Short Communication
Pak. J. Agri. Sci., Vol. 56(X), xxx-xxx; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI:10.21162/PAKJAS/19.7454
http://www.pakjas.com.pk

ALLEY CROPPING SIMULATION: AN OPPORTUNITY FOR SUSTAINABLE CROP PRODUCTION ON TROPICAL UPLANDS

Khalid Hussain[1,*], Ayesha Ilyas[1], Aftab Wajid[1], Ashfaq Ahmad[1], Nasir Mahmood[2], Thomas Hilger[3] and Thanuchai Kongkaew[4]

[1]Agro-Climatology Lab., Department of Agronomy, University of Agriculture, Faisalabad; [2]Government College Women University Faisalabad: [3]Institute of Agricultural Sciences in the Tropics (Hans-Ruthenberg-Institute) (490), University of Hohenheim Stuttgart-Germany; [4]Department of Soil Science, Kasetsart University, Bangkok, Thailand.
[*]Corresponding author's e-mails: khalid.hussain@uaf.edu.pk

Agroforestry, intercropping or grass barriers have a great potential to enhance cropping system's productivity and work as a source of soil conservation on hilly terrain. These soil conservation cropping methods comprise of complex interactions between plant, soil and atmosphere. Sustainability of such cropping systems can be assessed by measuring resources use limitations, above ground biomass production (AGB) and Land Equivalent Ratio (LER). Modeling is an alternate approach to assess such cropping systems sustainability. Water, Nutrient and Light Capture in Agro-forestry **S**ystem (WaNuLCAS) model was used to investigate the sustainability of various soil conservation maize-based cropping systems and to figure out some mitigation strategies to overcome the resources limitation in-case of competition. A two years field experiment (2010, 2011) with maize alone (monocropping, tillage), maize intercropping with chili and hedgerow with and without fertilization and minimum tillage were used to assess the sustainability of these studied cropping systems on uplands of Thailand. The results revealed that maize AGB was maximum 1.8 g m^{-2} in intercropping treatment of maize intercropping with chili and hedgerow including fertilizer application and minimum tillage. LER also showed that maize intercropping with chili and hedgerow including fertilizer application and minimum tillage used the resources judiciously to produce higher quantity of maize biomass. Model suggested that small but targeted amount of additional nitrogen and phosphorous application overcome nutrient limitation and sustain productivity of cropping systems. Such management options are easy to practice under field condition and can also be adopted by the local farmer's for sustainable crop production in future.
Keywords: Cropping system, soil conservation, wanulcas, land equivalent ratio, uplands agriculture.

INTRODUCTION

Uplands agriculture in Western Thailand is depend on hilly terrains. Farmers have very less restriction to clear the bushes on the slopes and start agriculture. Heavy but short duration rainfalls on these bare slopes remove most fertile layer of the soil along with water runoff. This is not only reducing agriculture on uplands but also problem of silting in water ways, canal and rivers. Now a day there are lot of campaigns to educate the farmers to use the land especially uplands with proper soil management practices. Lot of government organization and non-government organizations are quite active for this task with slogans of save the soil to save life. Upland agriculture on the slopes can be saved for longer period of times with soil conservation practices like minimum tillage, allay cropping or agroforestry, grass barriers, soil cover maintain ace etc. Awareness campaigns about soil conservation and soil management are actually encouraging famers to practice soil management options for sustainable production. Proper crop management with proper rotations and keeping crop residue in the field is also important for sustainable agricultural production (Mupangwa and Thierfelder, 2013).

Studies carried out on this specific issue of soil management with hedges and grass barriers inclusion with crop plants showed satisfactory results of soil conservation with sustainable production (Hilger *et al.*, 2013; Tuan *et al.*, 2014; Hussain, 2015; Hussain *et al.*, 2015, 2016). Research proved several advantages of soil conservations but still the upland farmers are not so much convinced to adopt above mentioned soil conservation techniques. They have the thoughts that such practices compete with major crops and reduce their cropped area mainly when they are practicing allay cropping agro-forestry system or using grass barriers. This study was mainly focused to address these concerns of the farmers. We also tested modeling approach to address the issues raised by the uplands farmers. Modeling can be used as a tool to help policy makers and researchers to solve the problems of area specific farmers with site specific technology transfer.

MATERIALS AND METHODS

The experiments were carried out under field conditions of Thailand's Western Province, Ratchaburi uplands with slope 20-25% on already establish hedges in 2010 and 2011. Randomized Complete Bloch Design was practiced with three replicates. The treatments were T1=Maize sole crop (with tillage and fertilizer); T2=Maize + Chilli intercrop (with tillage and fertilizer); T3=T2 with mini. Tillage + Jackbean as relay crop; T4=T3 plus hedgerows (Leucaena); T5=T3 without fertilizer; T6=T4 without fertilizer.

Soil of the experimental area was tested for pH, bulk density, soil texture, soil available Nitrogen, Phosphorous, Carbon (organic), CEC etc and used as input for modeling approach (Hussain *et al.*, 2016 can be consulted for further readings). Model parameterization/calibration was done with three treatments (2, 3 and 5) while remaining three treatments (T1, T4, T6) were used for validation or evaluation of the model. Field measurements includinge biomass yield, nitrogen concentration in grain, land equivalent ratio (LER) were recorded. For LER calculations, two chilli sole crop plots were also established in the field. For modeling approach weather data obtained from weather station installed at the experimental site, was also used as input for simulations. SAS Version 9.2 was used for statistical analysis. PROC GLM was used to compare the treatments means. Statistical approach (Goodness of Fit (GOF)) developed by Loague and Green (1991) was followed for model performance assessment.

RESULTS

***Maize biomass production, nitrogen concentration in grains, LER*:** The highest maize total biomass (1.37 kg m^{-2}) was observed in T2 while T2, T3 and T4 biomass yield was statistically at par but higher than T1 (which was established as control and mostly being practiced in the area by the farmers). Grain nitrogen concentration did not differ significantly in T1, T2, T3 and T4 but was higher than nonfertilized treatments. Land Equivalent ratio (LER) was the highest (1.23) in T4 (hedge treatment/Agroforestry system), 23% higher than T1 (Table 1).

***Resource use and limitations in soil conservation systems*:** Maize biomass yield was higher in the distant maize rows while maize plants near to the leucaena hedges produced lower yield (Table 2). Both positions of maize planting near and away from hedges effected nitrogen and phosphorous uptake which was also justified by the model and it simulated identical trends as observed under field conditions. Phosphorous uptakes by the both positions were also in accordance to simulation (Table 2).

***Modeling sustainable options for production systems on uplands*:** Simulations of biomass yield with continuous five years growing showed that agroforestry systems are very sustainable production systems on uplands.

Table 1. Maize biomass yield (kg m^{-2}), Grain nitrogen con. (%N) and land equivalent ratio (LER) during 2011.

Treatments	Biomass yield	Grain N	LER
T1	1.16 bc	1.45 ab	1.17
T2	1.37 a	1.56 a	1.03
T3	1.24 ab	1.51 ab	1.23
T4	1.25 ab	1.51 ab	0.88
T5	1.03 d	1.31 c	0.94
T6	1.07 dc	1.39 bc	1.17
	p=0.001	*p*=0.001	*p*=0.001

Table 2. Maize biomass yield and nitrogen and phosphorous use dynamics during 2011.

Maize Row Position (P)	Treatment 1	Treatment 4	Treatment 6
	Maize biomass yield (kg m^{-2})		
P1	1.11	1.02b	0,79 b
P2	1.22	1,48 a	1.36 a
	NS	*p*=0.001	*p*=0.001
	Simulated N uptake		
P1	8.50	7.92 b	3.84 b
P2	8.22	8.54 a	5.75 a
	NS	*p*=0.05	*p*=0.01
	N concentration in maize grains (observed data)		
P1	1.43	1.37 b	1.30 b
P2	1.46	1.64 a	1.48 a
	NS	*p*=0.01	*p*=0.001
	Simulated P uptake		
P1	4.47	1.91 b	2.47 a
P2	4.14	6.30 a	5.89 b
	NS	*p*=0.001	*p*<0.001
	P concentration in maize grains (observed data)		
P1	1.10	1.50 b	1.09 b
P2	1.06	2.49 a	2.27 a
	NS	*p*=0.01	*p*=0.01

Maize row position (P1) = close to hedges; (P2) = distant to hedges, N= nitrogen, P=Phosphorous.

First two years simulation results showed similar trends as observed under field conditions during 2010 and 2011 growing seasons. Model calibration showed satisfactory results with R^2 = 0.83, p=0.001, model efficiency 0.82, root mean square error 6.3. Model validation also revealed good results with R^2 = 0.76, p=0.001, model efficiency 0.69, root mean square error 4.2. Model predicted continuous decrease in production but decreasing trend was lower in T4. In T1 and T6, there was no production after five years simulation (Fig. 1). Model suggested a small additional amount of fertilizer application just at crop rows planted close by to the hedgerows which sustain maize total biomass yield up to 1.8 kg m^{-2} over a period of five years (Fig. 2).

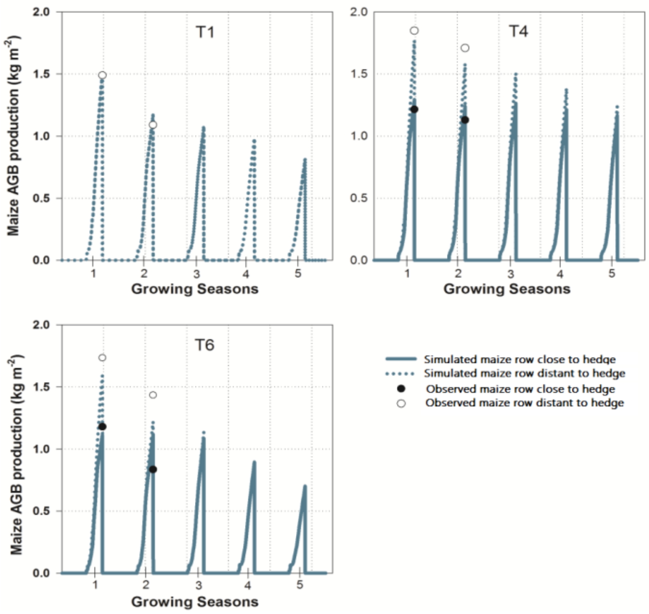

Figure 1. Performance of maize alone vs Agroforestry systems with five growing seasons. Growing seasons 1 & 2 are also showing AGB observed values from 2010 and 2011 field experiments, respectively.

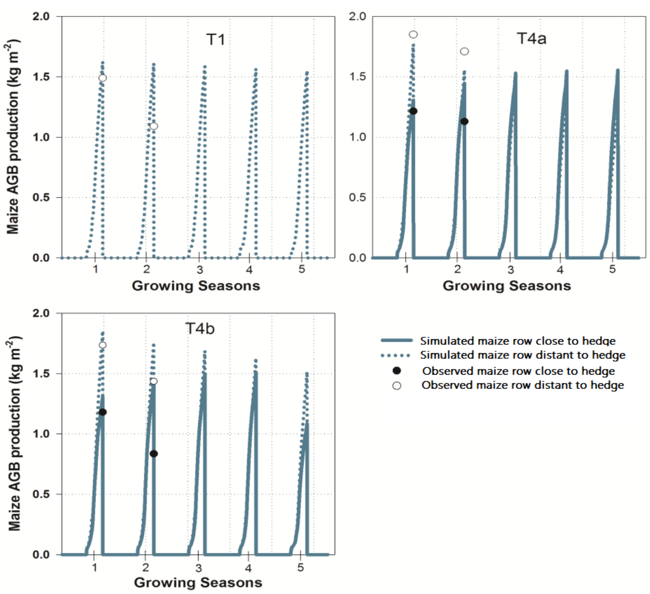

Figure 2. Simulated options for sustainable maize production in agroforestry systems with five growing seasons. Growing seasons 1 & 2 are also showing AGB observed values from 2010 and 2011 field experiments, respectively.

DISCUSSION

High maize biomass yield in intercropping and alley cropping/agroforestry was due more space for light capture and below ground resources. This was also indicated from field experiments that yield decrease was observed in the similar way as showed by model simulations (Hussain *et al.*, 2016).

Highest LER in T4 (Agoforestry system) indicated 23% better utilization of resources than maize alone. In other words, maize sole cropping (T1) need 23% more area to produce equal to that of T4. This is due to more favourable conditions for production of crop under hedge row conditions because the hedges act as barriers to reduce soil upper fertile layer from removal due to heavy rains under tropical upland conditions (Pansak *et al.*, 2008). This fertile top layer will remain in the field which is important for maintaining the soil fertility over time.

Simulations of the data showed continuous decrease of biomass yield along with the growing seasons due loss of soil fertility over time but with soil conservation management practices this decreasing trend can be overcome. Simulations also indicated that T4 (Agroforestry systems) is more sustainable than maize alone because it conserves the soil and reduce the loss of fertile soil (Hussain, 2015). Similarly, small additional but targeted increase in fertilizer application can make such type of agroforestry system more sustainable with passage of time due to soil fertility enhancement factor.

***Conclusions*:** Agroforestry systems/Alley cropping are very sustainable systems on uplands. Model evaluated options to overcome the major limiting nutrient at the crop-soil-hedge interface in the alley cropping. Small additional amount of fertilizer application at rows close to hedgerows will improve production sustainability. This modification will sustain total maize biomass yield up to 1.8 kg m^{-2}. This practice can easily be practiced by the local farmers for sustainable crop production on uplands in future. It will also reduce deforestation on uplands.

***Acknowledgements*:** Authors are thankful to University of Hohenheim Germany for student supervision, University of Agriculture, Faisalabad-Pakistan for some funding, KU Leuven—Belgium for funding field research, Kasetsart University Thailand for providing field for research.

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