Evaluation of Agricultural Production Systems Simulator (APSIM) as a Yield Predictor for Maize Cropping Systems in Sri Lanka

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Abstract - Contemporary agriculture undergoes enormous challenges in order to compensate the increasing food demand of the rapidly growing global population. Crop intensification is crucial to address that rising food requirement whilst focusing on the potential environmental impacts of intensive agriculture. Crop models are deployed in crop intensification process ensuring sustainability through virtualization of interactions between climate, soil, management practices and genotypes. Among the crop models, Agricultural Production Systems Simulator (APSIM) which is comprised of sub models capable of predicting crop yields and phonological parameters through integration of underlying factors. Present study evaluates the applicability of APSIM-maize sub model in yield prediction under Sri Lankan conditions. The study was undertaken in collaboration with CIC Grains (Pvt.) Ltd. for the existing maize fields in Siyambalanduwa area. The model was validated using the growth parameters viz., plant height and number of leaves, for 2016/17 maha cropping season. With the secondary soil, climate and management data, the model simulated growth parameters at weekly intervals and were compared statistically with the observed data. Plant height and number of leaves were predicted by the model with a strong correlation with observed data with calculated r2 values of 0.82 and 0.99. Student's paired t-test showed no significant difference where P value was 0.73 and 0.67 at 95% confidence level. Positive modelling efficiency of 0.60 for plant height and 0.79 for number of leaves affirmed that the model predictions were acceptable. The model achieved RMSE of 33.61 for plant height with a standard deviation of 73.3and RMSE value of 1.15 with a standard deviation of 5.51. However, the model overestimated the yield for 2016 (observed yield=5.24 mt/ha, Predicted yield=6.27 mt/ha) and 2015 (observed yield=3.85mt/ha, predicted yield=5.22 mt/ha by 21%. This discrepancy could have been aroused due to the generalization of the soil data for the entire cultivated area under the study.

Key words - Crop model, plant height, number of leaves, Validation, Yield prediction)

1. INTRODUCTION

Sustainable crop intensification concept has been recently disclosed with the aim of enhancing the crop production of agricultural systems in an environmental friendly manner to fulfill the unprecedented food demand of rising global population (Godfray et al., 2010; Tilman et al., 2011). Crop models are accepted as adequate tools for decision making in sustainable crop intensification since they are functional in predicting the crop performances and determining optimum conditions for crops (Gaydon et al., 2017; Oteng-darko et al., 2013). Agricultural Production Systems simulator (APSIM) is a well-developed crop model with its proven ability to predict the performances of a wide range of crops in various conditions throughout the world (Mccown et al., 1996; Holzworth et al., 2014).

Enhancing the production of maize crop through sustainable techniques is important to consider because it is among the most important cereal crops of the world with a rising demand as a food crop and a valuable source for bio fuel (Hareesh et al., 2016). Maize is considered as the second most important cereal crop while ranking as the most important coarse grain in Sri Lanka (Natesan and Jogaratnam, 1997). But, it is still cultivated under traditional practices primarily under chena cultivation with low level technologies (Natesan and Jogarathnam, 1997). Therefore, 26% of the national maize requirement has to be fulfilled with imports which cause a huge drain of foreign exchange and financial losses for the country (MASL, 2014). It is important to conduct more scientific studies using improved crop models such as APSIM in order to improve decision making in the maize sector and identifying the yield potentials. Although APSIM-Oryza sub model has number of applications in Sri Lanka, not a considerable research attention has been focused on evaluating simulation capability of APSIM model for maize crop in Sri Lanka (Amarasingha et al., 2015; Fernando et al., 2015; Suriyagoda and Peiris 2016).

With the purpose, APSIM-Maize sub model was used in the study to predict the potential yields of existing maize cropping systems in intermediate zone of Sri Lanka through an appropriate validation procedure. The model makes predictions on daily processes of maize, initiating from the day of planting until the crop is harvested. Input data on soil, climate and management practices are inserted using combination of other relevant sub models. Crop processes such as transpiration, phenology, biomass accumulation and partitioning, leaf area development, senescence, nitrogen uptake and plant death are simulated by the maize model. (APSIM 2017). Model calibration and validation has been under taken using relevant soil, weather and management data obtained from CIC Grains (Pvt.) Ltd., a reputed company in Sri Lankan maize sector performing contract farming operations in the study area.

2. METHODOLOGY

The APSIM model (version 7.9), including APSIM-Maize and APSoil sub modules was used for the study. The model was simulated using input data obtaining from maize fields in Siyambalanduwa area, regulated by CIC Grains (Pvt.) Ltd. Siyambalanduwa division belongs to Monaragala District which lies in Intermediate Zone of Sri Lanka within the respective latitude and longitude ranges of 6.9065oN and 81.5610oE.

2.1 Model parameterisation and calibration

Soil data

Electrical conductivity (EC), pH and cation exchange capacity (CEC) values of the soil were required to insert in order to develop soil profile (Table 1). Those basic soil data were obtained from Sricansol bench mark soil classification fact sheet (SSSSL, 1999) which categorizes the soil of the study area under Muthukandiya series.

Important measurable soil moisture parameters including bulk density, saturated water content (SAT), drained upper limit (DUL) and drained lower limit (LL15) were evaluated for the study area through appropriate laboratory and field tests (Table 2).

In bulk density measuring, undisturbed soil samples were obtained from the required soil depths by gently hammering a steel core into the soil. The undisturbed intact soil samples were removed by digging around the ring while avoid loosening the soil samples within the cores. The soil samples were oven dried for 8 hours in 105oC temperature and dry weight was measured after placing in the desiccator. The soil volume is calculated using the dimensions of the steel core which contained the intact soil samples.

In determination of DUL and SAT, intact soil samples were obtained from the field and they were saturated from capillary rise by placing the soil containing cores in a basin, adding distilled water and allowing to stand for 24hours (Mbah 2012). The water content of the completely saturated soil samples were measured by oven drying the samples in order to determine SAT. Separately saturated soil samples were allowed to drain for 24hours and their water content was determined by oven drying the samples for calculating DUL.

Table 1: Soil chemical properties

Depth (cm)	EC (dS/m)	PH	Cl^- (mg/kg)	CEC (cmol/kg)	Ca^{2+} (cmol/kg)	Mg^{2+} (cmol/kg)	Na^+ (cmol/kg)	K^+ (cmol/kg)
0-15	0.100	6.000	0.300	2.280	1.410	0.320	0.190	0.250
15-37	0.100	6.100	0.100	2.310	1.650	0.370	0.200	0.080

Table 2: Soil moisture parameters

Depth (cm)	BD (g/cm^3)	Air Dry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT (mm/mm)	KS (mm/day)
0-15	1.450	0.040	0.124	0.230	0.390	1296.000
15-37	1.500	0.064	0.138	0.217	0.390	1248.000
37-49	1.500	0.064	0.138	0.217	0.390	1248.000
49-69	1.500	0.064	0.138	0.217	0.390	1248.000

Weather data

Weather data file (met file) was developed within the APSIM using daily values of rainfall, sunshine hours, evaporation, maximum and minimum temperatures within the time duration of 1997 to 2017. The data were acquired from Department of Meteorology, Colombo, Sri Lanka in collaboration with the regional weather station in Maduraketiya, Monaragala. Temperature amplitude (Amp) and average temperature (Tav) were calculated for the study area within the considered time period.

Management data

Crop management data folder was developed, obtaining initial data from CIC Grains (Pvt.) Ltd. on recommended practices for land preparation, crop sowing, fertilizer application and crop harvesting.

2.2 Model validation

APSIM model was validated by statistically comparing actual and observed values of yield and considered crop growth parameters (crop height and number of leaves) of 2015/16 and 2016/17 maha seasons. Data validation was done by calculating Coefficient of determination (r2), root mean squared error (RMSE), modeling efficiency (EF) and student's paired t test.

3. RESULTS

3.1 Model validation

Plant height

Plant height parameter was predicted by the model with a strong correlation with observed data. Calculated r2 was 0.821 and adjusted r2 value was 0.803 which proved the model predictions are convenient (Figure 1). The student's paired t-test gave a significance of P=0.735 at 95% confidence level indicating that there was no statistical difference between predicted and observed data while positive modelling efficiency of 0.605 represented that model predictions are acceptable. The model achieved RMSE of 33.61 for the data set with a standard deviation of 73.3 which appeared the model is performing satisfactorily.

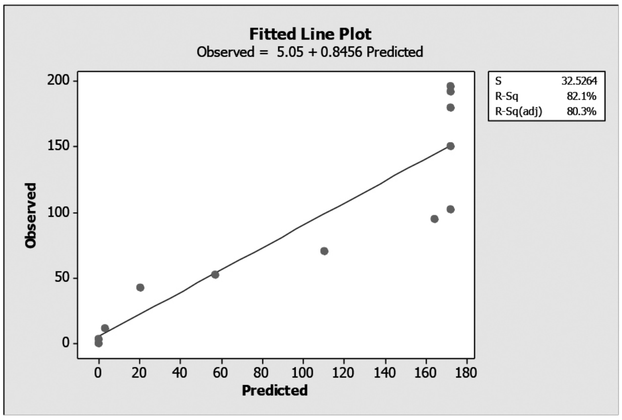

Figure 1: Regression of plant height

Number of leaves
The number of leaves were predicted by APSIM model with a good correlation to observed values providing evidences of high r2 (r2=0.993) and adjusted r2 (adj r2=0.992) values (Figure 2). In addition to determination of linear regression, RMSE value of 1.15 was derived which favorably compared with a standard deviation of 5.51. Calculated P value from the student's paired t test was 0.671 within 95% confidence level which suggests that no significant difference between predicted and observed leaf numbers of maize. Value of computed model efficiency (0.79) convinced that the model predictions are accurate.

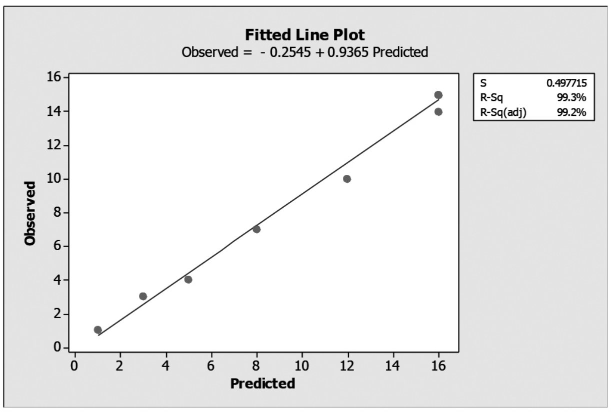

Figure 2: Regression of number of leaves

Yield prediction
APSIM achieved acceptable values in statistical analysis for model validation considering plant height and number of leaves. Thus, the ability of the model in yield prediction was demonstrated further through the study. The model predicted a potential yield of 6.27Mt/ha for 2016/17maha season in the study area in comparison to the observed yield potential of 5.24 Mt/ha for the cropping season. In addition, the model was simulated for yield prediction in 2015/16 maha season which predicted 5.22 Mt/ha of yield which was compared with 3.85Mt/ha of observed yield (Figure 3). Both simulations showed an over estimation of yield with a calculated error percentage of 21%.

4. DISCUSSION

The model showed a strong fit of observed and predicted growth parameters, with 21% of calculated error percentage in yield estimation. Nevertheless, a plot experiment conducted in the area by the company showed an average yield potential of 7.23Mt/ha for the study area (CIC, 2016). Therefore, it demonstrates that the reduction of potential yield in the area for considered cropping seasons can be due to some external and internal factors which are affecting the crop. Although farmers cultivate varieties with high yield potentials, variation in crop management practices and climatic conditions may stress on the crop which ultimately reduce the maximum yield of the crop due to the disturbances on crop physiological processes. Agro climatic factors are common for all farmers in the situation and the yield difference may be due to the level of optimal management practices and the knowledge of the farmers (Abeysuriya, 2012). The present study, based on crop models is a supportive tool in the context and important to determine the optimum levels of management for the study area.

Requirement of good quality dataset for soil component of the model is critical because the model predictions can vary according to the changes of the data (Gaydon et al., 2017). Therefore, soil moisture evaluation was undertaken with the purpose to obtain accurate soil data. According to the soil taxonomy, soil of the study area is categorized as poorly drained "Typic Endoaquents" (SSSSL, 1999). The soil evaluation revealed that the surface and upper layers of the soil has disturbed and loosen due to the intensive land preparation and agricultural practices. The soil has tended to well draining which resulted the water to drain quickly into the bottom layers of soil and ponded during the raining. Therefore, high permeability (hydraulic conductivity) values were obtained from the soil moisture evaluation, which were significantly different from the permeability values from the literature (SSSSL, 1999) regarding benchmark soils. During raining, the soil may exhibit compaction which suggests a detailed soil moisture evaluation within a considerable time period incorporating soil variability. It will produce more reliable prediction after modifying the model with accurate soil moisture data.

The study was conducted with basic soil data in literature which are representing typical characteristics for the soil in study area. Nevertheless, the soil of the area shows a considerable variability in different fields located in different locations. Therefore, overall soil parameter values fed into the model may cause over estimation of yield. As well as the soil data in literature are not specific for a cultivated maize land. It also may be an issue for over estimation of yield.

Research attention has focused on those uncertainties of APSIM-maize model. A recent study has been conducted to evaluate the impact of model and input uncertainty on maize yield simulation in West Africa (Waha et al., 2015). Performance of the point-scale crop model, APSIM and the global scale crop model, (LPJmL) has been analyzed with different climate and soil conditions under different agricultural management in Burkina Faso, West Africa. The study has demonstrated that the resolution of different soil, climate and management information influence the simulated crop yields in both models (Waha et al., 2015).

A similar study has been conducted by Mthandi et al., (2014) to modify, calibrate and validate APSIM model to suit maize production systems in Nkango irrigation scheme in Malawi. The study has revealed that during the latter stage of the maize growing season, the model under predicted. The model has made over predictions in the early stage of the growing season, and it has overestimated soil water contents in soil profile (Mthandi et al., 2014). Parameterization and evaluation of APSIM-maize model in Melkassa, Ethiopia was done by Mesfin et al., 2015. The study has also evaluated the influence of sowing date and nitrogen fertilizer rate on crop productivity. APSIM-maize model has been parameterized using field experiment of sowing maize on two dates under two nitrogen fertilizer rates. The model has shown acceptable performance in simulating grain yield in most cases except over-estimation of yield by 37% at the late sowing date and high N supply (Mesfin et al., 2015).

5. CONCLUSION

APSIM- Maize model has fewer applications in Sri Lanka regarding its potentials to predict yield or crop phenology. The present research shows that APSIM-Maize model performed in a statistically robust manner for simulating the crop performances. The model was successfully validated using the comparison of observed and predicted crop growth parameters of plant height and number of leaves. The model was validated with a strong fit for plant height and number of leaves with respective r2 values; student's paired t-test, modelling efficiency and RMSE. The model over estimated crop yield for 2015/16 and 2016/17 maha cropping seasons by 21% which may due to the variations in soil properties and management practices.

REFERENCES

1. Abeysuriya, D. Physiological growth stages of maize crop and their relation on yield, in: Maize Crop (Edition 4). Department of Agriculture Sri Lanka, pp. 37-46, 2012.
2. Amarasingha, R.P.R.K., Suriyagoda, L.D.B., Marambe, B., Galagedara, L.W., Silva, G.L.L.P., Punyawardena, R., Nidumolu, U., Howden, M., Parsons, D., and Meinke, H. Yield advantage and water productivity of maize-mungbean inter-cropping systems in the dry zone of Sri Lanka ; a modelling approach, Proceedings of 17th ASA Conference - Building Productive, Diverse and Sustainable Landscapes, pp.20–24,2015.
3. CIC, 2016. CIC Agri Business, [online] Retrieved 16/July/2017<https://www.cicagri.com>
4. Fernando, M.E.K.K., Amerasekara, D.A.B.N., Amarasingha, R.P.R.K., Suriyagoda, L.D.B., and Marambe, B. Validation of APSIM for long duration rice varieties in different agro-climatic zones of Sri Lanka, Building Productive, Diverse and Sustainable Landscapes- Proceedings of the 17th ASA Conference, pp.20-24, 2015.
5. Gaydon, D S, Baliwinder-Singh, Wang E., Poulton P.L., Ahmad B., Ahmed F., Akhter S., Amarasingha, R.P.R.K., Chaki, A.K., Chen, C., Choudhury, B.U., Darai, R., Das, A., Hochman, Z., Horan, H., Hosang, E.Y., Vijaya Kumar, P., Khan, A.S.M.M.R., Laing, A.M., Liu, L., Malaviachichi, M.A.P.W.K., Mohapatra, K.P., Muttaleb, M.A., Power, B., Radanielson, A.M., Rai, G.S., Rashid, M.H., Rathanayake, W.M.U.K.., Sarker, M .M.R., Sena, D.R., Shamim, M., Subash, N., Suriadi, A., Suriyagoda, L.D.B., Wang, G., Wang, J., Yadav, R.K. and Roth, C.H. Evaluation of the APSIM model in cropping systems of Asia, Field Crops Research, 204, pp. 52–75,2017.
6. Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty ,J., Robinson, S., Thomas, S.M. and Toulmin, C. Food security : the challenge of feeding 9 billion people, Science, 327 (February), pp. 812–18,2010.
7. Hareesh, V., Krishnaprasad, N.B., Vinod, T.P., Anu, V.P., and Vijayakumar, V. Maize special report June 2016, Geofin Research desk, Kochi, (June), pp. 1-14,2016.
8. Holzworth, D. P., Huth, N. I., deVoil, P. G., Zurcher, E. J., Herrmann, N. I., McLean, G., Chenu, K., van Oosterom, E. J., Snow, V., Murphy, C., Moore, A. D., Brown, H., Whish, J. P. M., Verrall, S., Fainges, J., Bell, L. W., Peake, A. S., Poulton, P. L., Hochman, Z., Thorburn, P. J., Gaydon, D. S., Dalgliesh, N. P., Rodriguez, D., Cox, H., Chapman, S., Doherty, A., Teixeira, E., Sharp, J., Cichota, R., Vogeler, I., Li, F. Y., Wang, E., Hammer, G. L., Robertson, M. J., Dimes, J. P., Whitbread, A. M., Hunt, J., van Rees, H., McClelland, T., Carberry, P. S., Hargreaves, J. N. G., MacLeod, N., McDonald, C., Harsdorf, J., Wedgwood, S. and Keating, B. A. APSIM-evolution towards a new generation of agricultural systems simulation. Environmental Modelling and Software. 62, pp.327–350,2014.
9. MASL, 2014. Food production book, [online] Retrieved on 17/July/2017 <http://www.agrimin.gov.lk/web/images/pdf/FoodProductionBook-English.pdf>
10. Mbah, C.N.Determining the field capacity , wilting point and available water capacity of some Southeast Nigerian soils using soil saturation from capillary rise, Nigerian Journal of Biotechnology, 24 (2012), pp. 41–47,2012.
11. Mccown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., and Freebrain, D.M. APSIM : a novel software system for model development, model testing and simulation in agricultural systems research, Agricultural Systems, 50 pp.255–71.,1996.
12. Mesfin, T., Moeller, C., Parsons, D., and Meinke, H. Maize (Zea Mays L .) productivity as influenced by sowing date and nitrogen fertiliser rate at Melkassa , Ethiopia : parameterisation and evaluation of APSIM, Proceedings of the 17th ASA Conference - Building Productive, Diverse and Sustainable Landscapes, pp. 1–4,2015.
13. Mthandi, J., Kahimba, F.C., Tarimo, A.K.P.R., Salim, B.A., and Lowole, M.W. Modification , Calibration and validation of APSIM to suit maize (Zea Mays L.) production system : a case of Nkango irrigation scheme in Malawi, American Journal of Agriculture and Forestry, 2 (6), pp. 1–11,2014.
14. Natesan, S., and Jogaratnam, T. Maize production in Sri Lanka, AgEnt Consultant Report, Colombo, Sri Lanka, pp.1-45, 1997.
15. Oteng-darko, P., Yeboah, S., Addy, S.N.T., Amponsah, S. and Danquah, E.O. Crop modeling : a tool for agricultural research – a review, Journal of Agricultural Research and Development, 2 (1), pp.1–6,2013.
16. SSSSL, SSSSL benchmark soils of the intermediate zone (fact sheet), Canadian society of soil science and soil science society if Sri Lanka, No 29, 1999.
17. Suriyagoda, L.D.B., and Peiris, B.L. Rice grain yield with organic matter addition and reduced nitrogen top-dressing: simulation using APSIM, SAC Monograph, 2016.
18. Tilman, D., Balzer, C., Hill, J. and Befort, B.L. Global Food Demand and the Sustainable Intensification of Agriculture, PNAS, 108 (50), pp. 20260–20264, 2011.
19. Waha, K., Huth, N., Carberry, P. and Wang, E. How model and input uncertainty impact maize yield simulations in West Africa, Environmental Research Letters, 10 (2015), pp. 1–11.,2015