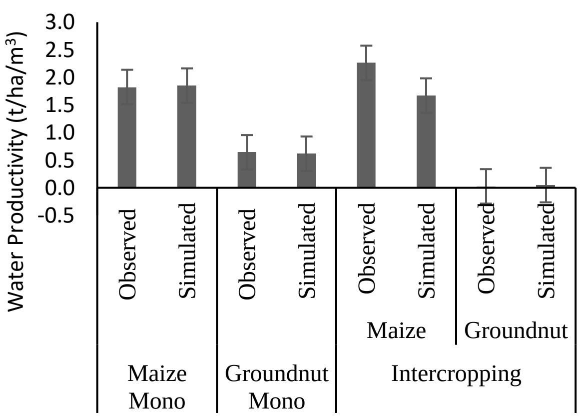

Fig. 2. Observed and Simulated Water Productivity of Maize Groundnut Monocropping and Intercropping in MI (2022/23 Maha Season)

IV. Discussion

The aim of this study was to evaluate the performance of maize-groundnut intercropping system which was recently found as a promising system in the dry zone of Sri Lanka. Since the value of LER was 1.74±0.2, which was greater than 1 indicates a yield advantage. Therefore, this system can be effectively practiced by farmers in the dry zone of Sri Lanka. The dry zone region of Sri Lanka, particularly during the *yala* season, grapples with water scarcity, significantly impacting crop cultivation. In light of this challenge, employing an intercropping system emerges as a principal and highly effective solution. The study scrutinizes the maximum water productivity of crops, particularly focusing on maize and groundnut monocrops. Water requirements for maize monocrop and groundnut monocrop were observed at 1.8 t/ha/m^3 and 0.6 t/ha/m^3, respectively, representing the essential amount of water necessary for their optimal growth in a monoculture scenario. However, the study underscores that in the intercropping system, the total water requirement was reduced as ground nut showed a lower water requirement in the intercropping system. Accordingly, for maize, the water requirement was 2.2 t/ha/m^3, whereas for groundnut, it was a considerably lower 0.02t/ha/m^3. Thus, intercropping manifests as a prudent strategy that optimizes water use, showcasing considerable water-saving potential compared to conventional monocrop cultivation. APSIM simulation model, a sophisticated tool in the agricultural modeling. This model operates by simulating crop growth, water utilization, and resultant yields based on specific input parameters. The results of model validation confirmed specifically with the RRMSE values that APSIM model could simulate the yields of maize and groundnut cultivars used in the experiment with good accuracy [3]. Thus, simulated outcomes aligned proportionally with the observed data, thereby validating the accuracy and reliability of the APSIM model in predicting maize and groundnut crop yields within an intercropping. The presented details highlight the importance and the potential of maize-groundnut intercropping as a pivotal approach to address the water scarcity issues in the dry zone of Sri Lanka, showcasing how it significantly economizes water usage while augmenting crop yields. Moreover, the inclusion of advanced simulation tools like APSIM enriches the research, affirming the credibility of intercropping strategies through data-driven modeling and predictions.

V. Conclusion

This study shows the potential of intercropping, particularly maize-groundnut intercropping, as a sustainable approach to water conservation and enhanced agricultural productivity. When combined with the use of advanced simulation tools like APSIM and following expert recommendations for optimal management, intercropping becomes a promising solution to address water scarcity and achieve high agricultural yields in Sri Lanka and similar regions.

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Reference

[1] Dilla, Aynalem, et al. "Potential of the APSIM model to simulate impacts of shading on maize productivity." Agroforestry Systems 92 (2018): 1699-1709.

[2] Amarasingha, R. P. R. K., et al. "Simulation of crop and water productivity for rice (Oryza sativa L.) using APSIM under diverse agro-climatic conditions and water management techniques in Sri Lanka." Agricultural Water Management 160 (2015): 132-143.

[3] De Silva, S.H.N.P., Takahashi, T., & Okada, K. Evaluation of APSIM-wheat to simulate the response of yield and grain protein content to

nitrogen application on an Andosol in Japan. Plant Production Science, 24(4) (2021).

[4] water requirements in Sri Lanka." Agricultural water management 93.1-2 (2007): 19-29

[5] Liu, ZhiJuan, et al. "Adaptability of APSIM maize model in northeast China." Acta Agronomica Sinica 38.4 (2012): 740-746