Yield advantage and water productivity of maize-mungbean inter-cropping systems in the Dry Zone of Sri Lanka; a modelling approach

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Abstract
Water is not efficiently used in most of the cropping systems in South Asia. Therefore, water-efficient agricultural practices are of immense importance when increasing the area to be cultivated, and/or conserving rain water to be used in drier regions through irrigation. Inter-cropping of maize (*Zea maize* L.) with mungbean (*Vigna radiate* L.) R. Wilczek may offer benefits in utilising water efficiently and maintaining or improving land productivity. Simulation models are useful tools to assess the performance of agricultural systems. The present study was conducted to evaluate the irrigation water requirement and yield of the maize-mungbean inter-cropping system in comparison with mono-cropping, using APSIM. Simulation results revealed that the maize-mungbean intercrop required only 4 % more water than the maize mono-crop ($P>0.05$). Moreover, intercrop maize yield was only 3 % less than that of the maize mono-crop ($P>0.05$) However, yield of mungbean was 21 % less in the inter-cropping system than the mono-crop system ($P<0.05$). The land-equivalent ratio of the maize-mungbean inter-cropping system was 1.8. Efficient use of water under the inter-cropping system, with a similar yield of maize to that obtained under mono-crop of maize, combined with an additional mungbean harvest highlights the greater efficiency of the maize-mungbean inter-cropping system in the Dry Zone of Sri Lanka.

Key words
APSIM, Evaluation, Inter-cropping, Maize, Mungbean, Sri Lanka,

Introduction

Water scarcity for crop production occurs in many parts of the world, mainly due to inefficient water management practices, resulting in very low water productivity, i.e. the amount of biomass or yield produced per unit water input (Thiyagarajan and Selvaraju, 2001; UNESCO-WWAP, 2009). Therefore, water efficient agricultural practices are of immense importance when increasing the area to be cultivated, and/or conserving water from rain to be used in drier regions or seasons through irrigation.

Inter-cropping is the simultaneous growing of more than one crop species in proximity, with the aim of increasing productivity per unit land area and time. Cereal-legume inter-cropping is practiced mainly in tropical regions of the globe (Hauggaard-Nielsen et al., 2001; Agegnehu et al., 2006; Dhima et al., 2007). Maize (*Zea mays* L.) is a major cereal crop grown in Sri Lanka, with an annual cultivation area of 30,000 ha. Mungbean (*Vigna radiate* (L.) R. Wilczek) is a major legume in the rain-fed farming systems in the Dry and Intermediate Zones of Sri Lanka. Inter-cropping of maize and mungbean may utilise water efficiently and improve land productivity.

Simulation models are useful tools to assess the performance of agricultural systems under different scenarios. The Agricultural Production Systems Simulator (APSIM) is a farming systems model that simulates the effects of environmental variables and diverse management decisions on production (crops, pasture, trees, and livestock), profits, and soil conditions (Keating et al., 2003). The model can be used to analyse risks and explore alternative management options such as irrigation management, crop choice, planting date, and fertiliser rate using local climate and farm specific soil data. The present study was conducted to evaluate the irrigation water requirement and yield of the maize-mungbean inter-cropping system in comparison with mono-crops using APSIM in the Dry and Intermediate Zones of Sri Lanka.

Materials and Methods

Parameterization of the APSIM Model

The maize and mungbean modules in APSIM 7.5 were parameterised for Sri Lankan cultivars. Phenological parameters for cultivars *Ruwan* (maize) and *MI6* (mungbean) were based on literature values (Amarasingha et al., 2014). The *maize.ini* and *mungbean.ini* files in APSIM were modified accordingly to simulate the crop productivity at Maha-Illuppallama (MI) area in the Dry Zone low country (DL) of Sri Lanka. The dominant soil in the study area was a Reddish Brown Earth (Mapa *et al.*, 2010). Daily weather data (maximum and minimum temperatures, rainfall, and solar radiation) from January 1976 to December 2014 for MI were sourced from the Natural Resource Management Centre of the Department of Agriculture, Sri Lanka.

Model evaluation

Secondary data on yield were sourced from the Field Crops Research and Development Institute (FCRDI) at MI. Fertilizer and management practices were adjusted according to the recommendations of the Government Department of Agriculture of Sri Lanka. Planting dates, planting method (direct seeding), and management strategies were adjusted in the model simulations as recorded at FCRDI. The simulated yield and phenology were compared with the observed values collected from the literature. Simulated and observed data were plotted on a 1:1 graph of predicted and observed values for cultivars *Ruwan* (maize) and *MI6* (mungbean). The statistical measures used for comparing simulated and observed data were: coefficient of variance (CV), root mean squared error (RMSE), coefficient of determination (R^2), and Student's t-test.

Definition of Scenarios Modelled

In order to test the changes in water and land productivities of the maize-mungbean inter-cropping system in comparison with corresponding mono-crops, simulations were run in *Yala* (minor rainy season from March to September) and *Maha* (major rainy season from October to February) seasons at MI with 37 years of historical climate data. The maize mono-crop had a row spacing of 60 cm with a sowing density of 5.5 plants m^{-2}. The row spacing of mono-crop mungbean was 30 cm, with a sowing density of 33 plants m^{-2}. In the inter-cropping system maize plant density was unchanged (*i.e.* 5.5 plants m^{-2}) and the mungbean plant density was reduced by 50 % (*i.e.* 16.5 plants m^{-2}). These inter-crop densities were based on farmer practice. Both crops in the inter-crop were sown on the same day. Irrigation was supplied in 7-day intervals until the soil reached field capacity, consistent with farmer practice. The grain yields of maize and mungbean under both mono-cropping systems and the inter-cropping system were simulated. Land Equivalent Ratio (LER-sum of the ratio of inter-crop productivity in comparison with mono-crop productivity) was calculated to determine the land productivity.

Results and Discussion

The relationship between observed and simulated maize grain yield during the model evaluation stage was strong (R^2 value of 0.98 for *Ruwan*) (Fig. 1) indicating that the parameterised model could explain a high level of the total observed variability in grain yield. Student's t-test found no significant difference between the observed and simulated grain yield values (P=0.7). The RMSE for *Ruwan* was 190 kg ha^{-1}.

The parameterised APSIM-mungbean module simulated the grain yield of mungbean variety *MI6* with R^2 of 0.97, indicating that the parameterised model could explain a high level of total observed variability in grain yield (Fig. 1). The RMSE for *MI6* was 75 kg ha^{-1}. This compares favourably with the observed experimental variability (standard deviation of 598 kg ha^{-1}), and hence the model predictions were within the bounds of experimental uncertainty. Student's t-test found no significant difference between the observed and simulated grain yield values (P=0.8). Therefore, the parameterised APSIM-maize and APSIM-mungbean models can acceptably simulate the yield of *Ruwan* and *MI6* at MI region in the DZ under optimal crop management.

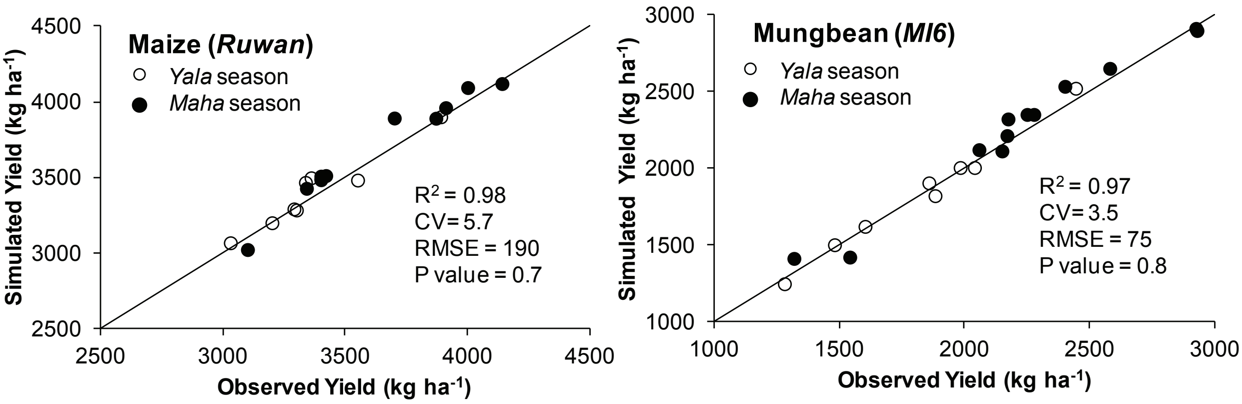

Fig. 1. Observed and simulated yield of maize (*Ruwan*) and mungbean (*MI6*) varieties in *Yala* and *Maha* seasons at Maha-Illuppallama under standard management practices at the model testing stage. The line indicates the 1:1 relationship.

Simulations of mono-crop mungbean required 50 % less water than the mono-crop of maize (P<0.05, Fig. 2), and the maize-mungbean intercrop required only 4 % more water than the mono-crop of maize (P>0.05, Fig. 2). Simulated maize yield was only 3 % higher in the inter-cropping system than in the mono-crop (P>0.05) whereas mungbean in the intercrop was 21% less than that in the mono-crop (P<0.05). The LER value of maize-mungbean inter-cropping system was 1.8. Therefore, inter-cropping of maize and mungbean has advantages over the mono-cropping of maize or mungbean at MI in the DZ of Sri Lanka.

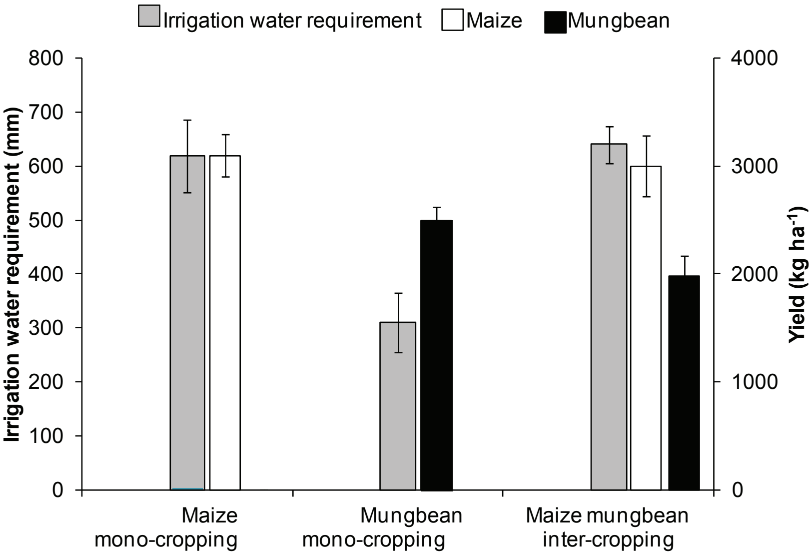

Fig. 2. The irrigation water requirement and yield of maize and mungbean in mono-cropping and inter-cropping systems during *Yala* season at Maha-Illuppallama.

Conclusion

The maize-mungbean intercrop utilises water efficiently, without significantly reducing the maize yield compared with the mono-crop of maize, and producing an additional mungbean yield, thus improving the land productivity.

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