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SIMULATING YIELD RESPONSE OF MAIZE TO CLIMATE CHANGE WITH AQUACROP MODEL IN NORTHWEST VIETNAM

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ABSTRACT

Maize has become the second most important crop after rice in Vietnam, particularly it is main cash crop for farmers in the Northwest region. To seek a solution for adapting to climate change, the impact of climate change on maize production needs to be analyzed. The AquaCrop model was used here to predict maize yield inresponse to climate change. The model was calibrated and validated for maize production at field scale in Muong Lum commune, Yen Chau district, Son La province during the period of 2008 - 2012. The AquaCrop model application under climate change scenario B2 shows that maize yield has a positive response to climate change with a predicted increase of 2.2% in 2100 compared to the period of 2008 - 2012. It recommends that maize production can be continued in the study area.

Keywords: AquaCrop, climate change, maize.

Mô phỏng phản ứng năng suất ngô với biến đổi khí hậu bằng mô hình Aquacrop ở vùng tây bắc Việt Nam

TÓM TẮT

Ngô hiện nay là cây trồng quan trọng thứ 2 sau lúa ở Việt Nam, đặc biệt ở vùng Tây Bắc ngô là cây hoa màu chính cho người nông dân. Để tìm biện pháp thích ứng với biến đổi khí hậu, ảnh hưởng của biến đổi khí hậu đến sản xuất ngô cần được phân tích. Mô hình AquaCrop được sử dụng để dự đoán sự đáp ứng của năng suất ngô đối với biến đổi khí hậu. Mô hình được hiệu chỉnh và kiểm nghiệm với nương ngô thuộc xã Mường Lựm, huyện Yên Châu, tỉnh Sơn La trong giai đoạn 2008 - 2012. Ứng dụng mô hình AquaCrop dưới kịch bản biến đổi khí hậu B2 cho thấy năng suất ngô phản ứng tích cực đối với biến đổi khí hậu với năng suất tăng thêm 2,2% ở năm 2100. Do đó, kiến nghị có thể tiếp tục trồng ngô ở khu vực này dưới điều kiện biến đổi khí hậu trong tương lai.

Từ khóa: AquaCrop, biến đổi khí hậu, ngô.

1. INTRODUCTION

Climate change is one of the most significant challenges that all living things on the Earth will need to face. Agriculture is highly influenced by climate change, as farming activities directly depend on climatic conditions.

Regarding adaption measures to climate change, land evaluation needs to be done under climate change contexts in order to analyze the impact of climate change on the yield of crops.

Maize (*Zea mays* L.) is the primary source of feed for Vietnam's rapidly growing livestock and poultry industry. Therefore, the demand for maize has grown dramatically and is expected to further increase in the future (Thanh Ha *et al.*, 2004). Consequently, maize production in Vietnam has increased sharply, especially since the government began to strongly support and promote maize hybrid technology in the 1990s. Maize has become the second most important crop after rice andhigher-yielding hybrid varieties have been widely adopted. (Thanh Ha *et al.*, 2004). This development has the potential to reduce rural poverty by offering attractive income opportunities to smallholder farmers (Delgado *et al.*, 1999). However, it promotes the expansion of agricultural cultivation into fragile agro-ecological zones, often leading to deforestation, soil erosion, and subsequent soil degradation, especially in the upland area (Dao *et al.*, 2002).

In Northwest Vietnam, agriculture is the main source of income for its population. In addition, maize is currently the main cash crop for farmers. Therefore, land evaluation under changing climate conditions for maize production is necessary in order to seek the measures to adapt to climate change. Changes in maize yield needs to be explored under climate change conditions to make significant contributions to land use planning for the future. With this point of view, it is necessary to answer these research questions: (i) What is the yield response of maize to climate change in Northwest Vietnam? and (ii) What are the recommendations for land use planning based on the yield response of maize?

Therefore, this study aims to simulate the yield of maize under climate change scenarios in Northwest Vietnam for improved land use planning. In order to achieve therefore mentioned objective, the following activities were conducted:

A study of the land resources and maize production management in the research sites

A simulation of maize yield in a time series under climate change scenarios

2. MATERIALS AND METHODOLOGY

2.1. Study site selection

Maize field schosen for this study were based on two criteria: (i) the land belongs to an area that has biophysical conditions representative for maize production in the Northwest region and (ii) a location within the cover age of daily climate data.

2.2. Data collection

- Climate data:

Climate data was collected from the weather station that was set up in Muong Lum commune within the framework of the Uplands Program (funded by Deutsche Forschungsgemeinschaft). The collected data included air temperature, precipitation, relative humidity and solar radiation.

- IPCC climate change scenarios:

This study used IPCC climate change scenario B2 with medium emissions, which has been scaled down for Vietnam and published by the Ministry of Natural Resources and Environment of Vietnam (MONRE, 2012). This scenario was applied as a global context for running the simulation model in this study.

- Maize yield data:

Maize yield was sampled from the chosen maize field by collecting and weighing maize grains from 3 random plots of 10 m x 10 m at harvest time.

- Land use history and crop management:

Interviews with the relevant farmer were conducted to get information about land use history and crop management in the field.

- Soil sampling:

A soil profile was created by digging a soil pit at a representative maize plot. The soil profile was described following FAO guidelines (Jahn *et al.*, 2006). Soil samples were collected from different soil horizons, and then analyzed for both physical and chemical properties.

2.3. Model selection

Models are used frequently to evaluate the effects of climate change on crop production and to assess the impact of potential adaptation measures (Aerts and Droogers, 2004). Regarding maize production in Northwest

Vietnam, water is identified as a main limiting factor, so it requires selecting models with a strong emphasis on crop – water - climate interactions. A model that is specifically strong on the relationship among water availability, crop growth and climate change is the AquaCrop model. Advantages of using AquaCrop include the focus of the model is on climate change, water and crop yields, and it was developed and supported by FAO.

2.4. Model specifications

AquaCrop is the FAO crop-model used to simulate crop yield response to water. The different features between AquaCrop and other crop models is its focus on water, the use of ground canopy cover instead of leaf area index, and the use of water productivity values normalized for atmospheric evaporative demand and of carbon dioxide concentration. These provide the model the extrapolation capacity to be applied in diverse locations and seasons, including climate scenarios in the future. In addition, it gives particular attention to the fundamental processes involved in crop productivity, and in the responses to water, from a physiological and agronomic background perspective.

The main components included in the AquaCrop model to calculate crop growth include: atmosphere, crop, soil, field management and irrigation management.

2.5. Creating input files for AquaCrop

- Climate file

Creating a climate file consists of creating a temperature file, ETo file, rainfall file and selecting a CO_2 file. In regards to temperature and precipitation, daily data from 2008 to 2012 were used to create the input files, respectively.

The ETo, is used in AquaCrop as a measure of the evaporative demand of the atmosphere. It is the evapotranspiration rate from a reference surface. The ETo can be derived from weather station data by using the FAO Penman-Monteith equation. The FAO's ETo calculator was used to compute reference evapotranspiration rates for the AquaCrop model. In the calculator, the data from a weather station was specified in a wide variety of units, and meteorological data was imported. The calculated Eto was then exported into the AquaCrop model.

Regarding CO_2 data, the atmospheric CO_2 concentration from 1902 to 2099 provided by the Aqua Crop model was used.

- Crop file

When creating a crop file, the type of crop, planting method, plant density, cropping period, and calendar of the growing cycle was inputted into the model.

- Management file

The field practice characteristics were specified in the model based on data from the field survey.

- Soil file

A soil profile file was created by specifying the number of horizon sand depth of the soil. At each horizon, soil characteristics, including soil texture, permanent wilting point, field capacity and water content at saturation, were specified. In this study, these soil water characteristics were calculated by using the Soil - Plant - Air - Water model (SPAW) developed by the USDA Agricultural Research Service from data on soil texture and soil organic matter content.

2.6. Model validation

Model validation was conducted by measuring the differences between the simulated data and field data obtained on grain yield from 2008 to 2012.

Two statistical measures were applied: root mean square errors (RMSE) and coefficient of efficiency (E). The RMSE was calculated by the following equation:

$$RMSE = \sqrt{\frac{1}{N}\sum_{1}^{N}\left(Si - Mi\right)^{2}}$$

Where: Si and Miare the simulated and measured values, respectively, and N is the number of observations. The unit for RMSE is the same as that for Si and Mi; and a model's fitwill improve when RMSE moves closer to zero.

The coefficient of efficiency (E) is calculated as:

$$E = 1 - \frac{\sum_{i=1}^{N}\left(Si - Mi\right)^2}{\sum_{i=1}^{N}\left(Mi - M\right)^2}$$

Where: M is the mean of measured values.

The RMSE represents a measure of the mean deviation between measured and simulated values, which indicates the absolute model uncertainty (Heng*et al.*, 2009), whereas the coefficient of efficiency (E) shows how much the overall deviation between measured and simulated values departs from the overall deviation between measured values (Mi) and their mean value (M). The value of E can range from $-\infty$ to +1, and the model estimation efficiency increases as E gets closer to +1 (Heng *et al.*, 2009).

3. RESULTS AND DISCUSSION

3.1. Land resources and maize production in the study area

3.1.1. General description of study area

* Geography

Muong Lum commune is a commune of the Yen Chau district, Son La province. It is located in the eastern part of the district. The entire area of the Muong Lum commune is 5,035 ha (Muong Lum Commune Office, 2005).

The study area of Muong Lum commune is characterized by a valley with steep slopes between 780 and 1320 m of elevation and a river.

Muong Lum catchment consists of steep limestone ridges in the East - West direction and small clayey shale ridges mainly in the North - South direction between the limestone ridges and out of the valley with alluvial deposits.

* Climate

\- Precipitation

During the measuring period (2008 - 2012), the average annual rainfall in Muong Lum was 1193 mm/year. It changed a lot throughout a year. Whereas the maximum rainfall amount was received in September (230.7 mm), the minimum rainfall amount was in December (16.2 mm) (Figure 1). The rainy season was from May to October with a range from 122.5 $mm.month^{-1}$ to 230.7 $mm.month^{-1}$.

The annual mean temperature in Muong Lum was relatively low (21.2 ^oC) because of the higher altitude. The temperature varied throughout the year, the coldest month being January, with a mean of 14.1^oC and an absolute minimum of 9.9^oC, and the hottest month was June, with amean of 26.9^oC and an absolute maximum of 30.9^oC.

\- Insolation

Insolation data show the changesin solar radiation during a year that were extrapolated from the Yen Chau meteorological station. They indicate that the monthly mean of sunshine hours ranged from 4.5 in January (coldest month) to 7.0 in May.

\- Relative humidity

The humidity in Muong Lumwas relatively high and did not changemuch throughout the years. Mean humidity during thefive years (2008 - 2012) was 75.2%, and ranged from 72.1% (May) to 79.3 (October).

* Social-economic situation

Muong Lum consists of nine villages, five populated by Black Thai and four by Hmong minority people with a total population of 2,356 in 440 households (Muong Lum Commune Statistical Report, 2012).

* Cultivation in Muong Lum

In Muong Lum, upland rice was cultivated in the past, mostly for subsistence. However, it was replaced by maize and cassava for increased income. Changes in the cultivation cycle from maize to cassava and from cassava to fallow are mostly due to reduced yields and rarely because of labor shortage.

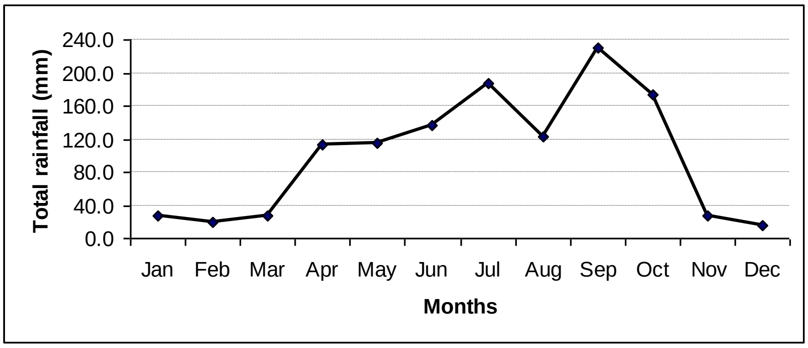

Figure 1. Monthly rainfall in Muong Lum

Almost all households (98%) in Muong Lum economically depend on agriculture (Muong Lum Commune Statistical Report, 2012). In terms of agricultural production, paddy rice, maize and cassava are major crops in Muong Lum commune. Rice plays a role as a subsistence crop, being planted in paddy fields mainly along the river, whereas maize and cassava are cash crops in the uplands (Saint-Macary *et al.*, 2010).

In the upland area, maize and cassava are the main crops covering 23% and 8.2% of the catchment area, respectively, whereas paddy rice is found in the valley (15.5%). Regarding land area, each household has 1.11 ha of cultivation land (Quang *et al.*, 2008).

* Maize production in Muong Lum

Maize serves as animportant cash crop for local households in Muong Lum. Recently, the maize production area was expanded to 375 ha (Muong Lum Commune Statistical Report, 2012). Within this area, farmers mainly cultivate hybrid maize varieties with an average yield reaching 7.1 tons.ha^{-1} (Muong Lum Commune Statistical Report, 2012).

Because of the characteristics of the rainfall pattern, the maize farming system is annually one crop (Summer - Autumn season). It starts in May when the rainy season occursand the crop is harvested at the end of August. In Muong Lum, maize is intercropped with cassava in some plots, however, generally a maize monograph is dominant in the upland fields.

In many cases, farmers have cultivated maize on steep slopping land with very limited soil conservation measures applied. However, due to the fact that this land was changed from forest land to agricultural land in the recent past; it still keeps enough soil quality for efficient maize production.

Overall, farmers need to apply chemical fertilizers to maintain the yield of maize. In some cases, soil is degraded strongly so that maize production is not effective. It leads to a situation in which farmers must change the farming system to cassava production.

3.1.2. Study field description

* General information

Are presentative maize plot in Muong Lum was chosen for this study to simulate yield responses of maize to climate change. The plot's coordinates were 21.02 North and 104.49 East with an average elevation of 815 m above sea level and a slope of 15%.

Farmers started to cultivate maize in this plot in 2000. Before that time, this land was covered by bush forest.

Soil is developed from limestone. Clay accumulation occurs in the soil, resulting in a finer texture in the subsoil. This process produces a diagnostic horizon of Agric in this Alisols soil.

* Soil water characteristics

Using the pedo-transfer function, the SPAW model is used to calculatethe soil water characteristics from soil properties such as soil texture and soil organic matter (OM) content.

The results of the soil water characteristics calculated by SPAW is shown in table 1. The table indicates that PWP received the minimum value at the topsoil due to its low content of clay, whereas it reached the maximum Figure (14.7%) at the Bt horizon where the clay content increases to 23% because of clay accumulation.

3.2. Maize yield simulation in the time series under climate change scenarios

3.2.1. Reference evapotranspiration

Evapotranspiration was calculated by the ETo calculator using climate data getting from the Muong Lum weather station. Figure 2 shows the average values of ETo and the change trends from January to December for the period of 2008 to 2012.

Results of the ETo calculation indicate that an average Eto was 3.6 mm.day^{-1} and its lowest value was duringa short period in January - February. During maize development from May to August in Muong Lum, the ETo keeps relative high values (4.1 mm day^{-1} on average) with low variation (Figure 2).

3.2.2. AquaCrop running for maize yield prediction in 2008 - 2012

In the maize research plot, the farmer cultivated maize variety CP888, which is a hybrid imported from Thailand. Maize was grown for 105 - 115 days during the rainy season. It was sowed between the 4th – 14th of May and was harvested in August. From interviews with the farmer, this maize field received an application of NPK fertilizer at levels of 25 kg N, 50 kg P and 15 kg K per hectare and Urea fertilizer at 236 kg N.ha^{-1}.

Table 2 clearlyshows theresults of the simulated biomass, simulated grain yields and measured grain yield after the calibration process. Deviation between the simulated yield and measured yield ranges from -0.85% in 2009 to 3.04% in 2010. The results show that Coefficient of Efficiency is 0.93. The data support that the model, after calibration, can simulate maize yield under rainfed conditions in Northwest Vietnam. It agrees with an argument that AquaCrop can predict maize yield (Teklu*et al*., 2011).

3.2.3. Maize yield response to climate change scenario B2 in 2013 - 2100

Climate change scenario B2 was used to predict the impact of climate change for the period of 2013 - 2100. The AquaCrop model, after calibration, was applied to simulate the yield of maize under climate change conditions. The results are shown in Table 3.

Figure 3 indicates a slightly increasing trend of maize yield for climate change scenario B2. It revealed that climate change has a positive impact to maize production at the study area. This result is compatible with the FAO finding that maize yield increases in the Red River Delta under climate change projections (FAO, 2011).

4. CONCLUSIONS AND RECOMMENDATIONS

The AquaCrop model wasapplied to simulate maize growth under rainfed conditions in Muong Lum commune, Northwest Vietnam. After calibration, the model reached the coefficient of efficiency level of 0.93.

Table 1. Soil water characteristics

Horizon	Thickness (cm)	Texture	PWP (% Vol)	FC (% Vol)	SAT (% Vol)
1	20	Loam	11.2	26.6	44.9
2	28	Silty loam	14.7	31.5	44.5
3	31	Silty loam	14.3	32.6	46.3
4	24	Silty loam	12.5	30.1	44.1
5	17	Silty loam	11.6	28.9	42.0

Note: PWP - Permanent wilting point; FC - Field Capacity; SAT - Water content at saturation

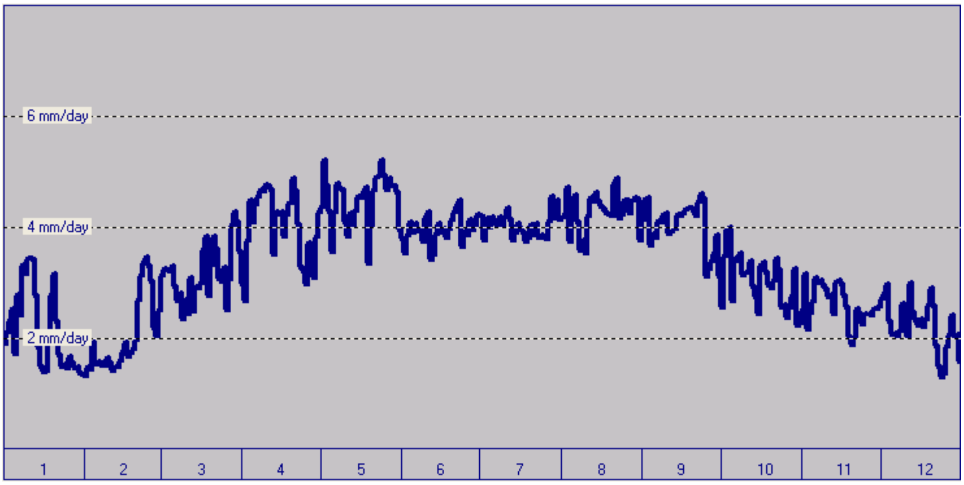

Figure 2. Reference crop evapotranspiration (ETo) at Muong Lum in 2008 - 2012

Table 2. AquaCrop simulation result

Year	Biomass (simulated) (ton.ha^{-1})	Grain Yield (simulated) (ton.ha^{-1})	Grain Yield (Measured) (ton.ha^{-1})	Deviation (%)
2008	15.66	7.20	7.1	1.41
2009	17.54	8.13	8.2	-0.85
2010	15.44	7.11	6.9	3.04
2011	14.83	6.92	7.0	-1.14
2012	15.88	7.30	7.4	-1.35
Root Mean Square Error (RMSE): 0.12 tons.ha^{-1}				
Coefficient of Efficiency: 0.93				

Table 3. Grain yield of maize simulated by AquaCrop under Climate Change Scenario B2

2010*	2050*		2100*	
Grain yield (2008-2012)	Simulated grain yield (tons.ha^{-1})	Change (compared to the baseline) (%)	Simulated grain yield (tons.ha^{-1})	Change (compared to the baseline) (%)
7.32	7.38	0.82	7.48	2.2

Note:: An average value over a period of 5 years around this point of time*

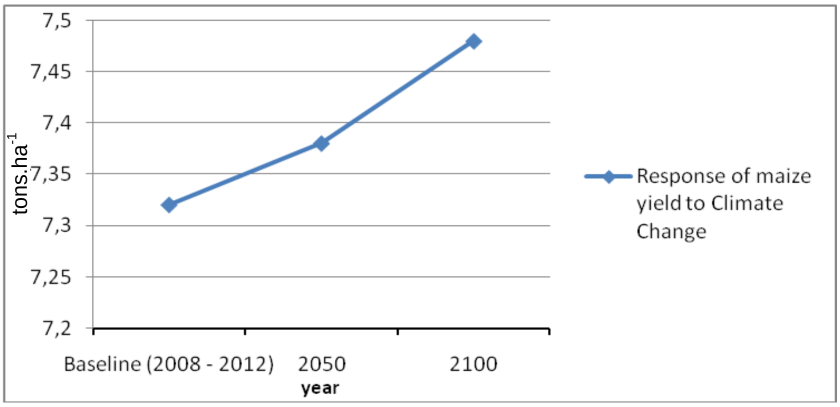

Figure 3. Response of maize yield under climate change scenario B2

Regarding climate change impacts, the model showed a positive impact to maize yield with an increase of 2.2% in 2010 compared to period of 2008 - 2012. It recommends that maize production can be continued in the study area under climate change conditions in the future.

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