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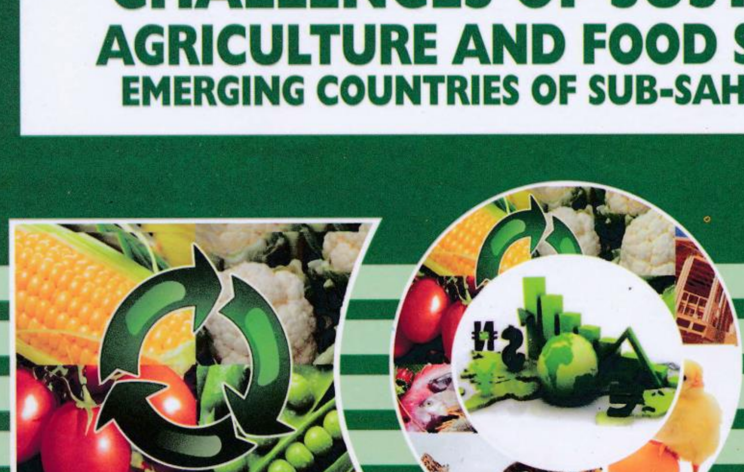

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CALIBRATION AND VALIDATION OF APSIM-SORGHUM (*SORGHUM BICOLOR (L.) MOENCH*) FOR SIMULATING GROWTH AND YIELD IN CONTRASTING ENVIRONMENTS IN NIGERIA

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Abstract

In semi-arid Nigeria, sorghum production is regarded as amajor cereal for food grain and fodder, predominantly grown under rainfed conditions. Witha demand for sorghum outweighing its current production, there is a need to explore a wide range of sorghums adapted to contrasting productionenvironments. In this study, we calibrated APSIM-Sorghum for phenological development, total leaf number(TLN), total biomass(TB) and grainyield (GY) of five(5) contrasted sorghum cultivars under optimum growth rainfed conditions in Nigeria: ICSV-400(early maturing, photoperiod insensitivity), Improved Deko (medium maturing, low photoperiod sensitivity), Samsorg-44 and CSR01(medium maturing, medium photoperiod sensitivity), and SK5912 (late maturing, high photoperiod sensitivity). Cultivars wereplanted at different dates during the 2016-2018 cropping seasons in the Guinea savanna and Sudan Savanna agroecological zones. Simulation results were thereafter evaluated against independent data collected fromon-farm technology demonstrations during 2013-2017.Phenology was captured with high accuracy (MBE: 1-4 days; normalized RMSE<10%). Grain yield and total biomass ranged from high accuracy RMSEn (SK5912: 9.2% for GY; 6.9% for TB)to fairly low RMSEn (34.5% for GY; 36.8 % for TB) of the observed mean across the sorghum cultivars. Furtheradjustment of cultivar-specific parameters provided a better agreement between simulated and observed grain yield for medium and late maturing cultivars thanfor early maturing cultivars.

Introduction

Agricultural system models have an important role in informing farmer practice (Hochman *et al.*, 2009), breeding strategies (Cooper *et al.*, 2009) and government policy (Bezlepkina *et al.*, 2010) that aim to address challenges such as food security and climate adaptation and mitigation. APSIM (Agricultural Production Systems sIMulator) is one such model that continues to be applied and adapted to this challenging research agenda (Keating *et al.*, 2003; Holzworth *et al.*, 2014). Specifically, APSIM can be described as a quantitative scheme for predicting the growth, development, and yield of a crop, given a set of genetic features and relevant environmental variables (Akinseye *et al.*, 2017).It is a valuable tool to understand crop physiology and ecology and to analyse and optimize planting (Dong *et al.*, 2014) and fertilizer management (Kpongor *et al.*, 2006; Akinseye *et al.*, 2018), inter alia.

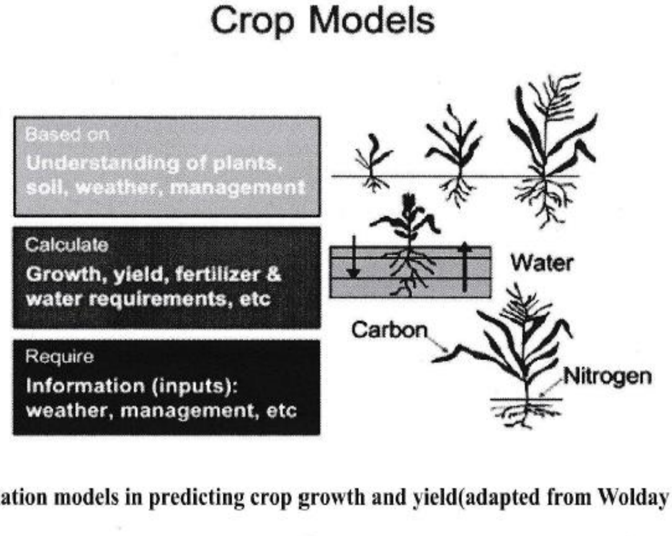


Figure1: Crop simulation models in predicting crop growth and yield(adapted from Wolday and Hruy, 2015)

Sorghum (*Sorghum bicolor*L. *moench*) is a major cereal for food grain and fodder crop, grown under predominantly rainfed conditions in semi-arid and sub-humid West Africa region (Abdel-Ghani *et al.*, 2015) where it has a comparative advantage over other rainfed crops like maize and rice (Ajeigbe *et al.*, 2018a,b). Encouraged by Nigeria's favourable government policy towards substitution of commodity imports for local production, demand for sorghum largely outweighs production. Industrial demand, in particular, is currently estimated to exceed total production by 20% and is predicted to increase with time. However, the growth and yield of sorghum can be limited by both abiotic and biotic factors,including weather (rainfall and temperature), soil conditions (water, and nutrients), parasitic weeds (Striga), disease incidence and management practices (cultivar, fertilization) (Ajeigbe *et al.*, 2010b), and pests.To explore the specific adaptation of varied sorghum germplasm to the wide range of production environments,crop simulation models such asAPSIM can help by evaluating crop response to variable risk management practices(e.g. planting date, fertilization strategies etc.), climate (e.g. rainfall amount and distribution) and soil types. The present study aims to(i) calibrate and evaluate APSIM for five (5) contrasted sorghum cultivars tested under optimum conditions and (ii) validate the performance of APSIM-sorghum using on-farm yield and management data for simulating grain yield over contrasting environments.

Material and Methods

Calibration data

Experimental data used for the calibrationwere generated from 2016-2018 on-station experimentsrepresenting the range of target environments for the study (Ajeigbe *et al.*,2018a,b).The contrasted sorghum cultivars used ranged from early to late maturing, low to high photoperiod sensitivity. Crop phenology and growth data such as sowing, flowering and maturity dates,yield and final biomass were provided from varietal characterization trials conductedin both the Southern Guinea Savanna and Sudan Savanna agroecological zones.

Validation data

A 2013-2017 dataset documenting the on-farm impact of various improved agronomic practices on the five sorghum cultivarswereused for model validation. Agronomic technologies involvedincluded seed dressing techniques, conservation agriculture (minimum tillage) and fertilization strategies aiming at increasingsorghum productivity. The dataset also included information from on-farm breeding trials. A total of 3,266 observed yield spread across four agroecological zones were thus assembled thatincluded the basic management data (sowing date, fertilizer application rate) and reference geographical coordinates (either at LGA or communities level) for each trial location.

Soil and weather data

For the purpose of this study,weather data were sourced from downscaled CHIRPS rainfall at 5.5km resolution (Funk*et al.*, 2015), then merged with NASA Power (temperature and solar radiation). Two sources of soil information were used: (i) field measured soil characteristics drawn from the Reconnaissance Soil Survey of Nigeria (FMARD,1990) and from a more recent soil survey in Kano, Kaduna and Kastina states (TAMASA project, 2015-2018); and (ii) downscaled ISRIC soil grids data with standardized layers depths at 5, 15, 30, 60, 100, and 200 cm. CHIRPS and NASA power data were combined and converted into a format readily ingestible by APSIM using R. Likewise, R was used to convert ISRIC soil grids into APSIM. SOIL format (including merging of 0-5cm and 5-15cm layers into a 0-15cm topsoil layer).

Model calibration and validation

APSIM-sorghum module (v. 7.9) was calibrated and validated for five sorghum varieties: ICSV-400(early maturing,low photoperiod sensitivity), improved Deko (medium maturing,low photoperiod sensitivity), Samsorg-44 & CSR01 (medium maturing and medium photoperiod sensitivity), and SK5912 (late maturing and high photoperiod sensitivity). Input data required by APSIM include cultivar's name, crop management practices/information, soil properties and daily rainfall, temperature (minimum and maximum) and solar radiation. Genetic coefficients were adjusteduntil agreement was reached between measured and observed values for phenology, total leaf number (TLN)and yield data. Simulation experiments were run with each set of genetic coefficients(associated with each replicate across the planting dates). Thereafter, simulated and observed yield wereused to compute mean bias error (MBE), absolute and relative root mean square error(RMSE).

Result and Discussion

APSIM accurately simulated phenology(days to 50% flowering and maturity) with respective mean bias error (MBE) of-3.9 to 3.5 days and 1.2 to 2.4 days, while RMSE (absolute value and % of the mean observed) confirmedthe robustness of the predictions (Table 1). The model adjustment of leaf appearance rate for leaf ligules help to get accurate total number of leaves (TLN) per plant, close to the observed mean. Model estimated TLN with MBE of 1-5 leaves per plant and relative RMSE ranging from high accuracy (6.4% for improved Deko) to fairly low accuracy (26.2% for Samsorg-44). Similar results wereearlier attributed to model inability to capture the early growth stage of the crop (Akinseye *et al.*, 2017).

Grain yield and total biomass were acceptably simulated across the fivecultivars within the bounds of statistical error(Figure.2). ICSV-400 featured the lowest MBEof 50 kg.ha^{-1} followed by improved Deko (114 kg.ha^{-1}). CSR01 displayed the highest MBE (436 kg.ha^{-1}). Relative RMSE ranged from high accuracy for SK5912 (9.2%) to very low accuracy for CSR01 (34.5%).Similarly for total biomass, relativeRMSE ranged from high accuracy for SK5912 (6.9%) to very low accuracy for improved Deko (36.8%).

Model validation againstthe 2013-2017 on-farm yield data, indicating better performance for grain yield onmedium and late maturing cultivars (Samsorg-44, CSR01 and SK5912) is depicted in Figure.3Overestimation of grain yield for ICSV-400 and Improved Deko could be associated to low recorded on-farm yield levels over 80% of the on-farm yield levels $\leqslant$ 2000kg/ha against potential yield of 2500-3500 kg/ha for ICSV400 and 3500-4000kg/ha for Improved Deko, followingother management and methodological issues.APISM thus demonstrated robust predictions of phenology (flowering, maturity) and variable predictions of growth (TLN, grain yield and total biomass) for the five sorghum cultivars of interest. By estimating crop phenology accurately, model will be able to capture all genotypic variations which affect the leaf area development, biomass production and grain yield (Robertson *et al.*, 2002).

Table 1: Model performance for simulating phenological development and totalnumber of leaves (TLN) of contrasting sorghum cultivars calibrated under optimum conditions

Cultivar parameters	**Unit**	**N**	**MBE**	**RMSE**		**Observed range**	**Observed mean**
				Absolute value	**% of mean observed**		
ICSV-400- Early maturing and low photoperiod sensitivity							
50% Flowering	DAP	9	-0.7	3.4	4.9	63 - 75	69
Physiological Maturity	DAP	9	1.9	3.9	3.8	92 - 106	98
Total Leaf number		4	3.4	3.5	20.5	16 - 18	17
Improved Deko -Medium maturing , low photoperiod sensitivity							
50% Flowering	DAP	7	-3.9	6.6	7.9	75 95	84
Physiological Maturity	DAP	7	1.2	5.5	5.0	107 - 122	110
Total Leaf number		4	0.4	1.2	6.4	16 -19	18
Samsorg-44-Medium maturing , medium photoperiod sensitivity							
50% Flowering	DAP	4	0.9	3.0	3.0	85 -114	99
Physiological Maturity	DAP	4	2.4	4.0	3.2	112-140	126
Total Leaf number		4	5.1	5.2	26.2	19 -23	20
CSR01-Medium maturing , medium photoperiod sensitivity							
50% Flowering	DAP	4	1.6	2.7	2.7	84 -112	98
Physiological Maturity	DAP	4	1.9	3.1	2.4	115 -143	129
Total Leaf number		4	4.0	4.1	19.5	19 -24	21
SK5912-late maturing , high photoperiod sensitivity							
50% Flowering	DAP	4	3.5	4.7	4.4	95 -122	108
Physiological Maturity	DAP	4	2.0	4.1	3.0	122 -149	135
Total Leaf number		4	3.8	4.0	17.6	20.4-25.4	23

MBE = positive implies over-simulated mean observed; negative impliesunder-simulated the mean observed value

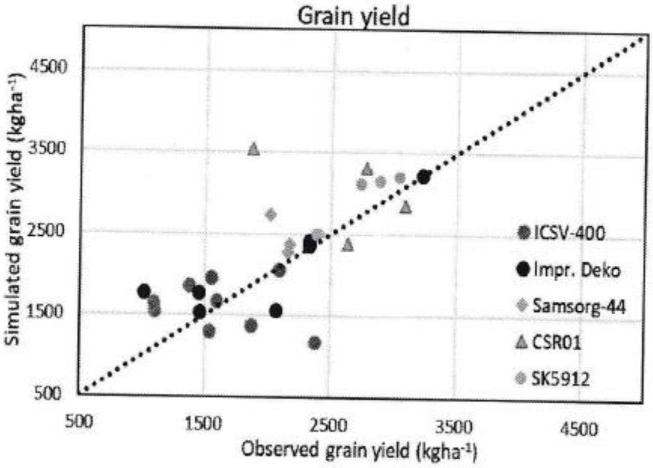


Figure.2a – Observed vs. simulated grain yield using experiment conducted 2016-2018 growing seasons for cultivars ranged from early to late maturing.
ICSV-400 (MBE =5.0 kgha^{-1};RMSE =532kgha^{-1},RMSEn =33.7%); Improved Deko (MBE= 114 kgha^{-1},RMSE = 370 kgha^{-1},RMSEn =18.7%); Samsorg-44 (MBE= 279 kgha^{-1};RMSE = 377 kgha^{-1},RMSEn =17.2%);CSR01 (MBE= 436 kgha^{-1},RMSE = 896 kgha^{-1},RMSEn =34.5%);SK5912 (MBE= 234 kgha^{-1};RMSE = 254 kgha^{-1}, RMSEn = 9.2%)

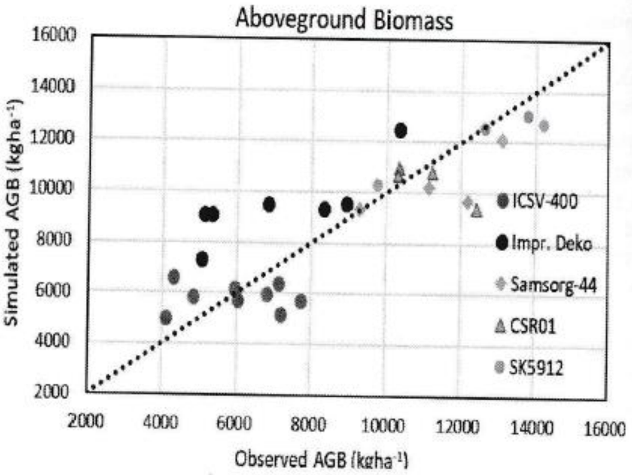
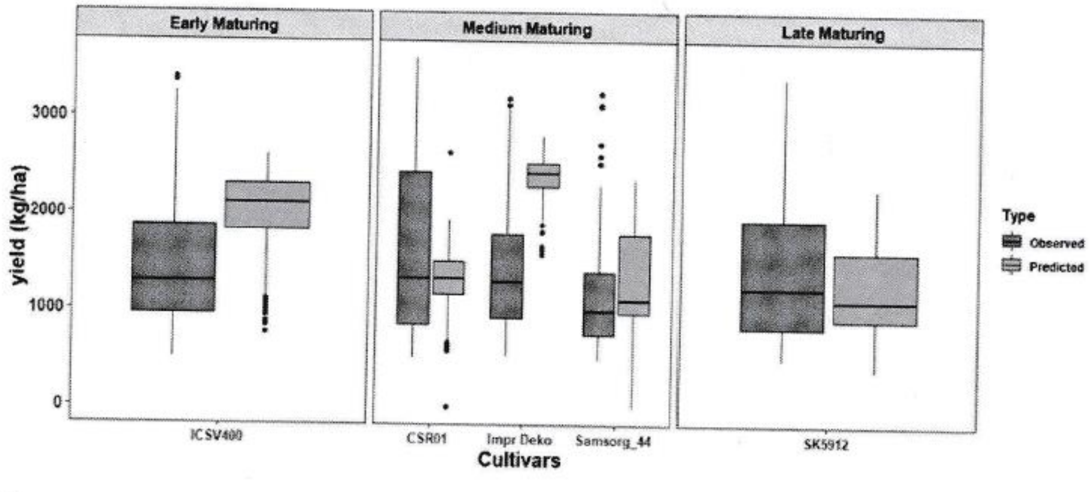


Figure 2b – Observed vs. simulated total biomass using experiment conducted 2016-2018 growing seasons for cultivars ranged from early to late maturing.
ICSV-400 (MBE =149kgha^{-1}, RMSE = 1353kgha^{-1},RMSEn =22.5%); Improved Deko (MBE=2344 kgha^{-1},RMSE = 2621 kgha^{-1},RMSEn =36.8 %); Samsorg-44 (MBE= 1100 kgha^{-1};RMSE = 1432 kgha^{-1},RMSEn =12.5%);CSR01 (MBE= -615 kgha^{-1},RMSE = 1583 kgha^{-1},RMSEn =14.3%);SK5912 (MBE= -429kgha^{-1};RMSE = 868 kgha^{-1}, RMSEn = 6.9 %)



Conclusion

APSIM-sorghum model depicted great potentialto simulate phenological stages (flowering and maturity day), morphological trait (leaf number),total biomass and grain yield close to the mean observed field data of the crop.The model evaluation indices MBE, RMSE and RMSE$_n$,confirmed the robustness of the model for simulating sorghum crop. The calibrated cultivars in the model could therefore be used as research tools to provide differentmanagement options under rainfed conditions. Thus, providing a sound scientific anticipation into yield variations in the contrasting environments in the semi-arid can serve as an input to policy and decision making.

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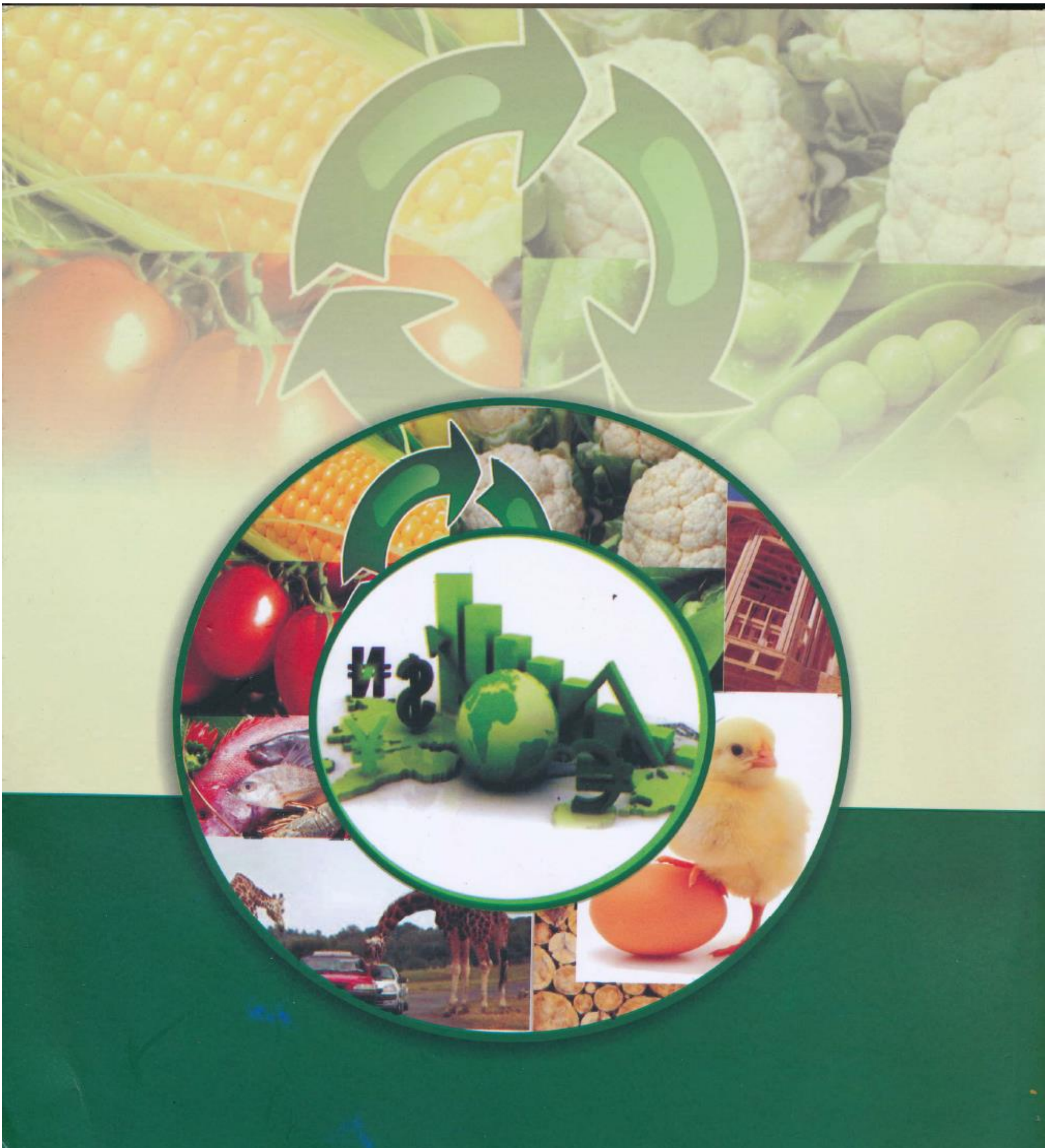

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