Mémoire de fin d'études

présenté pour l'obtention du diplôme d'ingénieur agronome
Option : Production Végétale Durable

Cropping system sensitivity to climate change in the northern uplands of Lao PDR

An agroclimatic modeling approach

par Esther LECHEVALLIER
Année de soutenance : 2015
Organisme d'accueil : CIRAD, UR AïDA
DALAM

Mémoire de fin d'études

présenté pour l'obtention du diplôme d'ingénieur agronome
Option : Production végétale Durable

Cropping system sensitivity to climate change in the northern uplands of Lao PDR
An agroclimatic modeling approach

par Esther LECHEVALLIER

Année de soutenance : 2015

Mémoire préparé sous la direction de :
Hélène Marrou

Présenté le : 18/09/2015
devant le jury :
Aurélie METAY
Hélène MARROU
Crystèle LÉAUTHAUD

Organisme d'accueil : CIRAD, UR AïDA
DALAM

Maître de stage: François AFFHOLDER
Encadrant au Laos: Pascal LIENHARD

RESUME

Titre : Sensibilité des systèmes de culture des régions montagneuses du nord du Laos au climat actuel et futur.

Dans un contexte de transition agraire, l'agriculture de subsistance des régions montagneuses du nord du Laos est aussi amenée à faire face au changement climatique.
L'objectif de ce projet a été de décrire les systèmes de cultures pratiqués dans les régions montagneuses du nord du Laos puis d'évaluer leur sensibilité au climat.
Pour cela, des entretiens avec des agriculteurs ont été menés afin d'identifier les cultivars utilisés et la dynamique de leur cycle de culture. Des mesures en champs de producteurs et l'analyse de données de rendement ont servi à déterminer le niveau d'intensification des systèmes de culture pratiqués. La caractérisation des systèmes de culture a permis de paramétrer un modèle agro climatique simple, Potentiel Yield Estimator (PYE), afin de simuler la croissance de 4 cultivars (1 cultivar de riz glutineux, 2 cultivars de maïs et un cultivar de larmes de Job) dans des conditions potentielles ou limitées par l'eau. Puis une expérimentation virtuelle a été mise en place pour simuler la croissance de ces cultivars dans des systèmes de cultures conçus sur la base des informations récoltées sur le terrain. Plusieurs modalités ont été testées pour les paramètres d'entrée variables du modèle (niveau de ruissellement, caractéristiques du sol, dates de semis). Cette expérimentation virtuelle, menée pour 16 années de données climatiques historiques (1985-2000) et pour 16 années fictives représentant une possibilité d'évolution du climat dans le futur, a permis d'évaluer la sensibilité des systèmes de culture au climat sous plusieurs aspects. Le rendement potentiel par cultivar a été analysé en fonction de la date de semis. Puis l'analyse de la sensibilité du rendement limité par l'eau par rapport au niveau de ruissellement et aux propriétés du sol a révélé l'existence d'une fenêtre de semis pour laquelle le rendement limité par l'eau est très proche du potentiel et dépend peu de l'année. D'une manière générale, le rendement limité par l'eau est peu sensible au ruissellement mais sa sensibilité (représentée par le niveau de rendement et sa variabilité interannuelle) à la réserve utile et la profondeur du sol est d'autant plus grande lorsque l'on s'éloigne des dates de semis optimales. Le changement climatique aurait pour conséquence d'abaisser le niveau de rendement potentiel mais n'affecterait pas outre-mesure le rendement limité par l'eau relatif et sa variabilité en fonction des propriétés du sol et du ruissellement. Le drainage, autre sortie du modèle, serait aggravé par le changement climatique, ce qui amène à considérer avec prudence l'usage de fertilisants minéraux pour palier la baisse de fertilité des sols due au raccourcissement du temps de jachère.

Mots clés

Modélisation, riz pluvial, maïs, changement climatique, systèmes de culture, rendement potentiel, rendement limité par l'eau, fenêtre de semis, drainage, réserve utile, ruissellement

ABSTRACT

Title: Cropping system sensitivity to climate change in the northern uplands of Lao PDR: an agroclimatic modeling approach

In addition to the actual context of agrarian transition, subsistence agriculture in northern upland of Lao PDR will face climate change. The aim of this project was to describe the cropping systems in northern upland of Lao PDR and to assess their sensitivity to climate. To begin with, farmers were interviewed to identify the cultivated cultivars and their crop cycle dynamics. Field measurements and yields data analysis helped with intensification level determination. From the collected information on cultivars and cropping systems, a simple agroclimatic model, potential Yield Estimator (PYE), has been calibrated in order to simulate growth of 4 cultivars (1 glutinous rice cultivar, 2 maize cultivars and 1 job's tear cultivar) in potential and water-limited conditions. Then a virtual experiment has been set up to simulate the growth of these cultivars in cropping systems designed based on collected information. Several modes were tested for variable input parameters (runoff level, soil AWC and soil depth, sowing date). This virtual experiment, run for 16 years of historical weather data (1985-2000) and for 16 years of virtual weather data representing a possible evolution of climate in the future, led to an assessment of cropping system sensitivity considering several features. Cultivars potential yield has been analyzed regarding sowing date. Then the analysis of water-limited yield and its sensitivity to runoff and soil properties revealed an optimum sowing window for which water limited yield is close to potential yield and its interannual variability is low. Generally, water-limited yield is low sensitive to runoff but its sensitivity (average decrease in yield and interannual variability) to AWC and soil depth is increasing when sowing dates digresses from optimum sowing window. Climate change would decrease the potential yield but should not affect critically the relative water-limited yield and its variability due to soil and runoff properties. Drainage, another output of the model, is supposed to increase with climate change, which lead to a questioning regarding use of fertilizer to cope with fertility losses due to fallow-period shortening.

Key words

Crop modeling, upland rice, maize, climate change, cropping system, potential yield, water-limited yield, sowing window, drainage, available water capacity, runoff

Remerciements

I address my grateful thanks to my supervisors: Francois Affholder and Pascal Lienhard who supervised me during this internship, respectively concerning the modelling approach and the field work. Thanks to Helene Marrou for her advises and encouragements.
Many thanks to UR AiDA in Montpellier and DALAM in Vientiane for their warm welcome.
Thanks to EU-GCCA (Global Climate Change Alliance) for the financial support.
The IRD/NAFRI soil laboratory agreed to provide me technical guidance and support to measure soil parameters. I would like to thank Christian Hartmann, Xaysatith Souliyavongsa, and Loun for his numerous useful advises concerning my soil analyzes.
Thanks to Guillaume Lacombe for providing the weather data from Luang Prabang station and the APHRODITE data shaped by IMWI for an easier use.
Many thanks to the CIRAD team in Laos: Jean-Christophe Castella, Guillaume Lestrelin, Marion Riviera, Leonor Bonnin for sharing information on cropping and farming systems, on vocabulary in lao or lunch with me. Thanks to Khack and Kongsen for the administrative help with the visa. And thanks to all the EFICAS team for punctual help: Vongson, Soulikon, Sisavath.
Special thanks to Thissadee for his translation and negotiation talents, and his help in every moment on the field.
I don't forget to thank to my colleagues and friends in Montpellier, Leo and Amadou, for their help on modeling and redaction questions.

I address grateful thanks to the naibans (village heads) and all the farmers who answered to my questions and who allowed me to take crop samples in their field. I thank them for their hospitality and the information they provided me.

ຂໍຂອບໃຈທຸກໆທ່ານທີ ເຮັດໃຫ້ຂ້າພະເຈົ້າມ່ວນຊື ນກັບປະສົບການທີ ເປັນເອກະລັກແບບນີ້

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

AWC: Available Water Capacity
APHRODITE: Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation
Asl: above Sea Level
BD: Bulk Density
CIAT : International Centre for Tropical Agriculture (Centro Internacional de Agricultura Tropical)
CIRAD: Centre de coopération Internationale en Recherche Agronomique pour le Développement
DAFO: District Agriculture and Forestry Office
DALaM: Department of Agriculture Land Management
DM: Dry Matter
EFICAS: Landscape management and Conservation Agriculture development for Eco-Friendly Intensification and Climate Resilient Agricultural Systems in Lao PDR
ET0: Evapotranspiration (Pennman-Montheith)
FAO: Food and Agriculture Organization of the United Nations
FC: Field Capacity
CGIAR: Consultative Group for International Agriculture Research
GCM: Global Circulation Model / Global Climate Model
GDP: Growth domestic product
ICEM: International Centre for Environmental Management
IMWI: International Water Management Institute
IPCC: Intergovernmental Panel on Climate Change
IRD: Institut de Recherche pour le Développement
JulD: Julian Day
LAI: Leaf Area Index
LMB: Low Mekong Basin
MAF: Ministry of agriculture and forestry, Lao PDR
MRC: Mekong River Commission
NAFRI: National Agriculture and Forestry Research Institute, Lao PDR
NMRI: National Maize Research Institute of Vietnam
NUDP: Northern Upland Development Program
NTFP: Non-timber Forest Products
pF = log cm (water)
pF 4.2 = -160m water= -16bar
pF 2 =-1m water= -0.1 bar
PWP: Permanent Wilting Point
PYE: Potential Yield Estimator
Sarra: Système d'Analyse Régionale des Risques Agroclimatiques
STICS : Simulateur multidisciplinaire pour les cultures standard
UR Aïda: Unité de Recherche Agroécologie et Intensification Durable des cultures Annuelles
USAID: United States Agency for International Development
Y0: potential yield, limited only by temperature and solar radiation
Yw: water-limited yield

I. Introduction

1) Economic and demographic growth effects on agriculture in Lao PDR

Lao People Democratic Republic (Lao PDR) experienced a rapid development over the past decade, among which Gross Domestic Product (GDP) increasing dramatically (about 7-8 %), and life expectancy being extended up to 68 year. The country also suffered a dramatic increase in population growth over the same period. Last census, led in 2005, revealed that the population has grown by nearly 55.6% in 20 years, rising from 3.6 million (1985) to 5.6 million in 2005, and is now supposed to reach 7 million people (Worldbank, 2015). From 1950 to 2015, population density increased from 7.6 to 29.3 persons/km^2. Agriculture is still playing an important role in the country economy, since added value from agriculture contributes for 27% to GDP (Worldbank, 2015). Approximately 61 % of the total population in Lao PDR are farmers (Worldbank, 2015) who are cultivating about 2 million ha of agricultural land (9% of the total land area). However, even if land expansion managed to absorb part of the increasing food demand, increasing land pressure cannot be neglected.

2) Northern upland of Laos is dominated by subsistence agriculture

Annual cropping systems in northern Laos fall into two distinct groups regarding their position in the topo-sequence and their modes of rice cultivation: (1) 'lowland' cropping systems, where flooded rice production predominates, are located on flat, low-lying areas generally flooded during the wet season. (2) 'Upland' cropping systems where crops rely only on rainfall for water supply. About 80% of rice surface in Laos is cultivated under rainfed condition (Food and Agriculture Organization, 2012). In our study, we focus on those upland areas which represent a major part of the northern part of Laos, since 80 percent of the country surface is mountainous (Phongoudome & Sirivong, 2008). In the northern region, only 6% of land area is with slopes lower than 20% compared to 50% area on slopes higher than 30% (Bounthong & Raintree, 2002).

Our study focused on the upland territories of Luang Prabang province. In this area, Upland farming systems are characterized by subsistence agriculture experiencing a shift to commercial agriculture. Farmers cultivate mainly upland rice for direct consumption, since it is the main staple food of the lao population. Other upland crops (e.g. maize, cassava, sesame) are cultivated for animal or human consumption, but in a lesser extent. More recently, the cultivated area in cash crops (e.g. hybrid maize, job's tear, vegetable) has dramatically increased along with the opening of new roads. Annual crops are cultivated under traditional rotational shifting cultivation. They are grown on a plot after fallow clearing (slashing and burning). After the cropping period (one to several years), cultivation area is moved to another part of the village and earlier cultivated plot returns to fallow for several years (until the next cultivation period): this is a rotational cultivation of fallow and annual crops. Pioneering shifting cultivation with deforestation is not common. A study by Messerli et al. (2009) estimates that shifting cultivation landscapes dominate 29% of the national territory and involve 17% of the population.

Those farming systems have low access to inputs (fertilizers, herbicides and pesticides), and field work is mainly manual. Hence, the agriculture is highly depending on climate.

3) Climate change intensity expected in northern upland of Laos

A recent study established predictions for climate change in the LMB (Lower Mekong Basin) with a 25 year baseline period of 1980–2005 (ICEM, 2013). Trends for climate change were established considering IPCC Scenario A1b. It is a moderate emission scenario representing a world of rapid economic growth, introduction of more efficient technologies, global population peaking by 2050 and a balance between fossil intensive and non-fossil energy sources (IPCC 2000). The study adopted six GCM (Global Circulation Models) that best simulate the historic climate conditions of the Mekong Basin.

Compared to the Southeast Asia global projections for 2050, the predictions for the study area are moderate regarding variation in rainfall and temperature (APPENDIX 1).

Annual precipitation is projected to increase by between 10% and 14% in the north of LMB, representing an average increase of 150mm/ year, with variations from 100 to 350 mm/year. In the northern Lao PDR, there will be a decrease in drought months of up to 25%—a decrease of around two weeks of drought per year. Considering extreme precipitation event, cyclone-related rainfall rates will increase, the frequency of the more intense cyclones will increase substantially. Considering this, we can assess that projected increases in precipitation for the LMB could be compounded by increasing cyclone intensities, with peak daily precipitation increases up to more than 16% in northern highlands Lao PDR (ICEM, 2013). Other studies on climate change tendencies for central Mekong basin show slight wetting tendency that are considered as low that they should not affect agriculture. Beginning of rainy season could be delayed of 0.16 d/year et 0.29 d/year in this regions depending on the scenario (Lacombe et al., 2013).

The increase in temperature is predicted to be relatively low for the study area—between 1.7 and 1.9°C, compared to other area in the LMB.

4) Presentation of EFICAS project and objectives

Climate changes will increasingly have greater impacts on the poorest farmers, because of their lack of resources to cope with the impacts. The EFICAS project (Landscape Management and Conservation Agriculture Development for Eco-Friendly Intensification of Agricultural Systems in the Northern Uplands of Lao PDR) is aiming at supporting sustainable and climate resilient land use approaches and adapted farming systems at local level, informing policy making and improving communities' resistance and resilience to climate change. The project is managed by CIRAD (International Centre for Agricultural Research for Development, France) in partnership with the Department of Agricultural Land Management (DALaM) of the Ministry of Agriculture and Forestry (MAF, Lao PDR). It is funded by the European Union under the Global Climate Change Alliance Program (GCCAP) and the Agence Française de Développement over a three-year period (2014-2017). Target areas of the project are upland territories of three provinces of northern Laos (Luang Prabang, Huaphan, Phongsali).

5) Objectives and problematic of the 6-months study

Since annual cropping systems represent a major part of income for the households, effect of climate change on cropping systems should be assessed to estimate the vulnerability of upland farming systems. Sensitivity is the degree to which a system will be affected by, or responsive to climate change exposure (Olmos, 2001). If sensitivity is high and adaptability is low, then vulnerability will be high.

Our study aims to contribute answering the following a general question: What is the sensitivity of agri-environmental performances of cropping systems in the northern uplands of Laos under current and future climate conditions?

A first specific objective of this study is to identify and describe the main annual cropping systems practiced in the study area. The most representative ones will be selected to assess their sensitivity to climate.

Through a modeling approach, a second specific objective is to assess the influence of temperature and precipitations, under current and future climate, on grain yield and water balance in upland cropping systems. To do so, we will use a modeling approach based on the PYE crop model. PYE is numerical model that simulate the dynamics of potential and water-limited crop growth. The model will be parameterized for 4 main cultivars found in the study area:

-Upland glutinous rice which represents the main cultivated species in the northern upland of Laos as well as in the two villages selected
- Long cycle maize which is an important cereal to feed an increasing livestock
- Hybrid maize LVN10
- Job's tear

The two latter are developing cash crops representing an increasing income for farmers in the area.
Various cropping systems considering soil, runoff and sowing dates characteristics will be tested. Yield variations will be studied as the main output for farmers and effects on water balance will also be analyzed.

First, we will present our method to characterize the cropping systems and to parameterize the model considering the data collected on the field, leading to the construction of the virtual experiment. Then, cropping systems description based on our investigations will be presented. In a second part, virtual experiment results will be exposed and analyzed. In a last part, results will be discussed regarding the possible evolutions of cropping systems, as well as the method for parameterization.

II. Material and methods

1) Location of the study

Our study has been led in the upland territories of northern Laos. Our agroclimatic approach forced us to choose a study area where climatic data were available. Another constraint was to select an easily accessible study area (even during the rainy season) to led several measurement campaigns. We chose to focus on villages already involved in EFICAS project to get an easy access to information on the villages and cropping systems. Moreover communication with the village head and the farmers was already established with the project staff.

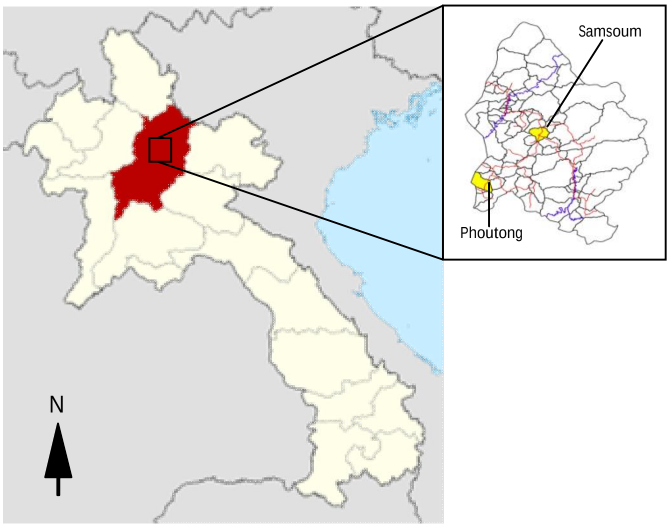


Figure 1: Location of the study area. Source: EFICAS project

Considering those constraints, we chose to lead our study on two villages in Viengkham district in Luang Prabang province, with common characteristics of northern upland territories in term of landscape, farming and cropping systems (tab.1). In the study area, geological substrate is formed by acidic rocks: granite and metamorphic schists. Population densities are low compared to the national average of 29.3(World Bank, 2013).

Table 1: Comparison of the two villages' characteristics

	Samsoum	Phoutong
Nb household	25	71
Nb inhabitants	206	429
Area (ha)	1687	2032
GPS coordinates	20°13'39.44"N 102°49'27.47"E	20°12'224"N 102°47'257"E
Altitude (m asl)	1035	1045
Ethnic group	Hmong	Khmu
Main cultivated crops	-Rainfed rice -Maize -Job's tear	-Rainfed rice -Maize

In this study, we used the climatic data of Luang Prabang weather station (N19° 52'679" E102° 09'170", 304m asl), situated respectively at 80 and 100 km away from Phoutong and Samsoum. A correction considering difference of altitude was applied for temperature.

2) Climatic data are necessary for an agroclimatic approach

a) Historical available climatic data analysis

Climatic data from Luang Prabang weather station were provided by IMWI. We led an analysis of the following data before implementing them into the model:
- Daily rainfall in mm recorded from 1961 to 2007
- Minimum temperature and maximum temperature in °C, daily recorded from 1985 to 1988, then monthly recorded until 2001
- Wind speed (m/s, monthly recorded from 1985 to 2001)
- Solar radiation (MJ/m²/day, daily recorded from 1985 to 2001)
- Sunshine duration (in hours, monthly recorded from 1985 to 2001)
- Relative humidity (monthly recorded from 1985 to 2001).

Some data (Temperature, Relative Humidity, Wind speed, Sunshine duration) are described in the file as O (observed), or E (estimated) data.

-Estimated data are also available for rainfall: data from APHRODITE datasets (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation). APHRODITE database provide daily gridded precipitation data at the continental-scale on the long-term (1951 onward). The grid box data are calculated by interpolation based on data obtained from a rain-gauge-observation network. We compared observed climatic data to APHRODITE estimated data (transformed and provided by IMWI) when both were available to estimate the level of uncertainties on estimation and screen for errors in observation records.

Solar radiation has been recalculated from the astronomical length of the day and sunshine duration because of highly inaccurate data. To do so, we used Angström coefficients adjusted for Vietnam (Affholder, personal communication).

b) Construction of future climate dataset

Based on the available weather dataset for the period 1985-2001, we constructed a new dataset to test the vulnerability of cropping system to future climate was based on the predictions of ICEM report (ICEM,2013) for 2050 horizon.

We assumed that temperatures will experience an increase of + 1.8°C (we simply increased daily mean temperature by 1.8°C). We assumed that precipitations will increase by about 150mm on the annual scale. 14% of event rainfall has been added to major events and the amount of total added rainfall over the year should not exceed 150mm (fig.2). The threshold for considered major events has been adjusted each year.

For example, for the year 1995, we added the 14% additional rainfall to all the rain days with rainfall >22mm, but for year 1998, we added the 14% to all the rain days with rainfall >8mm, to reach the increase of 150mm on the whole year.

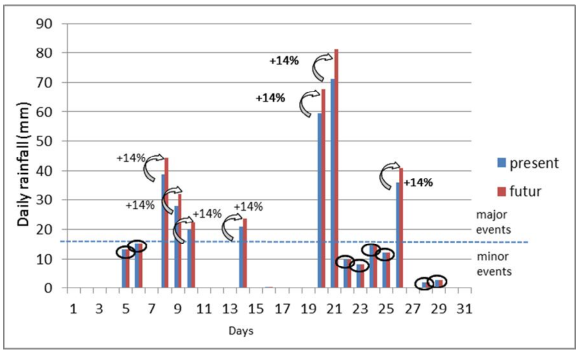


Figure 2 : Future dataset construction strategy: 14% rainfall is added to major events

3) Identification of cropping systems characteristics

a) Species, cultivars and cropping systems management interviews

Characterization of cropping systems and cultivars has been done through interviews of experts of the project, use of data collected by other interns in the villages studied, and explorative farmers interviews to get information on: number of species and cultivars cultivated in the villages, and for each cultivar: characteristics (ex: glutinous/ non-glutinous for rice, early/late maturing varieties), sowing, flowering and harvest windows. Other cropping system characteristics were asked, like sowing densities, fertilization, herbicide and pesticide use, tillage, and grain yield range.

b) Field observations and measurements

To get precise information on cropping system intensification level, we recorded specific observations and we did measurements in 40 plots (22 fields), chosen among a diversity of cropping situations for the villages' main cultivated cultivars (tab.2). For rice and two job's tear fields, we considered the intra-field variability with 3 plots (cropping situation) studied per field (high, medium, low location along the slope in the field). For maize, only one measurement per field was conducted. Plot size was dependent on the species considered. 2m²-plots were selected in maize and job's tear fields and 1m²-plots were selected in rice fields (APPENDIX 2).

Table 2: Number of investigated plot per cultivar and location

Plot number		Rice			Maize*				Job's tear
type		Non-glutinous rice	Glutinous rice		Local maize (long cycle)		Local maize (short cycle)	Hybrid maize	Job's tear
cultivar		Khao Deng	Khao Na bok	Khao Yuok	Sali Yao	Sali Khao	Sali Luang	LVN10 Sali Pan	MakDuay Khao
Location	High	2	3	2	3	3	3	3	3
	Medium	2	3	2					2
	Low	2	3	2					2
Total per cultivar		6	9	6	3	3	3	3	7
Total per type		6	15		6		3	3	7
Total per species		21			12				7

*Sampled in June only

in Samsoum   in Phoutong

➢ Information recorded on cropping situation characteristics

- The following cropping situation information was recorded: sowing density, sowing date, slope (degrees), location along the slope, intercropping description when present (species, density).
- Crop growth information was recorded: crop stage (number of leaves), crop height, disease or pest occurrence, weed and growth homogeneity note was given (from 1 to 5).

I measured the leaf area index (m² leaf/m² soil) and the biomass (t/ha) along the cropping season: 2 times for rice and job's tear: at the end of June and end of July, one time for maize (end of June) because it was already at the maximum LAI (which is considered to be reached around 10 days before flowering).

➢ LAI measurement:

All plants in the delimited plot were cut down. Leaves were removed from stems with scissors, and humid weight of all the leaves was recorded (same way than biomass). From the "all-leaves" sample, a representative subsample of leaves (all sizes from all plants, 20 leaves) was picked and weighted with the small portative balance.
Back in the village, subsample leaves were displayed on paper sheets and pictures were taken (1st field trip/ end of June), or sheets were scanned (2nd field trip/ end of July) (fig.3). Specifics protocol adjustments for each crop are presented in APPENDIX 3.

Area of sampled leaves were measured by computer processing on Image J software, with a 5*5 cm green paper benchmark positioned on every picture for scale calibration.

Figure 3 : Sampling protocol and LAI measurement

LAI (m^2/m^2) was calculated from the subsample area measured by picture analysis.

$$LAI = \frac{[(\sum sampled\ leaves\ area) * total\ leaves\ humid\ weight]}{(sampled\ leaves\ humid\ weight)} / area\ of\ plot$$

Sampled leaves area and area of the plot were measured in m^2 and weight in g.

➢ Biomass measurement

Humid weight of the total biomass of the plot was recorded after the plants were cut down. After LAI subsample has been taken off, a representative subsample for biomass was taken from the remaining part of leaves and stems. Humid weight of this subsample was recorded, then the sample have been pre-dried in air (or air-dried) during 2 weeks and then dried in an oven at 60°C during 30h. Specifics protocol adjustments for each crop are presented in APPENDIX 3.

Biomass (t/ ha) was calculated from the dried subsample. Area of the plot were measured in m^2 and weight in g.

$$Biomass = \frac{sampled\ dry\ biomass\ weight * total\ biomass\ humid\ weight}{(sampled\ biomass\ humid\ weight)} / area\ of\ plot * 100$$

➢ Yield interviews

Yield data were collected by technicians of the DAFO for EFICAS project during general village interviews in late 2014. The farmers came to the technicians to answer individually their questions about their productions. In Samsoum, production was given directly by farmers in ton. In Phouthong, production was given in bags. We converted production in ton/ha using given weight of bags given by farmer's interviews, 41 kg per bag for rice and 25kg for maize. Those results were compared with the declared yield of farmers during detailed and rapid surveys led by the other interns. The yield has been given regardless of the cultivar. Those data helped us to have an idea of the level of actual yield compared to potential or water-limited yields.

c) Soil characterization

Soil is a component of cropping system which influences crop growth. In order to take the soil characteristics into account for our study of cropping systems, we led soil analysis regarding the Available Water Capacity (AWC).

➢ Measured variables

AWC is the amount of water available for plants in the soil (Padarian et al, 2014). It represents the water held by the soil (soil water content at field capacity) but it is not considering the fraction of soil water which is not extractible by the roots because of higher soil suction pressure (soil water content at wilting point).

AWC available water capacity for the profile (mm/m) is calculated by the formula:

$$AWC = \sum_{i=1}^{n} (hcc(\mathrm{i}) - hmin(\mathrm{i})) * BD(\mathrm{i}) * epc(\mathrm{i}) / 10$$

- i, soil layer (1 to n, between 0 and 1m)
- *epc*, layers thickness (mm)

- *hcc (gwater/gsoil)*, soil water content at field capacity: Soil water content held in the soil after excess water has drained away by gravity. The soil moisture content at field capacity represents the highest limit of water availability for crops. It has been measured by the method by depressurization (sand box) on undisturbed soil samples to measure PF at 2.0.
- *hmin (gwater/gsoil)*, soil water content at wilting point: Soil water content held in the soil when the forces, which retain water in the soil, are stronger than the plants suction force and the plant cannot extract more water. It has been measured by the method by pressurization (pressure membrane apparatus) on disturbed soil samples sieved at 2mm to measure PF at 4.2 (−1500 J/kg of suction pressure).

- *Bulk density (BD),* was measured by soil sampling with a cylinder of 98 cm³. Samples were dried in the oven at 80°C during 48 hours and weighted. Bulk density was calculated by formula: $\frac{Ms}{Vs}$
- *Ms*, mass of dry soil (g)
- *Vs*, volume of soil (cm³)
- *Stone content* (weight and volume) has been assessed on undisturbed samples after sieving at 2mm.

➢ Soil sampling

The soil samples were taken in the two villages. A total of 108 soil samples in 18 locations on a diversity of soil types were analyzed. In Phoutong, the samples were taken in fields that were just burnt and which will be cultivated this year. In Samsoum, one sample was taken in a field that was just burnt, one in a 1-year-fallow field and one in an 8-year-fallow field. However, since the fields are cultivated one year, we consider that their land-use will not affect the field water capacity. Three toposequence locations per field were sampled (high, medium and low position on the slope). Three samples at different depth were sampled. For each layer, disturbed (with an auger) and undisturbed (with a mace and cylinders) samples were collected (fig.4).

108 samples= 2 villages × 3 fields × 3 slope positions × 3 soil layers ×2 methods

villages	fields	slope positions	soil layers	methods
Phoutong	1	High	0-10 cm	Disturbed
Samsoum	2	Medium	10-30 cm	Undisturbed
	3	Low	30-50 cm	

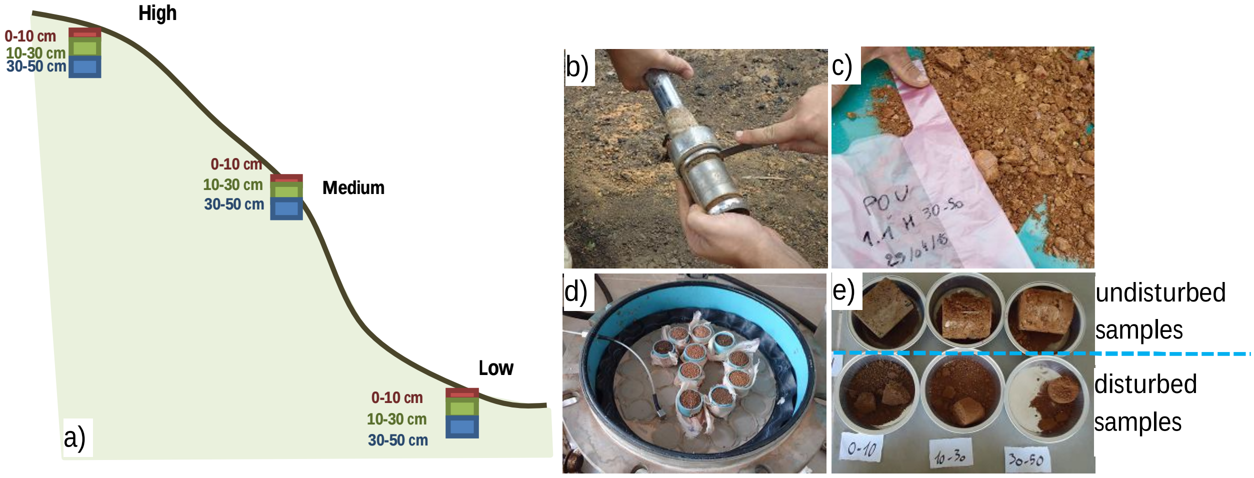


Figure 4: Soil sampling strategy: a) location of the samples along the slope b) undisturbed soil sampling; c) disturbed soil sample; d) pressurization in pressure membrane apparatus for hmin determination; e) undisturbed and disturbed soil samples after drying

➢ Data statistical treatment

For each village data from the 3 fields were gathered the average and standard deviation were calculated. Soil presents an organized variability along the toposequence, and a random variability (taken into account by the repetitions set in the village). We compared the samples along the toposequence (high, middle and low position along the slope) and considering their vertical position in the soil profile (depth), through Student test (with α=0.005), considering the very small number of observations per mode (n=3) when we cross all the modes (village, depth and location).
Our measurements gave us the AWC of three layers until 50cm. In PYE model, only one soil layer is considered, hence the input parameter for AWC in the soil compartment is one AWC value in mm/m (supposed to be the same for all the soil profile). We chose to represent the real heterogeneity of the soil depending on depth built from our measurements.

AWC on 0-50cm has been calculated by addition of averages values for AWC in each layer. To get AWC on the first meter, we chose to extrapolate value for deepest layer to 1m. Another method considered the decreasing trend in AWC from surface to deep layer. Virtual values were extrapolated following a trend function. In our modeling approach, we chose to test a high hypothesis, corresponding to our measurement, and a low hypothesis lower than the calculated AWC, to ensure that the range of AWC present in the area is represented in our virtual experiment.

4) Modeling approach construction

a) Presentation of Potential Yield Estimator model (PYE)

The preliminary exploration of the functioning of the cropping systems and their interaction with climate has been led using the model PYE (Potential Yield Estimator), written in VBasic under Microsoft Access. PYE is a daily time step model that simulates the growth and development of a crop, depicted by its genetics features, into a cropping system, depicted by soil characteristics and crop management operations, under a climatic environment (Affholder et al., 2013). PYE considers a standard stand density and simulates potential yield Y0 and water limited yield Yw as defined by van Ittersum and Rabbinge (1997). Y0 is non-water limited, under potential conditions where the crop is not affected by any stress and depends only on temperature and solar radiation. Yw stands for water limited yield, which considers rainfall limitation on growth in case of rainfed crops. A conceptual diagram of the PYE model is proposed in fig 5. Development and growth modules are based on STICS model (Brisson et al., 1998, 2003).

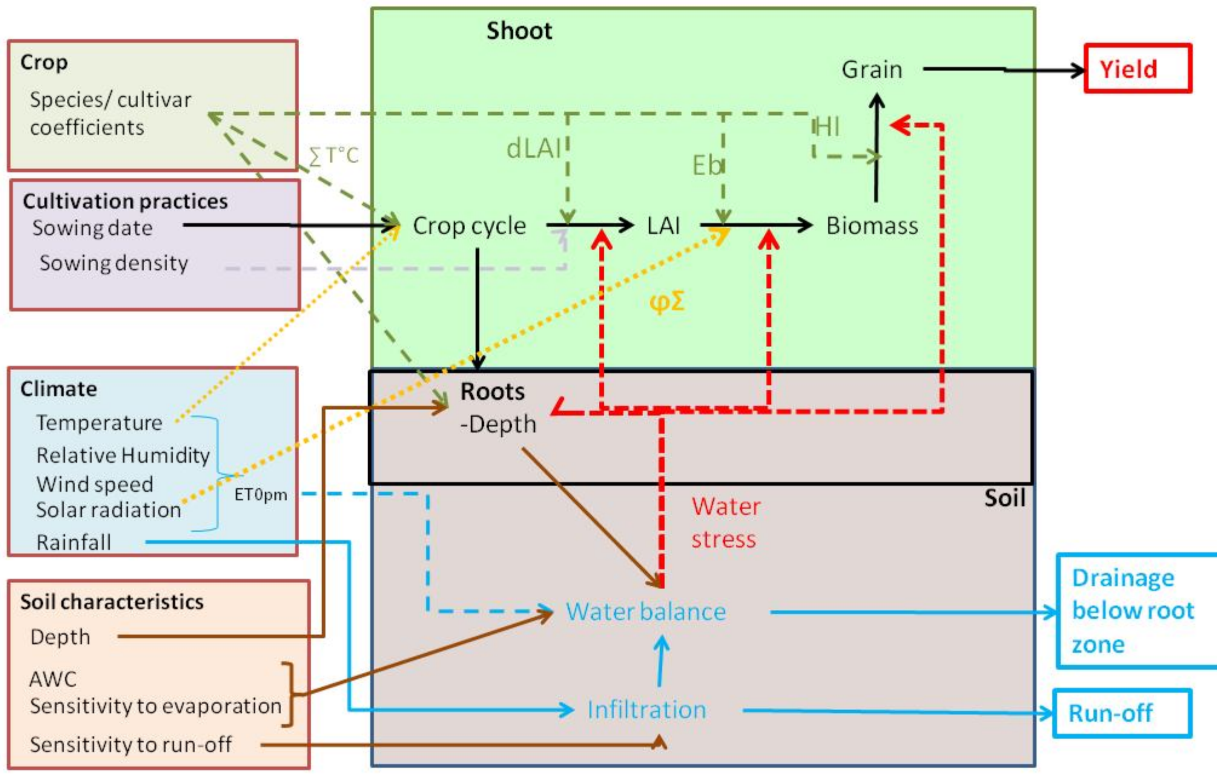


Figure 5: Conceptual model of PYE

Under potential growth, crop phenology and potential leaf area index are only determined by thermal time and the water stress calculated from the water balance is not influencing the calculation. Under water-limited conditions potential daily increase in leaf area index and biomass are both multiplied by a water stress coefficient calculated as an output of the water-balance.

b) Water balance

Water balance model is based on Sarra-mil model (Système d'Analyse Régionale des Risques Agroclimatiques) (Affholder, 1997). It is considering the soil compartment as a water reservoir.

Water stock in the soil is calculated at daily step.

$$Stock(dayi) = Stock\ (dayi\ -\ 1) + precip(dayi)\ -\ Esol(dayi) - transpi(dayi)$$

- *Stock*, available water stock for crop in the soil (mm) (stock≤ $AWC\ *\ Zrac$)
-*dayi*, simulated day
- *precip*, rainfall of the day (mm)
- *Esol*, soil evaporation of the day(mm)
- *transpi*, plant transpiration of the day (mm)

A water stress coefficient influencing crop growth is calculated from the water balance.

$$ContrainteW(dayi)\ = \frac{Stock(dayi)}{(AWC\ *\ Zrac)}$$

- *Zrac*, root depth (cm)
- *ContrainteW*, water stress coefficient, 0<ContrainteW<1

Outputs of the water balance model: drainage and runoff:

$$Dr(dayi) = precip(dayi) + Stock(daysim - 1) + (Deltazrac * AWC) - AWC * (Zracmax - Zrac)$$

$$Ruis(dayi)\ =\ \alpha * \ (precip(dayi)\ -\ seuil)$$

- *Dr,* drainage (mm)
- *Deltazrac*, daily increase of root depth
-*Zracmax,* mamimum root depth
- *Ruis*, runoff(mm)
- α, runoff coefficient is the percentage of non-infiltrated water (runoff water) over the total amount of fallen stormwater (0< α<1)
- *seuil*, critical rainfall is the amount of rainfall required to exceed the infiltration capacity and to generate runoff (mm)

Main input parameters influencing on the water balance are: soil available water capacity, top soil layer depth (which is affected by evaporation), runoff coefficient, and species-dependent parameters that regulates root growth and crop. In our study, we tried to assess AWC in our study area. Species-dependent parameters were found in the literature for rice and maize (Luu Ngoc Quyen et al., 2013).

c) Crop phenology

Phenology approach is based on the occurrence of 5 stages during the crop cycle: Emergence-bolting stage (Juv), tillering-max heading (Tall), heading-full flowering (Flo), Full flowering-senescence (Grain), Senescence-maturity (Matu) (fig.6). Current stage determines crop behavior regarding LAI and biomass growth, grain formation, and sensitivity to water stress.

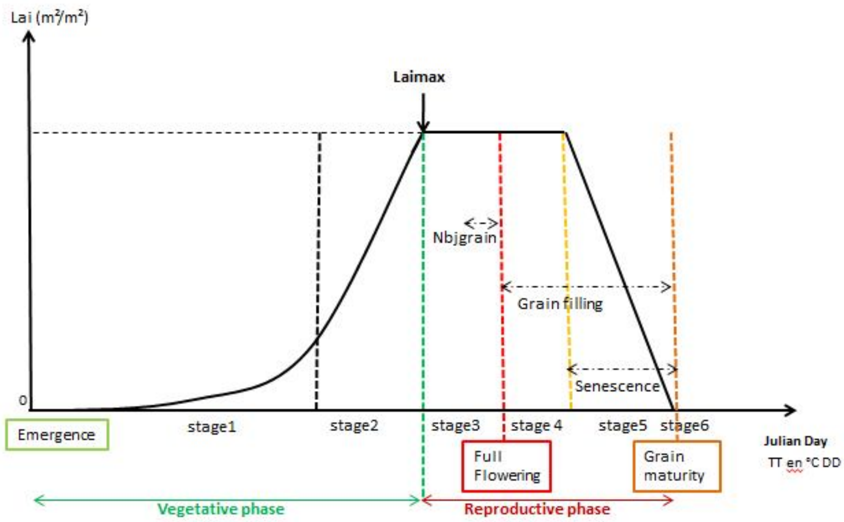


Figure 6: Crop stage and LAI growth during crop cycle

Accumulated degree-day sum lead to stage shifting. Stage i is reached on day n when

$$TT(i) = \sum_{k+1}^{n} (f(Tm))$$

- *TT(i)*, thermal constant for stage i en °C.day $^{-1}$
- *k*, day when stage (i-1) is reached
- *Tm*, average day temperature (Tmax-Tmin/2), in °C

- $f(Tm)$, a function of temperature:
  if *Tm* < *tdmin*, $f(Tm)$ = *0*
  Tm > *tdmax*, $f(Tm)$= *tdmax-tdmin*
  else, $f(Tm)$= *Tm-tdmin*
- *tdmin* minimal temperature for crop development
- *tdmax* temperature threshold for increasing growth speed

Thermal constants for crop development stages are cultivar dependent. A special parameterization of the model is needed to represent the growth of our cultivars.

d) Leaf Area Index (LAI)

Daily increase of LAI (*dLAI)* is depending on the stage and crop density

$$dLAI = \frac{dlaimax}{1+\exp\,(5.5*(Vlaimax-Ulai)} * f(Tm) * Turfac * \Delta idens(denspl)$$

- *dLAImax* maximum daily increase of LAI (m².day $^{-1}$)
- *Ulai* leaf development unit
- *Vlaimax* is *Ulai* at inflection point of function *dLAI= f(Ulai)*
- *densplt*, sowing density

$\Delta idens$, effect of sowing density on LAI

- $f(Tm)$, a function of temperature:

if *Tm* < *tdmin*, $f(Tm)$ = *0*
Tm > *tdmax*, $f(Tm)$= *tdmax-tdmin*
else, $f(Tm)$= *Tm-tdmin*

- *Turfac,* water stress sensitivity coefficient

$$Turfac(dayi) = \frac{ContrainteW}{(1 - SeuilTurg(icult))}$$

SeuilTurg, species-dependant parameter

LAI evolution depends on dlaimax and on the model calibration for phenologic stages. Once calibration for phenologic stages is done, only dlaimax has to be adjusted through a trial and error approach.

e) Biomass

Biomass production depends on the crop capacity to intercept photosynthetically active radiation (PAR). This capacity depends on the crop radiation-use efficiency (RUE), which is a species-dependent coefficient, and is regulated by temperature and water stress.

$$dBiom = Ebmax * WSfact * Ftemp * \frac{raint}{100}$$

- *dBiom*, daily increase of biomass ($T.ha^{-1}.day^{-1}$)
- *Ebmax* maximal crop radiation use efficiency (species-dependent parameter)
- *Ftemp*, temperature sensitivity coefficient

- *WSfact*, water-stress sensitivity coefficient (0<WSfact<1)

$$WSfact(dayi) = \frac{ContrainteW(dayi)}{(1 - SeuilWS(jcult))}$$

- *SeuilWS,* species-dependent parameter
- *ContrainteW*, water stress coefficient calculated from water balance

- *raint*, daily intercepted solar radiation ($MJ.m^{-2}$), calculated from Lambert-Beer law.

$$raint = 0.95 * ParsurRg * Rg * (1 - (e^{(-coeffextin*LAI)})$$

- *Rg*, daily global solar radiation ($MJ.m^{-2}$)
- *ParsurRg* photosynthetically active radiation fraction (PAR/Rg)
- *CoefExtin*, extinction coefficient of solar radiation by LAI (species-dependant parameter)

Ebmax was already validated for maize and rice by previous studies (Luu Ngoc Quyen et al., 2014). We use those data for parameterization in our study.

f) Grain yield

Grain yield is calculated as the minimal value between two approaches:

-Grain yield is calculated using a harvest index (HI) approach coupled with a sink limitation (Brisson et al., 1998). Daily increase of HI during grain filling stage is calculated as a function using a crop specific maximal HI (IRmax), and a cultivar specific daily rate of increase in HI (vitircarb).

-Grain yield is calculated considering the period of flowering stage which determines the grain number. In this case, grain number per unit area (Ngrain) is depending on the growth rate during this time (Vitmoy). Grain yield is calculated as the product of a crop specific maximal weight of one seed (W1Smax) and the simulated value of the number of grains per unit area. Ngrain is a linear function of two cultivar dependant parameters (Cgrain and CgrainV0).

$$Ngrain = Cgrain \times Vitmoy + CgrainV0$$

Vitircarb, Cgrain and CgrainV0 are cultivar dependent coefficients, which has to be adjusted through a trial and error approach considering our cultivars phenologic development.

5) Model calibration

Some parameters are robust for a species regardless of the cultivar. Others are highly dependent on the cultivar considered. In this part we will distinguish the model parameterization considering species-dependent parameters and cultivar-dependent parameters, which have been assessed from our field work.

a) Model parameterization regarding crop management operations

Some cropping management parameters are critical inputs for the model. Sowing dates and sowing densities have a great effect on the plant growth. Those data were investigated through farmers' interviews. In each village, I asked a group of farmers the earlier and later sowing dates for each cultivar. I also compared those dates with the observed sowing date in each of the visited fields. I deduced the most common sowing dates and a threshold sowing window possible for each cultivar, which would be also tested in the virtual experiment.

The average sowing densities for each cultivar were calculated as the average sowing densities/ m² observed among all the visited plots.

b) Model parameterization regarding species-dependent coefficients

The PYE model have been validated in previous studies for rice and maize considering observed data of crop phenology, leaf area index, aboveground biomass and grain yield in plots maintained, respectively, in potential growth conditions (Luu Ngoc Quyen et al., 2014) and water-limited conditions (Luu Ngoc Quyen, 2012, Affholder et al, 2013). Species-dependent coefficients were directly based on those parameters (tab. 3).

PYE have never been parameterized for Job's tear. Considering the analogy with maize, we used maize parameters to parameterize it. Same crop parameters were used for hybrid and long-cycle maize.

Table 3: Species-dependent parameters implemented in the model

Parameter	Description	Upland Rice	Maize	Job's tear
TDmin	Minimal temperature for development	9 (1)	6 (2)	6
TDmax	Maximal temperature for development	40 (1)	28 (2)	28
TCmin	Minimal temperature for radiation-to-dry matter conversion efficiency	10 (1)	8 (2)	8
TCmax	Maximal temperature for radiation-to-dry matter conversion efficiency	42 (1)	42 (2)	42
TCopt	Optimal temperature for radiation-to-dry matter conversion efficiency	25 (1)	29(2)	29
Ebmax	Coefficient of maximal net radiation conversion	2.6 (3)	4 (4)	4
HImax	Maximal harvest index	0.38 (5)	0.56 (6)	0.56
W1Smax	Maximal one-seed weight	0.034(7)	0.342(8)	0.342
Kmax	Maximal cultural coefficient	1.12(9)	1.11(9)	1.11
LAImax	Maximal leaf area index	5(10)	6(11)	6
Extin	Extinction coefficient	0.5 (12)	0.7 (11)	0.7
Zracmax	Maximal root depth	150 (13)	180(13)	180
Cgrain	grain number set up per gDM/day of average biomass growth during Nbjgrain preceding the beginning of stage 4	855	76	76
CgrainV0	grain number set up if no growth during the nbjgrain (grains /m²)	-1775	674	674

1: Luu Ngoc Quyen et al. (2014); 2 : Affholder (2001) ; 3 : Boonjung and Fukai (1996), 4: Brisson et al. (1998);5: 11: Saito et al. (2007);6: Hay and Gilbert (2001), 7: Asai et al. (2009);8: Golam et al. (2011);9: 15: Allen et al. (1998);10: 18: Bouman et al. (2005);11: Lindquist et al. (2005);12: Dingkuhn et al. (1999) 13: Affholder et al. (2013)

c) Model parameterization regarding cultivar-dependent coefficients

- **Phenologic stages thermal constants**

Crop cycle length needed to be adjusted to our cultivars. Thermal constants for phenologic stages were investigated through farmers' interviews. In each village, I asked a group of farmers the earlier and later observed dates for 3 main crop stages in their fields for each cultivar used in the village (for maize, rice and job's tear). Dates were only asked for emergence, flowering and harvesting, because they are easily observable. Then average day's number for these stages were calculated for each cultivar.

Average lengths in days between those 3 stages were used to assess the thermal constants for the 5 stages described in the model. Based on previous parameterization for rice and maize (Affholder, 2013), thermal constants were gradually adjusted to fit to the average cycle length given by the interviews in the average of the 17 years tested, for usual sowing dates. To avoid an inaccurate representation of the growth, thermal constants for each stage were adjusted keeping the same proportion between the stages into the vegetative and flowering phase.

- **LAI and biomass growth rate parameters**

The lengthening of crop cycle due to cultivar specificities led to an adjustment of cultivar parameters which control the growth speed of LAI and the grain filling speed.
The following parameters were adjusted by through a trial-and-error approach:
Dlaimax: maximum LAI daily growth rate ($m^2.m^{-2}.day^{-1}$)
Vitircarb: daily increase of harvest index (g grain. g^{-1}. DM. day^{-1})
To estimate the above parameters in the absence of direct measurements of maximal LAI and Yield under potential conditions, we used expert knowledge on the highest values of LAI and Yield recorded in the region for the cultivars of our study, as shown in the following table (Lienhard, Affholder, personal communication). We first set Dlaimax so that simulations in the absence of water stress led to the estimated potential values of LAI, and then applied the same principle to set Vitircarb so that simulated potential yield reached the estimated potential value.

	Rice	Maize long cycle	Hybrid Maize	Job's tear
Y0 max yield (t/ha)	4	4	9	4

6) Virtual experiment to assess sensitivity of cropping systems to climate

To assess the sensitivity of the cropping systems to climate, we simulated the growth of the 4 selected crops in various cropping systems. The model was used to explore different soil and runoff conditions.

a) Range of soil types simulated: AWC and depth

Soil depth seemed to be heterogeneous in the studied area. We considered 3 type of soil depth in our study to cover the range of possible soil depth in the area: very shallow soil, with a depth of 50cm (observed in one fallow where the soil was only alterite when we reached 50cm-depth), common soil with a depth of 1m (we supposed that most of the soils on the slopes are around 1 m deep), and deep soil with a depth of 2m, which would be probably the case in the low parts of the valleys.

From the AWC measured on the field, we selected 2 soil types for the simulation: one common soil with an AWC of 120mm/m and a low hypothesis with an AWC of 80mm/m (tab.4).

Table 4: Tested soil characteristics

Soil types	AWC120D200	AWC120D100	AWC80D100	AWC80D50
AWC	120 mm/m	120mm/m	80mm/m	80mm/m
Soil depth	200cm	100cm	100cm	50cm
	Best hypothesis	Common soil	Common soil	Worst hypothesis

b) Range of runoff level simulated

The runoff in the model is described by two parameters: the critical rainfall and the rainfall coefficient. Critical rainfall is the amount of rainfall required to exceed the infiltration capacity and to generate runoff. We chose to fix it at 10mm. Runoff coefficient for a mountainous catchment with an average slope of 52%, similar to our case of study, is approximately of 30% for annual crops (Upland rice and job's tear) (Patin et al., 2012).

Through modeling, we explored the case of an average runoff of 30%, but we also set up an high hypothesis of 50% and a low hypothesis of 0 % (no runoff).

c) Simulation of top soil layer depth (evaporation flux)

We considered an average value of 15cm, advised for modeling by Allen et al (1998) in case of unknown data.

d) Sowing dates

20 sowing dates were tested (each 5 days) around the most applied sowing date (based on farmers interviews). Around 5 sowing dates represent the sowing window actually applied but a broader range of sowing dates was tested to assess effects of very early or late sowing, and to eventually assess the relevance of sowing dates shift under the hypothesis of climate change.

e) Virtual experiment design and output analysis

First the growth of the 4 crops has been simulated for potential growth. Then the water-limited growth conditions were applied to the cropping system simulation, considering 12 different conditions (4 soil types, 3 levels of run-off), 20 options regarding sowing dates, for the 17 years of available weather data for the present climate, and for the 17 years of constructed weather data to simulate a climate-change hypothesis.

Results of the virtual experiment were analyzed through the grain yield output, modified into the ratio Yw/Y0 to ensure a fairer comparison between cultivars with different yield level. Water balance output (drainage) has also been analyzed.

Interannual average and interannual variability over the 17 years have been commented.

III. Results

1) Description of the observed upland cropping systems

Upland cropping systems of northern Laos are highly influenced by the village organization and the community work. Hence we described the cropping systems and also the village organization and farming systems to better understand cropping systems design.

Residents are involved in a variety of livelihood activities, though annual cropping undertaken through a shifting cultivation system constitutes the single most-important livelihood activity for all village households.

➢ Land use management

The uplands include steeply sloping hills interspersed with small fertile river valleys. Upland systems are located on gentle to steep slopes, where upland crops are grown under non-flooded (aerobic), rainfed conditions, and fields are neither bounded with banks nor leveled. Shifting cultivation is set up at the villlage-scale. The villagers slash entire parts of valley at one time for the year, so that they can organize the common tasks/work, and a production road can be built for the common benefit. The land is the property of the village and the fields are attributed every year to the farmers depending on the household constitution. The entire cropping area is fenced since there is free roaming in these villages (the livestock is divagating freely in the fallows). During the fallow period, the vegetation is developing without any management and provides products to the farmers such as wood (fences construction) and non-timber-forest-products (NTFP): bamboo shoots, medicinal products, mushrooms…. After several years, bamboo bushes and trees are major components of the fallow.

➢ Cropping systems characteristics

Farmers often cultivate around 3 ha (1-5 ha). Subsistence farming is characterized by upland rice and traditional maize cultivation for human and livestock consumption. Cultivation of cash crops like hybrid maize LVN10 are increasing in the study area, as well as job's tear cultivation (sown for the first time this year in Phoutong). There are no paddy fields in these villages. Usually one main species (and sometimes two cultivars but grown on distinct areas) is cultivated in a field: Upland rice (*Oryza sativa*), maize (*Zea mays*), job's tear (*Coix lacryma jobi*), cassava (*Manihot esculenta*), and sesame (*Sesamum indicum*). But it is common that some other crops are cultivated in intercropping with the main species in specific areas of the field. Some observed examples: pumpkin (*Cucurbita pepo*), cucumber (*Cucumis sativus*), rice bean (*Vigna umbellata),* pigeon pea (*Cajanus cajan*), groundnut (*Arachis hypogaea)*. Cropping system illustrations are proposed in APPENDIX 4. Major constraints in cropping systems are steep slopes, low access to inputs (fertilizers, herbicides and pesticides) and lack of mechanization.

Species and cultivars:

For selected annual crops in our study, several cultivars are cultivated in the villages (mainly long-cycle) (tab.5). Seeds and crop illustration are proposed in APPENDIX. 5

Table 5: Cultivar names and type

	Village	Cycle type	Cultivar name
Rice	Samsoum	Long cycle	K.Yuok, K.Kam, K.Lang, K.Deng(NG) , K.Luan(NG)
	Phoutong	Long cycle	K. Niat, K. Nang, K.Kam, K.Na bok pi
		Short cycle	K Na bok ka
Maize	Samsoum	Long cycle	S.Khao, S.Luang pi, hybrid LVN10
		Short cycle	S.Kam, S.Luang ka
	Phoutong	Long cycle	S. Yao, LVN10
		Short cycle	S.Deng
Job's tear	Samsoum	Long cycle	M.D.Khao
	Phoutong	Long cycle	M.D.Khao

NG: Non-glutinous
G: glutinous

➢ Cultivation practices and crop cycle dynamics

Many field works are organized in common: slashing, burning, fencing, sowing, harvesting. Slashing is carried out in January or February and burning the dry biomass in March or April, before the onset of the rainy season, requiring 3 rain-free days. The fields are not ploughed. Sowing is done after some days of rain from mid-April to mid-May (fig.7). Crops are sown in bunches with a dibble stick in rows most of the time, with several seeds per hole. Usually the farmers sow maize, then rice and job's tear (tab.6). Weeding is done around 2-3 times and represents a peak of work during the rainy season. We estimated that the maturity occurs 21 days before harvest date for maize and job's tear, and 14 days before for rice. Harvest is delayed to reach a low degree of grain humidity. Fields are cultivated one year only, and then they come back to fallow for 5 to 8 years.

Table 6: Data related to cycle dynamics collected from interviews

	Rice	Long-cycle Maize	Hybrid Maize	Job's tear
Average sowing date	120	115	125	165
Average flowering date	258	221	214	273
Average maturity date	306	296	288	345

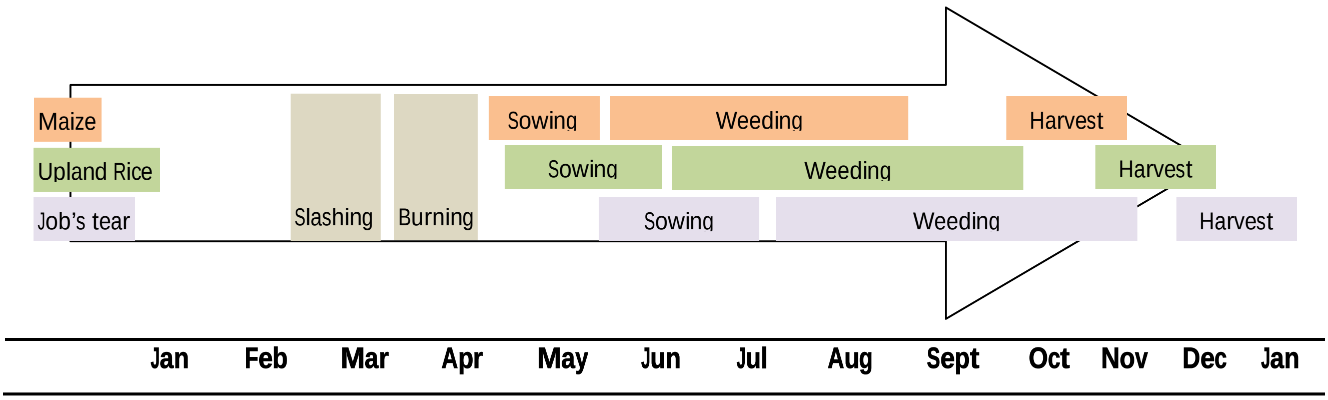


Figure 7: Crop calendar with main cultivation practices

Apart from data collected from interviews, we also collected directly observed data in the investigated plots, like sowing densities and actual sowing dates for this year. Sowing densities were expressed in plants/ m² for maize and job's tear, and in bunches/ m² for rice (tab.7).

Table 7: observed sowing densities and sowing dates

Crop type	Glutinous rice long cycle	Non-glutinous rice long cycle	Local maize long cycle	Local maize short cycle	Hybrid maize LVN10	Job's tear
Average sowing date (+std) (JulD)	115(±5.2)	113(±9.3)	106(±7.0)	109 (±6.8)	123(±5.1)	147(±4.6)
Average sowing density (+std) (plant/m²)	10.8(± 1.5)	9.6(± 1.2)	4.5(± 0.7)	5.8 (±0.4)	5.8(± 2.2)	6.1(± 1.6)

2) Actual crop growth data in farmer's field

a) Yields data from interviews

Average declared yields are about 40% lower than potential yields (fig.8). For maize, we consider the data from Samsoum valid for long-cycle maize and the data from Phoutong valid for hybrid maize. Both are not close from potential yield. Job's tear is also quite far from his potential level. Regarding rice, some declared yields are higher than the potential yield but it can be due to errors in cultivated area estimates: upland cultivated area are usually unknown (no land titling of rotational agricultural lands) and cultivated areas are estimated from the quantity of seeds sown, with sowing density varying importantly from one farmer (and/or one field) to another one.

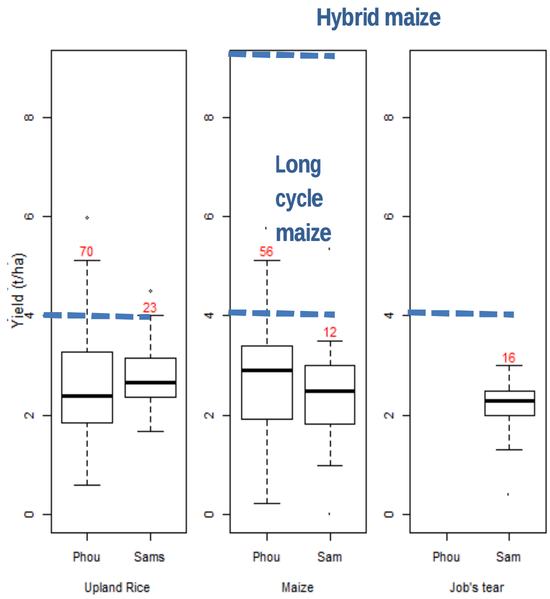


Figure 8: Comparison of yields recorded from interviews (2014) with potential yields - - - *: potential yield level*

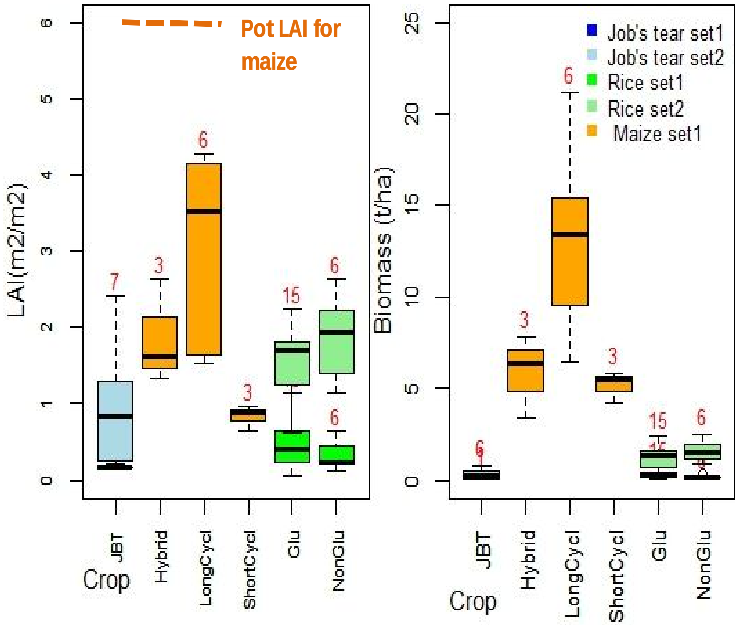


Figure 9: Measured LAI (m²/m²) and biomass (t/ha) in farmers' fields (+number of observations in red)

b) LAI and Biomass data from field measurement

LAI and biomass measurement (fig.9) illustrate the very low growth rates of this year, especially for rice. Rice and job's tear were not measured at their maximum LAI (occurring later in the season). However, LAI will probably be far from the potential considering the strong drought experienced this year.

Observation of current cropping systems revealed their low level of intensification. Crop growth and yields are far from the potential, which means that they have certainly lower needs for water than crops growing under potential conditions. (which are developing higher LAI and higher biomass, resulting in higher evapotranspiration and higher water consumption).

c) Soil analysis

Analysis of bulk density and AWC was done on 3 samples per location, which is not reliable for real statistical analysis. However the analysis was done with Student test at 0.05 to have at least an idea of differences and variability.

➢ Bulk density

A high heterogeneity is observed through the villages and locations. Variation coefficients are higher than 10% in most of the case. In Phoutong, we observe no differences in bulk densities neither considering the location along the toposequence or the depth (p values between 0.30 and 0.83) (fig.10). In Samsoum, there are some significant differences between layers considering different locations. When all the locations are gathered (n=9), we can observe significant differences between superior and medium layer (p-value = 0.003) and between medium and bottom layer (p-value = 0.004).

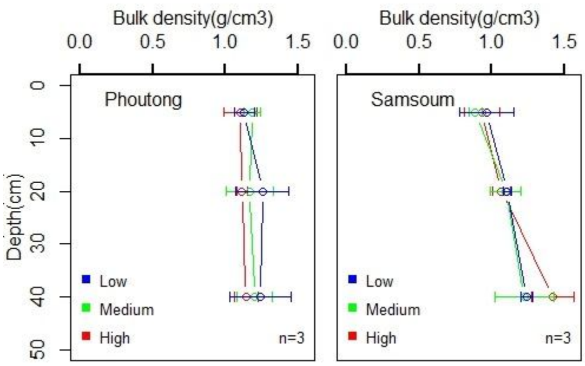


Figure 10: bulk density per depth and location on the toposequence (average+std)

➢ Water content per soil layer at wilting point and field capacity

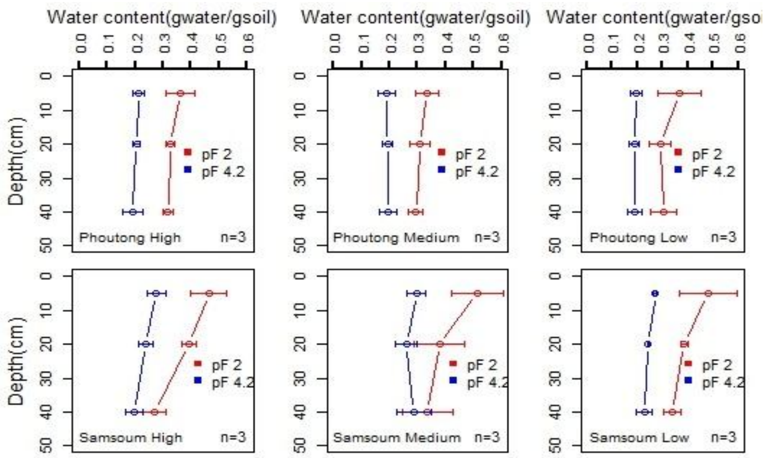


Figure 11: mass humidity at pF2 and pF4.2 per depth and location (g water/g soil)

Water content per layer has been calculated as the difference of mass humidity at pF 2 (field capacity) and pF4.2 (wilting point) (fig.11).Since water content per layer seems to be constant or slightly changing with depth in Phoutong, water content seem to decrease with the depth in Samsoum.

➢ AWC per layer

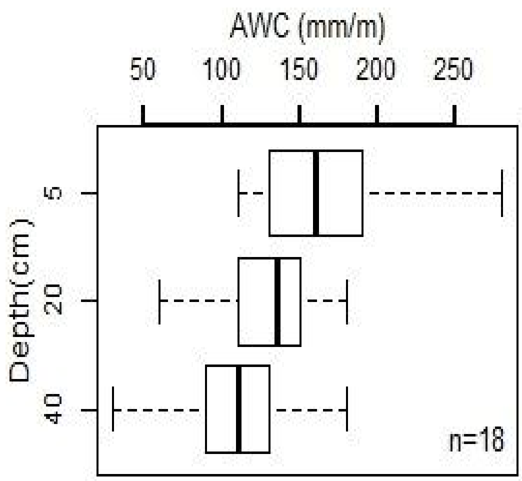


Figure 12: AWC per layer (mm/m)
n: observation number per mode

In Phoutong, some differences between layers in specific locations on the slope are significant (student test, p-value <0.05) and there is a difference between the above layer which has a higher AWC than the other regardless of the position along the toposequence. (p-value = 0.01 and p-value = 0.03 with 10-30 and 30-50 layers respectively)
In Samsoum we can suppose a slight tendency for smaller AWC in deeper layers but the variability is very high and no significant differences are visible. If the data are gathered regardless of their position on the toposequence, there is a significant difference between above and deeper layer (p-value = 0.01).

Gathered data show a decreasing AWC from the top-layer to the deepest layer (fig.12).

➢ Calculated AWC as an input parameter of PYE model

Since we did not find any significant difference between toposequence locations or between the villages, we considered only one type of soil from the average to calculate total AWC.

	AWC (mm/m) (1st meter)
Prolongation of 30-50 layer	117
Logarithmic extrapolation	98

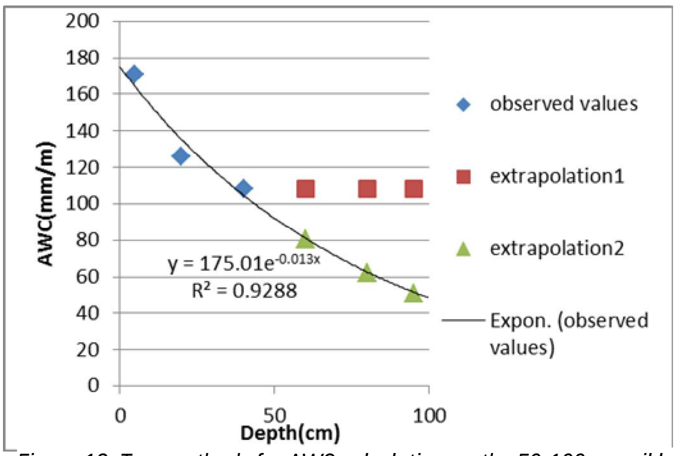


Figure 13: Two methods for AWC calculation on the 50-100cm soil layer

Our extrapolation method gave two AWC values (117 and 98 mm/m) (fig. 13).

The high hypothesis tested in PYE (120mm/m) corresponds to a possible common soil in the study area. The low hypothesis (80mm/m) is low enough to ensure inclusion of soils with lowest AWC in the area.

➢ Stone content and soil depth

Stones found in the soil are alterite (much degraded schist). It is hard to separate stones from soil, as alterite can disaggregate easily. Alterite porosity is high, so it is wrong to consider it as stone (without any water retention) and it is also wrong to consider it as soil (with real soil properties for water retention).

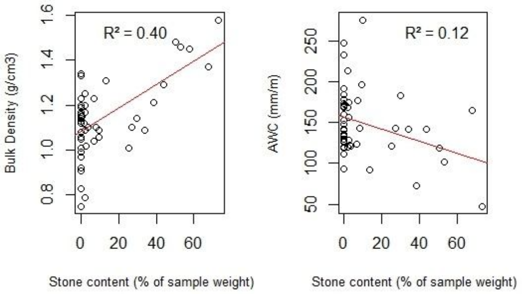


Figure 14 : Correlation of stone content with bulk density and AWC

More than 1/3 of the soil profiles have at least one horizon where stone content is more than 10% of the weight and only ¼ of the profiles have no stones at all in any of their layers. The presence of stones seems to be correlated with the bulk density but does not seem to be really correlated with the final AW per layer (fig.14). When only soils with stone content higher than 10% are considered, correlation between stone content bulk density is slightly higher (R^2=0.58), but almost inexistent with AWC (R^2=0.05).

Figure 15 Soil profile visible in Phoutong next to a production road

High stone content in the bottom layer (30-50cm) is probably a proxy for the soil depth. In 5 over 18 soil profiles, stone content in this layer was higher than 40% (maximum was 73%). High stone content is the bottom layer probably indicates that the basement rock is shallow.

Moreover observation of a soil profile visible after the opening of a production road indicated that there is a stony horizon at approximately 1m depth (fig.15). It could be the top of the rock basement or only a stony horizon with soil below. Uncertainties on the soil depth led us to simulate 3 different alternative: a very shallow soil (50cm-deep), an average soil (1m-deep), and a deep soil (2m-deep).

3) Climatic data analysis

Mountainous areas of northern Laos experience a sub-tropical climate. The climate is dominated by the monsoon with annual pronounced wet and dry seasons, respectively. The wet season occurs from May to late September and the dry season runs from October to April. 80% of total rainfall is occurring during rainy season. Seasonal rainfall distribution shows the onset of rainy season in April-May, though the leading peak is occurring in August–September, representing the return of monsoon strength combined with the onset of the tropical storm season (fig.16). Average annual precipitation over the 17 years is 1340mm. Average annual temperature is 25.7°C in Luang Prabang (304masl), but it is lower in higher elevations.

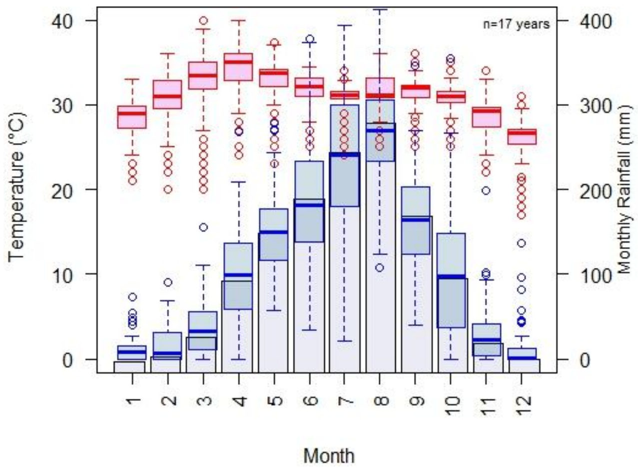


Figure 16: Ombrothermic diagram of Luang Prabang weather station (modified to represent the variation of temperature and rainfall over the 17 years of available data)

Critical analysis of other weather data, comparison between observed and estimated values for rainfall and spatial comparison of estimated values are presented in APPENDIX 6.
The critical analysis revealed the need to recalculate solar radiation data from sunshine duration data. We chose to present here the comparison between raw and recalculated data.

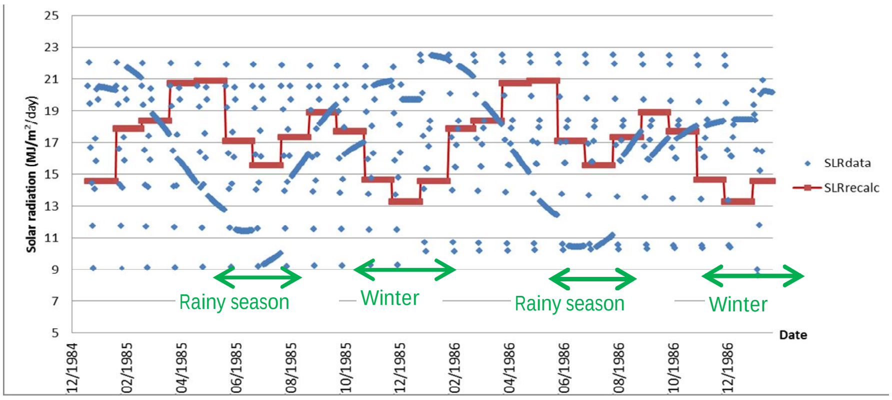


Figure 17: Comparison between raw (blue) and recalculated (red) solar radiation data over 2 years (1985-86)

Recalculated solar radiation is very different from the raw data (fig.17). Solar radiation is the lowest during the winter because of the short length of the day. Solar radiation is maximal at the onset of the rainy season, in May. During the rainy season, solar radiation decreases until reaching 15 MJ/m²/day in July, because of the cloud cover. After the end of the rainy season, solar radiation increases again up to 19 MJ/m²/day.

4) Model calibration

a) Crop cycle dynamics and crop management operations

Table 8: Thermal constants adjusted based on farmers' interviews

Adjusted thermal constants (°C days)		Rice	Long cycle Maize	Hybrid Maize	Job's tear
Phenologic stage	1	787	750	600	750
	2	1063	950	800	950
	3	110	602	602	602
	4	218	350	350	220
	5	290	270	270	260

Thermal constants for crop stages were adjusted to fit with the stages' dates (emergence-flowering-harvest) collected from the farmers' interviews (tab.8). Average observed sowing densities were input into the model.

b) Cultivar-dependent parameters adjustment

Crop cycle dynamics adjustment was followed by cultivar-dependent parameters adjustments (tab.9).

Table 9: Adjusted cultivar-dependent parameters

Cultivar-dependent parameters	Rice	Maize long cycle	Hybrid Maize	Job's tear
Dlaimax	0.00043	0.001335	0.00126	0.00099
Vitircarb	0.0065	0.00272	0.00667	0.00312

5) Virtual experiment outputs analysis

The results of the virtual experiment will be presented considering the potential yield Y0, water-limited yield Yw and relative yield Yw/Y0 (calculated as the ration between simulated yield under water-limited conditions and potential yield Y0 simulated from a same location and cropping practices). Results for actual and future climate will be presented at the same time.

a) Analysis of potential yield Y0 depending on species & sowing date

Interannual variability of potential yield (Y0, non water-limited, only determinde by temperature and solar radiation) is represented on the fig.18. The sowing date represented were taken in a broad range around the actual sowing date practiced by the farmers.

Potential yields Y0 of maize and job's tear seem to increase with the sowing date until 180 days. This is due to low solar radiation during the rainy season because of cloudy weather while daily solar radiation increases after the rainy season (October). Potential yield Y0 of rice is decreasing shortly (from 130 JulD) after the sowing dates most applied by farmers probably because of a lower tolerance to cold temperatures. Potential yield of job's tear is decreasing if it is sown after 180 JulD because of decreasing temperatures and solar radiation. Rice is the most constant crop regarding the interannual variability of yield. Long-cycle maize and job's tear have an higher interannual variability for late sowing dates.

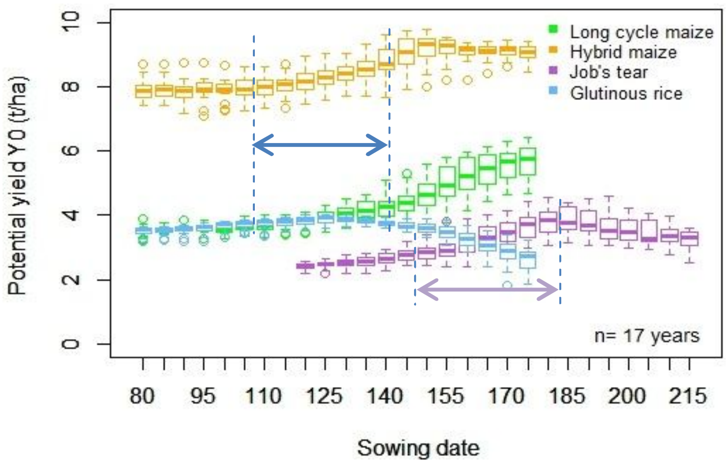


Figure 18 : Potential yield/ sowing date under actual climate

Actual sowing dates window (from farmers' interviews)
- for maize and rice
- for job's tear

Under climate change hypothesis, the optimum sowing date to reach the maximum Y0 is moving later in the season (fig.19). For maize, optimal sowing date is the latest posible in the season, for rice and job's tear it is also moving to later sowing dates. Temperature increase will cause a shortening of cycles, and to take advantage of the solar radiation increasing at the end of the rainy season, crops optimum sowing dates will shift to a later sowing window. We can also observe that the potential yield would decrease under climate change hypothesis for all the species (except for rice for late sowing date).

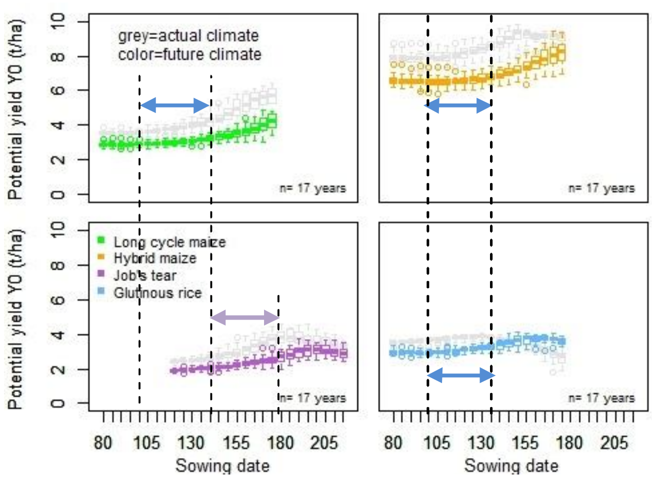


Figure 19 : Comparison of potential yield per sowing date under actual and future climate

Maize would be more impacted than other species. Fig. 20 is showing at the year-scale how the shortening of cycle due to the increase of temperature, is affecting the potential yield, because the shortening of stage prevent the crop to reach its potential growth.

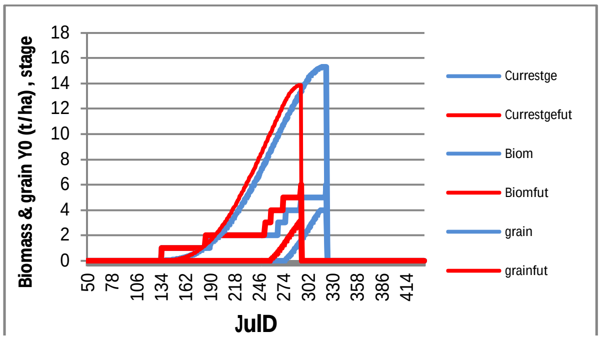


Figure 20: Comparison of upland rice potential growth (crop stage, biomass and grain) under current (blue) and future climate (red)

a) Analysis of water-limited yield Yw depending on species & sowing date

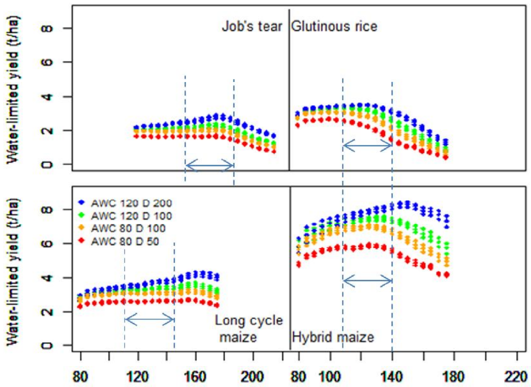


Figure 22: Yw range per cultivar, AWC and sowing date

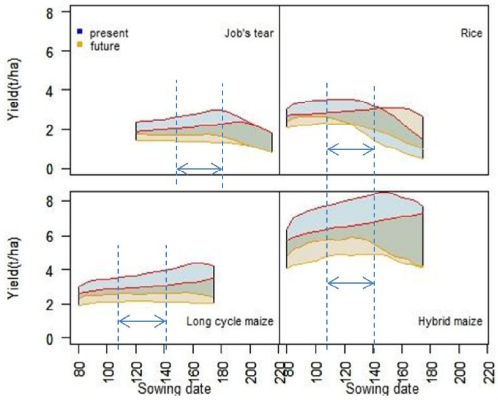


Figure 23: Comparison of Yw range under current and future climate

We will comment the raw data of Yw (water-limited yield, growth limited by temperature, solar radiation and water availability) across sowing dates, AWC and run-off. Fig.21 shows the interannual Yw for the 4 cultivars under actual climate. We can observe that the applied dates are dates which combine a general good yield level but also a minimal yield gap between high and low AWC. This is a good sowing window to minimize the risks because the farmers do not know the soil properties before cultivation. For glutinous rice only, the applied sowing window seems late to minimize the yield losses under the hypothesis of the small AWC. To compare the situation under current and future climate, we reported the shape of the range of simulated Yw under several conditions from fig.21 to fig22, on which we added the shape of the range of simulated Yw under the hypothesis of climate change. From the comparison, we observe the same tendency than for Y0. Yw are decreasing for all the cultivars (except for rice for late sowing dates) but the currently applied sowing window seems to keep the same advantage than under present climate, which is a relative small difference in Yw between high AWC and low AWC, even if the optimum sowing dates seem to shift to later dates for the highest AWC (which is comparable to the shift of optimal dates for Y0 to later dates). The differences between actual and future Yw is more attributable to difference between actual and future Y0. For this reason we decided to study the evolution of Yw through the water-limited yield relative to the potential for the same sowing date (Yw/Y0) (fig.23). Under this case, we can observe that there are minimal differences between current and future climate for the genaral shape representing the range of Yw. The water risks for later sowing dates seems lower under future climate.

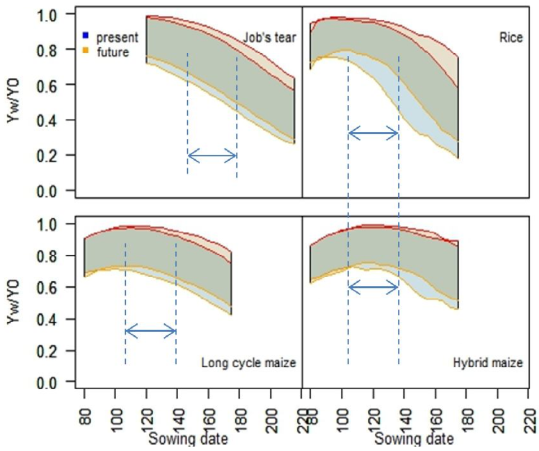


Figure 21: Comparison of Yw/Y0 under actual and future climate

For the following analysis we used the water-limited yield relative to the potential date (Yw/Y0)

b) Analysis of relative Yw (Yw/Y0)

➢ Interannual variability of Yw/Y0 for common soil, runoff and sowing date under current climate

To present an example of simulation results for a common cropping system, we simulated the growth of the 4 crops on an average soil (AWC120 D100, runoff 30%), and for the most common applied sowing date. Relative yield for the 17 years have been represented. The annual rainfall is also represented (fig.25). We can observe that yield sensitivity to interannual rainfall variability is the lowest for long-cycle maize and hybrid maize: for the 17 years considered the lowest relative yield reached respectively and 74 and 77% of potential yield (fig.24). Job's tear and glutinous rice seem to be more sensitive to this water availability, because the lowest relative yield reached respectively 60 and 53 % of the maximum yield.

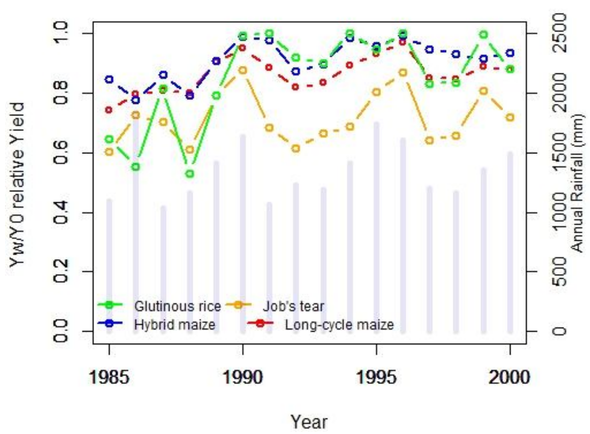


Figure 25: Relative yields and annual rainfall for usual sowing dates and average soil (AWC120 D50 & Runoff 30%)

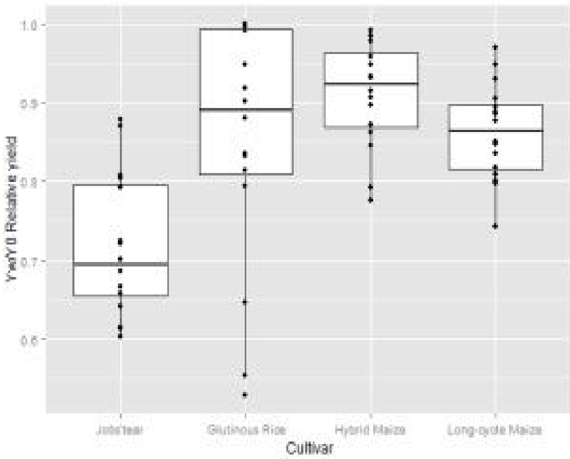


Figure 24: Distribution of relative Yw yield considering species and years

➢ General analysis of Yw/Y0 dynamics

Fig.26 represents the interannual average of all the tested factors for soil type* runofff*sowing date. Under current climate, usual sowing dates match with an optimum were the water-limited yield Yw is the nearest to the potential yield Y0, which means that the optimization between water availability and solar radiation is good, except for job's tear. For good soils and for a broad range of sowing dates (~30j), the Yw is very close to Y0, which means that the water availability is not the main constraint for yield for these cropping systems. Maize seems to be less sensitive to soil type and sowing dates than rice and job's tear. Rice is the most sensitive species to late sowing dates. Generally, we can observe that the actual sowing date applied by farmers are slightly later than optimal sowing dates to maximize Yw/Y0. Runoff has a lower influence than total AWC on the yield. For some sowing date, Yw/Y0 difference for different soil types or runoff levels is more pronounced. Under future clinate, the tendencies are the same but Yw/Y0 is slightly higher than under current climate for all the situations. Uner future climate, the optimal sowing window for which Yw is very close to Y0 and for which runoff and AWC levels have low influence on yield should be slightly broader than under current climate.

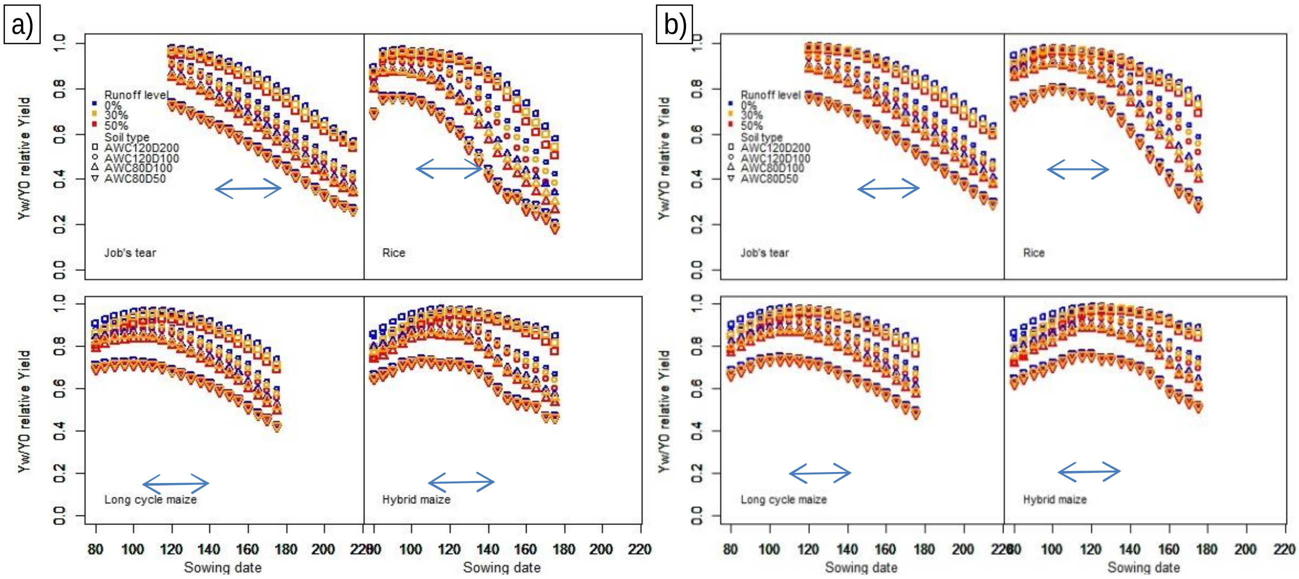


Figure 26 : Interannual relative yield (average) per species, sowing date, soil type & runoff, under current climate (a) and future climate (b)

- **Yw/Y0 sensitivity to soil type and sowing date**

Fig. 27 shows the behavior of the relative yield. Generally, we can report that AWC is highly impacting on the yield because we can observe that even in the best conditions for sowing dates, the lowest AWC lead to an average yield 20% lower than with the best AWC.

Interannual variability of yield depending on soil type is not high for usual sowing date (125 for rice & maize, 165 for job's tear). But under current climate, earlier or later sowing date increase the interannual variability of the yield, especially for soil with low AWC. For example, late sowing date for rice impact dramatically the yield, with a high interannual variability (= high risk for farmers). For usual sowing dates, rice and job's tear are more sensitive to soil type. Rice is also highly sensitive to interannual variability especially for soil with low AWC. For usual sowing dates maize yield on soils with low AWC is around 20% lower than for soil with highest AWC.

Under future climate (fig. 27 b), sensitivity to AWC seems to be lower for all the species, but especially for usual sowing dates for rice. Risk for late sowing for rice is decreasing under future climate for medium to good soils. Interannual variability seems to decrease for all the situations, and it is almost inexistent when crops are grown on soil with high AWC and for optimum sowing dates.

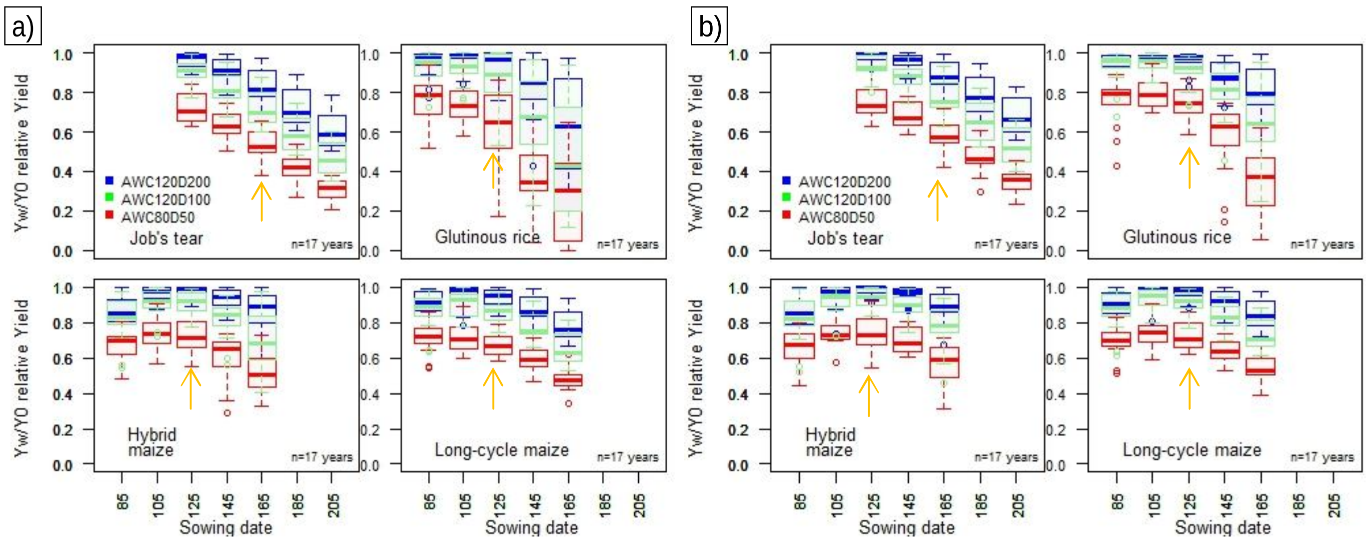


Figure 27: Yw/Y0 interannual variability per species, sowing date & soil type (runoff fixed at 30%) under actual (a) and future (b) climate.

↑: among usually applied sowing date

➢ Yw/Y0 sensitivity to runoff

We fixed the soil type as an average soil (1 meter-deep, AWC 120 mm/m) to simulate a common soil. The 4 crops have different behavior regarding runoff. As well as for soil type, rice is the most sensitive crop to runoff (fig.28). Under current climate, this sensitivity increases with late sowing. For long-cycle maize and job's tear, difference between no runoff and high runoff is constant. However for hybrid maize, the difference in runoff levels is higher for early and late sowing and the interannual variability is also higher for those modes.

↑: among usually applied sowing date

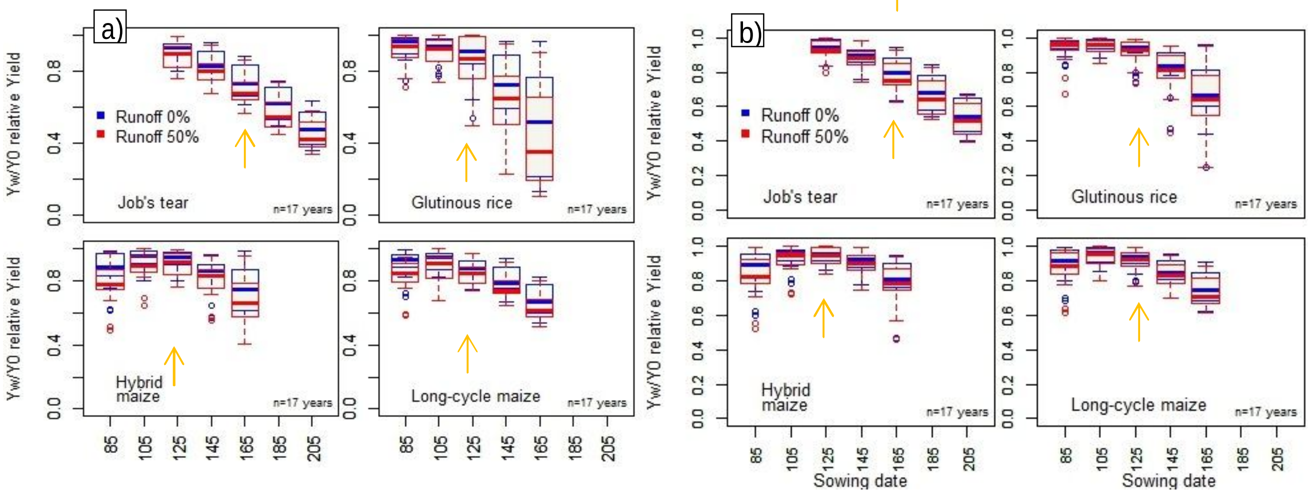


Figure 28: Interannual Yw/Y0 variability per species, sowing date & runoff level (Soil fixed AWC120D100) under actual (a) and future (b)

Under future climate, sensitivity to runoff is almost inexistent because Yw/Y0 values are very similar (average and interannual varaiblity) for the two extreme modes for runoff (fig.28.b).

For current climate, we tested the sensitivity to runoff for extreme types of soil. For soil with high AWC, differences in relative yield between runoff levels are lower for applied sowing dates for maize, and internanual variability is lower when there is no runoff, especially for maize (fig.29). Late sowing for rice always leads to a high sensitivity to run-off. Although this is not the case for soil with low AWC (AWC80 D50), for which the two runoff levels lead to similar rice yields. For all crops, average yields and their interannual variability are very similar with any runoff level. Runoff level is not affecting much the yields in areas with low AWC, but runoff action is more critical in areas where the AWC is common or high. Under future climate, sensitivity to runoff is lower for all the simulation but the crop behavior regarding runoff is not very different.

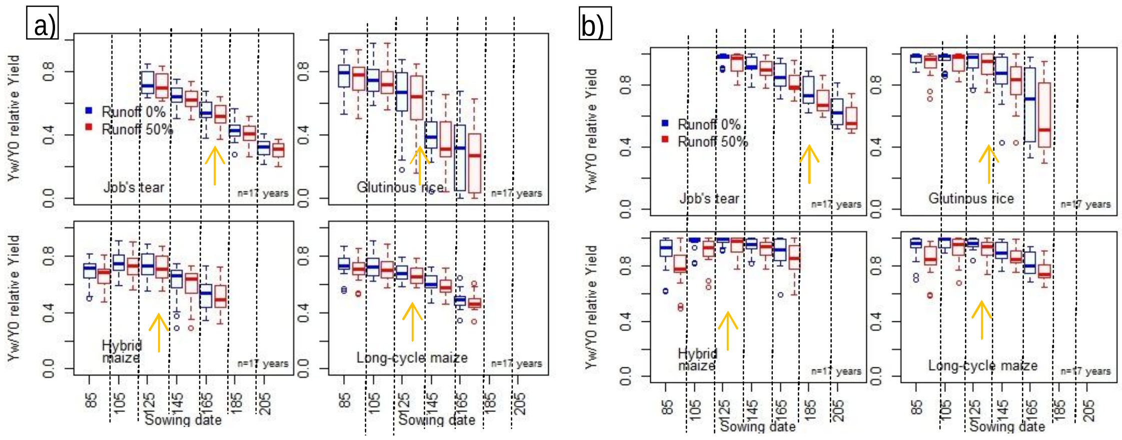


Figure 29 : Interannual Yw/Y0 variability per species, sowing date & runoff level for low (a) and high (b) AWC under current climate

↑: among usually applied sowing date

c) Daily-step description of specific cropping systems

Fig.30 details the sowing date and AWC influence regarding the daily-step functionnning of the model. We selected rice and weather data of year 1991. Three sowing dates were tested: 80, 125 and 165 for an average soil (AWC 120 D100). This example shows the growth dynamics of each crop depending on its sowing date. In case of early and normal sowing, the crop took advantage of the water that filled the soil compartment at the beginnig of the season For early sowing, the AWC is filling with the first rainfall of the season at the same time that crop water demand is high for growth. The AWC is filling slower than when the crop is sown for usual date. For usual sowing dates, available water is increasing with the root growth because earlier rainfall already filled the soil, hence the stock available in the root zone depends only on root growth. The crop is grown under the best conditions and reaches the best biomass value and the potential yield. This simulated year, the rainy season ends at the end of September (260 JulD). After, precipitations are very scarce and not sufficient to fill the AWC. The stock available for roots is decreasing and lead to a water-stress. Water stress will not affect the grain filling of the crop with usual sowing dates because the latter stage is not very sensitive to drought. However, this drought occurs just before the beginning of grain filling for the late-sown crop. Drought during the flowering period will limitate the grain number, and thereby the final yield.

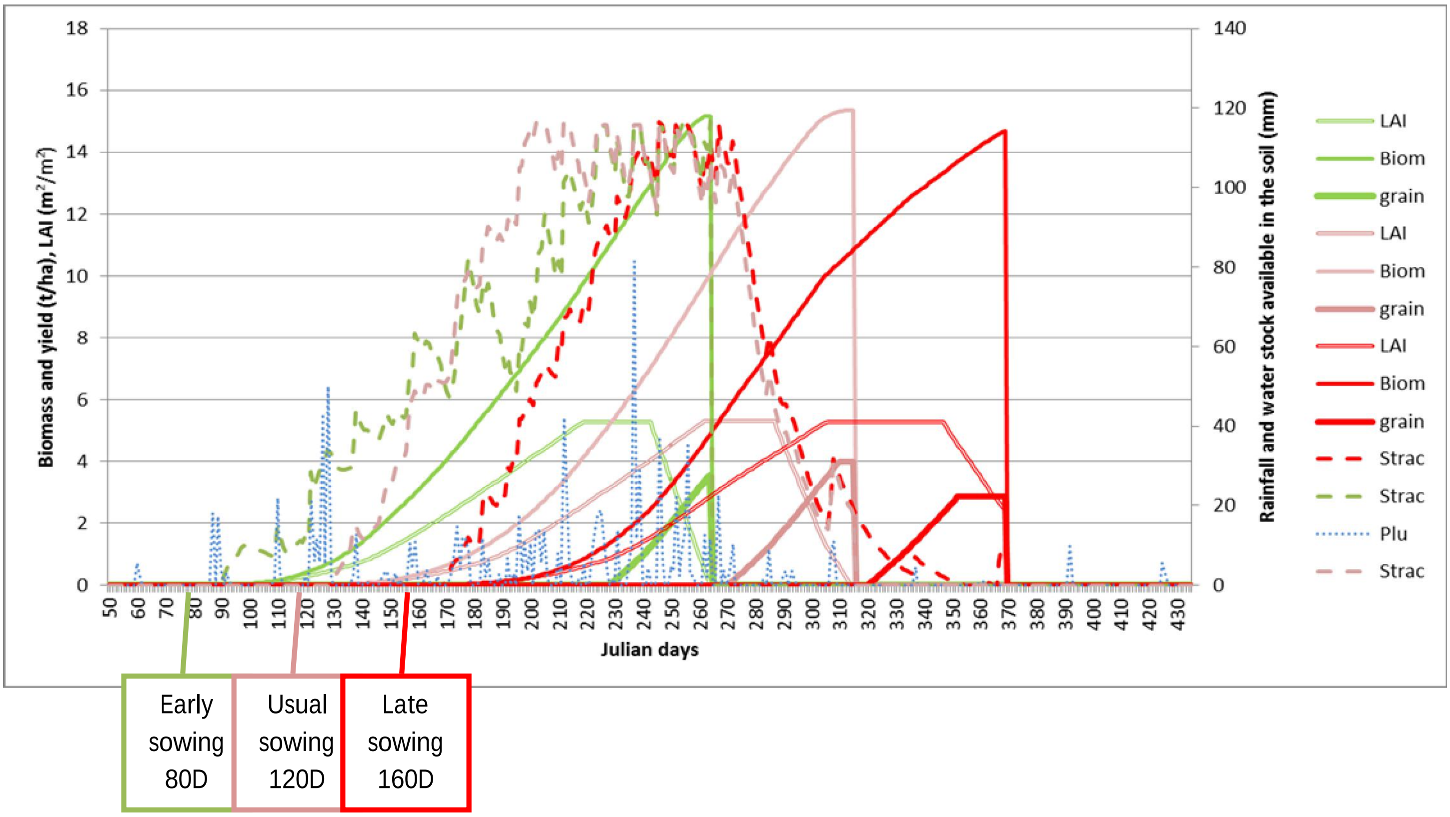


Figure 30: Growth and water-use of rice with early, usual and late sowing date, in year 1991

d) Analysis of drainage sensitivity to soil and runoff characteritics

The total drainage over a cropping season is an other output of the model and characterize an environmental performance of the cropping system. Drainage is following the same trend regardless of the crop cultivated (fig.31.a). It is increasing with late sowing dates because drainge is more important before the crop settlement. No runoff results in high level of drainage, especially for shallow soils with low AWC. However, even in a deep soil with a high AWC, a system with no runoff (0%) creates 3 times more drainage than a system with 50% runoff. Contrary to yield, drainage is more sensitive to runoff than to AWC. Under future climate, drainage is increasing especially for cropping systems with low runoff rate (fig31.b). Under future climate, drainage will be higher, increasing the same way than precipitation. For example, drainage will increase by 150-175mm/cropping season under rice cropping system with common AWC and depth. Fig.32 presents the superimposed range of drainage for no runoff and high runoff under current and future climate, which shows precisely that drainage is increasing more when the runoff is low under future climate.

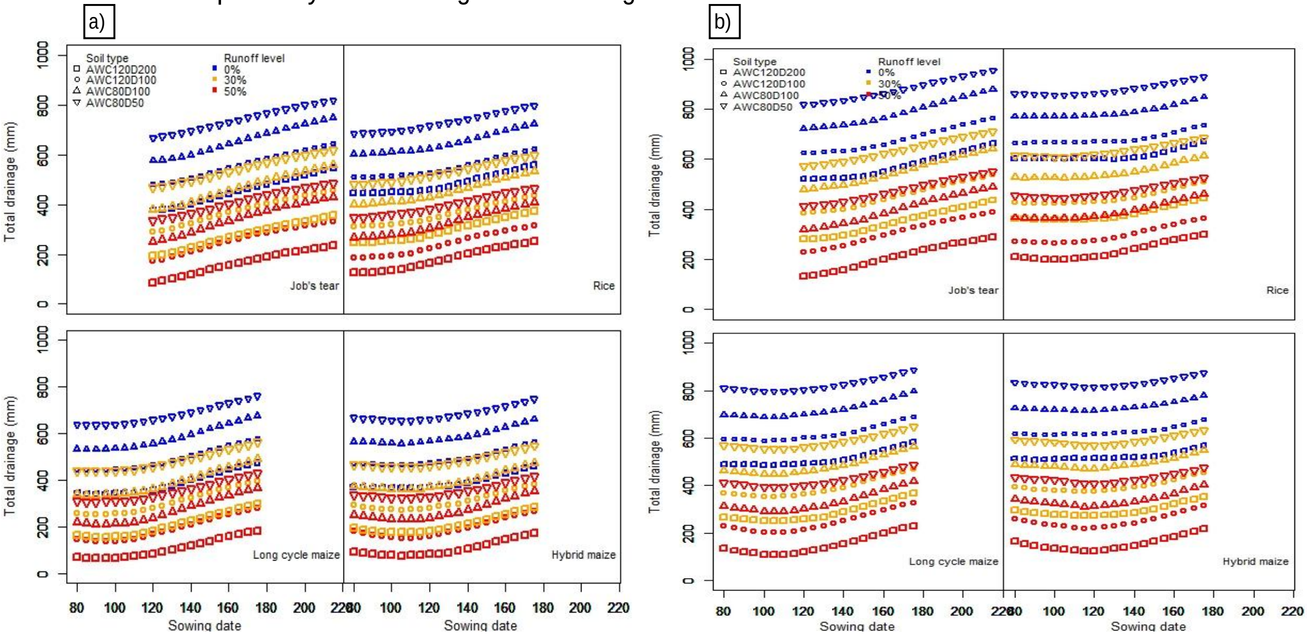


Figure 31 : Internannual drainage average per soil and cropping system characteristics (AWC, runoff level, sowing date) under current (a) and future (b) climate

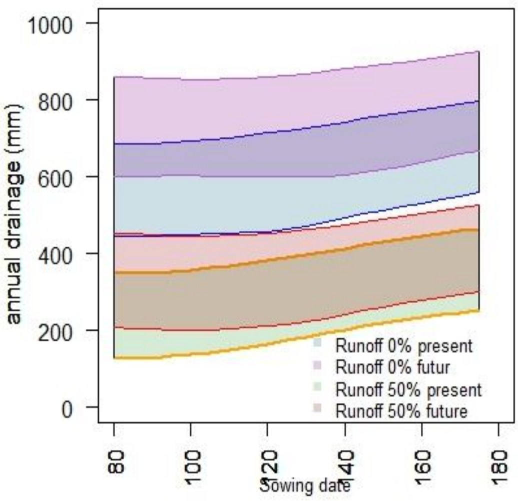


Figure 32: Annual drainage range under glutinous rice copping system for 0% and 50% runoff under current anf future climate

IV. Discussion

1) Potential yield Y0 is expected to decrease under future climate

Optimum sowing window for potential yield Y0 (growth limited by temperature and solar radiation only) is not corresponding to the optimum sowing window for Yw (water-limited yield, growth limited by temperature, solar radiation and water availability). The optimum Y0 is occurring for late sowing dates because the solar radiation limiting for Y0 is very low during the rainy season and increases again at the end of the rainy season. For this reason optimal sowing dates are postponed to the end of the rainy season so that the crop can take advantage of the high solar radiation. However, considering that our solar radiation data have been recalculated and that we did not take into account its interannual variability, it would be judicious to do a sensitivity analysis of the model considering this variable to assess the importance of accurate solar radiation data for yield assessment and set the appropriate measurement equipment if needed. Generally, importance of weather data quality (for example if we consider daily data instead of monthly) could be determined through a sensitivity analysis of the model.

Nevertheless, since we work exclusively with rainfed crop, the optimum sowing date for Y0 is less informative than the optimum sowing date for Yw. But it is interesting to explore the change of Y0 behavior under the climate change condition.Y0 is expected to decrease for almost all the crops and all the sowing dates (except for rice for late sowing dates), because of the cycle shortening caused by the temperature increase. The stages are reached quicker and the daily increase of LAI/ biomass and grain is insufficient to reach the current potential in a shorter time.

2) A specific sowing window for reduced water stress

Our virtual experiment showed that water stress has low influence on water-limited yield (Yw) under current climate. The most influencing parameter on Yw is the sowing date, but its effect variable among the crops tested. A specific sowing window for each crop seems to result in approximately constant water-limited yield, close to the potential yield. Within this sowing window, other cropping system parameters have less influence on Yw. But out of this sowing window, the interannual variability of Yw increases with a different intensity depending on the crop.

For rice and job's tear, the sowing dates applied by farmers are slightly later than the optimum window described by the virtual experiment. Should these crops be sown earlier by the farmers? We can question on the reasons which lead the farmers to sow these crops after the optimum sowing dates.

A first hypothesis is the field work planning. The onset of the rainy season marks the beginning of sowing period, and usually the farmers sow maize first, and then they sow rice, the most important crop since it is the basis of their alimentation. They would sow job's tear only after taking care of the growth of rice (with appropriate weeding). And since the sowing work is delayed, harvesting will be also delayed, and will not provide additional work to the farmer during rice and maize harvest period. Another advantage to sow a crop later than the other is that farmers can resow rice or maize plots with job's tear if the crop died (it was the case in some fields this year due to the strong drought).

A second hypothesis is that the farmers do not want to sow too early for phytosanitary reasons. Risk of grain rot because of high humidity could happen if the grain is maturing before the end of the rainy season. Other risks not included in the simulation could also influence the farmers on their sowing dates (occurrence of diseases, pest problems).

3) Available water capacity in the study area has low influence on Yw

a) Simulated Available water capacity influence on Yw

The second most influencing factor is the Available Water Capacity (AWC), which is also responsible for variations of Yw, especially on shallow soil with low AWC. On those soils, relative Yw are at least 20% lower than relative Yw simulated on deep soil with high AWC. In the future, this proportion should not change critically but interannual Yw/Y0 variability will decrease, especially on the most impacted soils (shallow soils with low AWC). Under future climate, rainfall will be higher and interannual variability of Yw/Y0 should decrease.

b) Simulation of cropping system intensification level

Cropping systems simulated in our study have a low intensification level and they are far from their potential growth. To represent better the Yw of the cropping systems observed in the study area, we could do another virtual experiment with lower value for biological efficiency (Ebmax), harvest index (vitircarb), taking into account best observed values for biomass and yield in the study area.

However, our study already showed that cropping systems do not suffer strong water stress even when simulated at their potential growth. Being less intensive and less productive, cropping systems in our study area are less water-demanding than the potential ones. However, we could test if shallow soils with very low AWC would impact Yw in the case of less intensive cropping system.

c) AWC determination

Since the AWC has an effect on Yw, it was necessary to have an idea of the soils AWC in the study area. Water availability in the soil could have been slightly overestimated, because the humidity content at field capacity was determined at pF2 and not pF2.5 (undisturbed soils). However, to prevent any wrong interpretation, we simulated Yw variation for a soil with lower AWC than the measured one (80mm).

A deeper sampling would validate one of our 2 assumptions for extrapolated AWC to 1 meter deep. But we can note that the extrapolation method did not have a great impact on AWC value, and differences between these 2 values would not have a high impact on Yw. The combined effect of soil depth and AWC is more important than AWC value itself (for the same depth, difference between AWC into the tested range has a low effect on Yw). The broad range of tested soil depth/ AWC allows us to draw robust conclusions taking into account uncertainties on AWC and depth.

4) Runoff has low impact on Yw but its increase would cause higher erosion

Runoff does not appear as a critical factor for yield, because even a high runoff coefficient does not impact yield highly, high runoff rate only causes yield losses when the sowing dates are very unusual for the crop. Runoff impacts Yw the most when sowing is practiced late on soils with very high water storage capacity. For most of the tested years water resource is exceeding the crop's requirements plus the water storage capacity of the soil during the first part of the growing season. Under future climate, runoff effect on Yw will even be lower in case of common soil because waterresource will be higher.

Under the current climate and given the moutainous relief of the region, runoff is likely to be high in actual cropping systems, and this implies erosion risks under annual crops on sloping land, but our results indicate that reducing runoff through land or crop management is likely to result in increased drainage, with risks of nutrient leaching. Under future climate, runoff and erosion would even increase because of predicted rainfall increase. Since the market-opening is operating, chemical fertilizers are more accessible for the farmers. However leaching by drainage could impede the fertilizers efficiency.

In some parts of northern Laos, shifting cultivation is developing towards more permanent annual cropping systems. In association with short fallow periods which is leading to a use of manual tillage to control weeds. High erosion rates and soil degradation is associated with these practices (Dupin et al, 2009).

Considering this evolution, it would be judicious to keep shifting cultivation with long fallow period on the sloping areas, or permanent perennial crops. To do so, agriculture could be intensified were the erosion risks are lower, with paddy field installation of in the bottom of the valleys for example.

5) Necessary steps to model validation is this case study

- **Model parameterization and Yw precise assessment**

The model has not been calibrated for the yield components P1grmax, Nbgrainmax, Cgrain and Cgrain V0. These parameters were determined for others cultivars , from Vietnam (Luu Ngoc, 2012).

Hence our Yw calucation may not be representative of the cultivars present in Laos. However the main idea for our study was to reach an indicator for water stress and the parameters regulating it are species-dependant, thus our study on sensitivity to climate is robust.

We should have an acces to yield components to parameterize it precisely. After this parameterization only, we could lead a validation of the model with measurments under non-limiting growth conditions.

To assess the importance of Cgrain/ CgrainV0 parameterization depending on the cultivar, we can calculate the rate of situations in which Yw is limited by the grain number determined during the flowering period (i.e when there is a water-stress during the floweing period). In this case, Yw is calculated based on the values of Cgrain/ Cgrain V0. If the rate is high, then we should pay attention to their parameterization. It would also be interresting to analyse how this rate changes within the optimal sowing window and when this window is digressed.

- **Model parameterization for job’s tear**

Job’s tear Y0 and Yw variations have been represented like the other crops but we should remind that model parameterization for job’s tear was based on maize for all the crop parameters. Only cultivar–dependent parameters were adjusted to fit with the crop cycle dynamics collected from interviews. However, the plant development may be different from maize and may be for example more suitable for its applied sowing dates.

- **Condition to validate the model with field measurements**

We did not validate the model with observations because no access to weather data for this year was possible. Independent calibration and validation was not possible. Measurements in water-limited or potential conditions are necessary to validate the model in some conditions.
This year cropping systems experienced a critical drought. It would have been very informative to have access to weather data for the current year to simulate the crop growth and see if PYE represented well the strong water stress that crops are suffering. Among the simulated years, no droughts period appeared just at the onset of the rainy season, when the AWC has not been filled, which seemed to be the case this year.

Cropping systems experienced a strong drought this year, especially rice. A drought assessment was led by the project staff. They estimated 30% (percentage of dead crops) of crop losses due to drought in end of July (Sisavath, personal communication). Interviewed farmer estimate that they will lose 80% of their harvest for rice compared to last year. However, root aphids were also observed. A simulation representing this year would help to determine the relative role of drought and the relative role of pests, weeds…, among the yield losses.
To assess farmers’ yields losses, proper yield measurements should be led, our study relied only on declared yields, not measured. Yields should be weighed because usually production is measured in bags, but the conversion to weight is not always reliable. Apart from that, some cultivar are never husked to grain nor weighted (short cycle maize, then it is very hard to get yield data on it). Yields should be recorded regarding of the cultivar and not only regarding the species. For example, there could be a high difference between hybrid maize yields and long cycle maize yields. Plot areas should be measured because there is a strong bias when we rely on farmers words. Declared area and measured area were compared in another study of the project in seven fields. Area was always underestimated, with an average underestimation of 28% of the plot area (under-estimation from 7 to 59% of area) (Bonin, personal communication).

d) Climate change prediction uncertainties

To assess the climate change, we considered the scenario of moderate emissions A1-b among the 40 scenarios described by IPCC. In the decade since the emissions scenarios were defined, monitoring data has shown that global emissions have been equal to or exceeding the highest emissions scenarios (ICEM, 2013). However considering the projected time-scale centered on 2050, the variability in IPCC scenarios is approximately 0.5°C for the Mekong region (Eastham et al. 2009), while variations between GCM (Global Circulation Model) outputs vary by more than 6°C. Predictions for climate change are established according to different GCM. In studied area, maximum temperature variability is 1.5 to 2°C in the wet season and 2.5 to 3°C in the dry season, and rainfall variability among GCM reaches 200-300mm for the wet season and 100-200 mm during the dry season. This predicted variability is very high compared to the change predictions we applied to the climate.

Interannual rainfall variability increase has not been studied yet. The trend of light wetting tendency has been assessed in average but the increasing variability has not been taken into account. This risk should be assessed for a better representativeness of the future climate.

We make an assumption for future rainfall distribution but this assumption is questioned. Rainfall intensification (in mm) should also be questioned (increasing rainfall amount would not have the same effect on cropping systems if rainfall intensity in mm/h is increasing or if rainfall events are lengthening in time.

We only based our study on ICEM projections (2013). Other studies could be taken into account, for example through the overview led by Meynell and Rudgard on climate change predictions for Laos (2015, unpublished).

Moreover the C02 concentration in the atmosphere should be adjusted considering the predictions for climate change and its effects on biomass growth should be analyzed.

6) Perspectives

a) Adaptive strategies to impede Y0 and Yw decrease and limit drainage under climate change hypothesis

To compensate yield losses due to Y0 decrease, we can use genetic means to increase the thermal constants of the stages to keep the crops at their current potential. Moreover the photosensitivity of local rice cultivars could be an interesting trait because the cycles are not determined by thermal constants (which make the cycle sensitive to temperature), but they are determined by photoperiod which will not move under climate change. The photosensitive rice has not been parameterized in our study but it would be very interesting to see how the photosensitive cultivars' cycles and yields evolve under climate change hypothesis.

The high drainage suggest that's it is necessary to transpire more water during the growing season. If the water is not transpired, it is drained. Considering the climate change hypothesis (cycles shortening), it would be interesting to investigate the possibility to grow two sequenced short-cycle crops instead of one long-cycle crop, to take advantage of the high temperatures and the high rainfall under climate change. Another way to transpire more water would be to enhance intercropping.

To do so, we should focus on a refined analysis of possible sowing and harvest windows and how they could be adapted to consider future cropping systems. We asked the common sowing window but the data are not precise on the most applied dates for sowing. This broad sowing window (~25 days) should be partitioned to define the most common sowing date(s). Moreover, investigations on sowing dates should be led carefully because the ethnic groups in Laos have different calendar (lunar), and it is sometimes hard for interviewers to convert into international calendar dates.

However, we have to remind that rice is the staple food for the farmers and they will only diversify or switch to other crops when auto-sufficiency in rice has been reached. Since market is the main driver for agricultural change, they would change their cropping calendar (for example to cultivate two short-cycle crops instead of one long-cycle) only if market opportunities are present for these short-cycle crops.

b) Possible main constraints for annual cropping systems in northern upland of Laos

A study led by Roder et al. (1997) in Vienkham district (in our study area), identified weeds, rodents, insufficient rainfall, insects and soil fertility as main constraints to upland rice production, based on farmers interviews. Our study shows that water stress is not an important constraint for yields in our cropping systems. A next step would be to identify the main constraints for upland cropping systems and to assess their impact on yields. Our model did not take into account pest, nor weeds or fertility effects on crop growth.

Some of these constraints are linked to fallow period and their evolution will mainly depend on fallow period evolution. Even if the fallows are still quite long in our study area (~ 7 years); there is following a general decreasing tendency due to increasing land pressure. If the land pressure increases highly, fields may be cultivated several consecutive years. In this case, the decrease in fertility could have critical impacts on yields. Saito et al (2007) showed that after five years of continuous upland rice cropping, or intersected with very short fallow period (i.e one year), fifth-year yields ranged from 0.3 to 1.0 t/ha, while first-year field ranged from 2.3 to 3.3 t/ha. Continuous cropping seems also to enhance pests' occurrence (root aphids) (Saito et al, 2007).

Fallow-length decrease is also linked to an increasing weed pressure. In the 1950's, fallow periods of 38 years were common, and 2 weedings only were required. Nowadays, fallow periods dropped to 5 years, and up to 4 weedings are required (Roder et al, 1997), which represent a lot of work, which may not be suitable for all the managed fields.

Moreover climate change will not only affect the agricultural system but the entire ecosystem. Weed, pest and diseases presence is neglected in our model PYE, but their influence on yields may be significant. Even if our study suggested a low impact of climate change on Yw, actual yields could be highly impacted by better conditions for pest and diseases development. For example, increase in temperature and water availability will enhance the weeds' growth. Pests presence (rats, insects) could be enhanced by extreme climatic events and rainfall increase coupled with higher cloud covering will enhance the fungal diseases.

We have also to consider the changes that are acting in Laos and that could have greater impact on agricultural systems than climate change. For example, impact of climate change on crop yield was estimated around 3% to 12% for rice crops by 2050, while in the last 15 years in Vietnam total agriculture production has increased by 80% (ICEM, 2013). Then the climate change impacts are overshadowed by the other more immediate and dramatic local changes. In our case, land pressure would probably have a greater impact than climate change. Market integration is also a change influencing on the cropping systems. The farmers are getting a better access to inputs and the use of fertilizers could be a solution to cope with the loss of natural fertility of shifting cultivation systems (in the case drainage is well-managed so that fertilizers are used by crops.

Conclusion

Our study led us to identify the characteristics of upland cropping systems. We focused our interest on four main annual crops and we described the cropping systems associated through farmers' interviews, and their intensification level through observations and measurements in the field (cultivation practices, sowing densities, LAI and biomass growth). Through a virtual experiment, the growth of these crops under potential and water-limited condition have been simulated for 17 years in 12 distinct environments considering runoff level and soil characteristics.

From this virtual experiment we identified a specific optimal sowing window for water-limited yield Yw for each crop, characterized by an optimal use of solar radiation, temperature and water resource. This sowing window minimizes the risks of yield losses due to water stress in all the cropping systems studied. Even if this sowing window is supposed to be delayed in the future, climate change should not have critical impacts on Yw, and would even increase Yw on soil with low water retention. Water availability for crops does not seem to be the major determinant of yield losses for these cropping systems. The indirect impact of climate change on pest (including weed) pressure and soil erosion increase might have a higher impact on crop yield losses than expected changes in rainfall and temperature patterns.

In the future, water availability is predicted to be higher, leading to a lower risk for water shortage. Runoff effect on Yw is low except for delayed sowing date on soils with high AWC. However, runoff is supposed to increase in the future due to wetting tendency and could lead to critical erosion level. But a reduction of runoff leads to an increase of drainage which implies nutrient leaching. Hence adaptive strategy would be to enhance the cover transpiration during the rainy season through intercropping or successive cropping of two short-cycle crop. Adaptive strategy will also have to include diversified and integrated pest and soil fertility strategies.

Bibliograhy

Affholder, F. (1997). Empirically modelling the interaction between intensification and climatic risk in semiarid regions. *Field Crops Research*, *52*(1-2), 79–93. http://doi.org/10.1016/S0378-4290(96)03453-3

Affholder, F., Poeydebat, C., Corbeels, M., Scopel, E., & Tittonell, P. (2013). The yield gap of major food crops in family agriculture in the tropics: Assessment and analysis through field surveys and modelling. *Field Crops Research*, *143*, 106–118. http://doi.org/10.1016/j.fcr.2012.10.021

Allen, R., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop requirements. *Irrigation and Drainage Paper No. 56, FAO*, (56), 300. http://doi.org/10.1016/j.eja.2010.12.001

Asai, H., Saito, K., Samson, B., Songyikhangsuthor, K., Homma, K., Shiraiwa, T., … Horie, T. (2009). Yield response of indica and tropical japonica genotypes to soil fertility conditions under rainfed uplands in northern Laos. *Field Crops Research*, *112*(2-3), 141–148. http://doi.org/10.1016/j.fcr.2009.02.010

Boonjung, H., & Fukai, S. (1996). Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions. 1. Growth during drought. *Field Crops Research*, *48*(1), 37–45. Retrieved from <Go to ISI>://A1996VN72000005

Bouman, B. a M., Peng, S., Castañeda, a. R., & Visperas, R. M. (2005). Yield and water use of irrigated tropical aerobic rice systems. *Agricultural Water Management*, *74*(2), 87–105. http://doi.org/10.1016/j.agwat.2004.11.007

Brisson, N., Gary, C., Justes, E., Roche, R., Mary, B., Ripoche, D., … Sinoquet, H. (2003). An overview of the crop model STICS. *European Journal of Agronomy*, *18*(3-4), 309–332. http://doi.org/10.1016/S1161-0301(02)00110-7

Brisson, N., Mary, B., Ripoche, D., Jeuffroy, M. H., Ruget, F., Nicoullaud, B., … Delécolle, R. (1998). STICS: a generic model for the simulation of crops and their water and nitrogen balances. I. Theory and parameterization applied to wheat and corn. *Agronomie*, *18*(5-6), 311–346. http://doi.org/10.1051/agro:19980501

Devendra, C., & Thomas, D. (2002). Smallholder farming systems in Asia. *Agricultural Systems*, *71*(1-2), 17–25. http://doi.org/10.1016/S0308-521X(01)00033-6

Dingkuhn, M., Johnson, D. E., Sow, a., & Audebert, a. Y. (1999). Relationships between upland rice canopy characteristics and weed competitiveness. *Field Crops Research*, *61*(1), 79–95. http://doi.org/10.1016/S0378-4290(98)00152-X

Dupin, B., de Rouw, a., Phantahvong, K. B., & Valentin, C. (2009). Assessment of tillage erosion rates on steep slopes in northern Laos. *Soil and Tillage Research*, *103*(1), 119–126. http://doi.org/10.1016/j.still.2008.10.005

Eastham, J., Mpelasoka, F., Ticehurst, C., Dyce, P., Ali, R., & Kirby, M. (2008). Mekong River Basin Water Resources Assessment : Impacts of Climate Change. *CSIRO: Water for a Healthy Country National Research Flagship*, (August), 153. Retrieved from http://wacc.edu.vn/vi/wp-content/uploads/2013/06/wfhc-MekongWaterResourcesAssessment.pdf

Golam, F., Farhana, N., Zain, M. F., Majid, N. A., Rahman, M. M., Rahman, M. M., & Mihdzar, A. K. (2011). Grain yield and associated traits of maize (Zea mays L.) genotypes in Malaysian tropical environment. *African Journal of Agricultural Reseearch*, *6*(28). http://doi.org/10.5897/AJAR11.1331

Hay, R., & Gilbert, R. (2001). Variation in the harvest index of tropical maize: evaluation of recent evidence from Mexico and Malawi. *Annals of Applied Biology*, *138*(1), 103–109. http://doi.org/10.1111/j.1744-7348.2001.tb00090.x

Johnston, R. ., Hoanh, C. T. ., Lacombe, G. ., Lefroy, R. ., Pavelic, P. ., & Fry, C. (2012). *Managing water in rainfed agriculture in the Greater Mekong Subregione*. http://doi.org/10.5337/2012.201

Lindquist, J. L., Arkebauer, T. J., Walters, D. T., Cassman, K. G., & Dobermann, A. (2005). Maize Radiation Use Efficiency under Optimal Growth Conditions Maize Radiation Use Efficiency under Optimal Growth Conditions. *Agron. J.*, *97*, 72–78.

Linquist, B., Saito, K., Keobualapha, B., Phengchan, S., Songyikhangsutho, K., Phanthaboon, K., … Horie, T. (n.d.). Improving Rice Based Upland Cropping Systems for the Lao PDR. *Shifting Cultivation and Poverty Eradication in the Upland of the Lao PDR*, 299–313.

Luu Ngoc, Q. (2012). Introduction d' une culture de printemps dans les systèmes de culture des « terres irrigables » des montagnes du Nord du Vietnam . Approche par modèle agroclimatique. *Ph.D. Thesis. Agronomie*.

Luu Ngoc, Q. , Montagne, J., Jourdain, D., Ripoche, A., & Capillon, A. (2015). Sowing Windows for a Spring Crop Introduced in Rice Cultivation Areas Affected By Low Temperature and Radiation. http://doi.org/10.1017/S0014479714000465

Messerli, P., Heinimann, A., & Epprecht, M. (2009). Finding Homogeneity in heterogenetity- A New Approach in Heterogeneity Finding Homogeneity to Quantifying Landscape Mosaics Developed for the Lao PDR. *Human Ecology*, *37*(3), 291–304. http://doi.org/10.1007/sl0745-009-9238-l

Meynell, P.-J., & Rudgard, S. (2015). Climate change projections used in Lao PDR. In *NAFRI - IRAS Conference Climate Resilience in the Agriculture Sector*.

Olmos, S. (2001). Vulnerability and Adaptation to Climate Change : Concpts, Issues, Assessment Methods, (July), 21pp.

Phongoudome, C., & Sirivong, K. (2008). Forest Restoration and Rehabilitation in Lao PDR. *Keep Asia Green Volume I "Southeast Asia"*, 57–84.

Roder, W., Phengchanh, S., & Keoboulapha, B. (1995). Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos. *Plant and Soil*, *176*(1), 27–36. http://doi.org/10.1007/BF00017672

Roder, W., Phengchanh, S., & Keobulpha, B. (1997). Weeds in slash-and-bum rice fields in northern Laos, 111–119. http://doi.org/10.1046/j.1365-3180.1996.d01-6.x

Saito, K., Atlin, G. N., Linquist, B., Phanthaboon, K., Shiraiwa, T., & Horie, T. (2007). Performance of traditional and improved upland rice cultivars under nonfertilized and fertilized conditions in northern Laos. *Crop Science*, *47*(6), 2473–2481. http://doi.org/10.2135/cropsci2006.12.0779

Saito, K., Linquist, B., Keobualapha, B., Phanthaboon, K., Shiraiwa, T., & Horie, T. (2006). Cropping intensity and rainfall effects on upland rice yields in northern Laos. *Plant and Soil*, *284*(1-2), 175–185. http://doi.org/10.1007/s11104-006-0049-5

Schiller, J. M., Chanphengxay, M. ., Linquist, B., & Appa Rao, S. (2006). *Rice in Laos*. Los Baños (Philippines): International Rice Research Institute. Retrieved from http://books.google.com/books?id=k3bLVNvzWcQC

Solomon, S., Qin, D., Manning, M., Chen, Z., Parry, M. L., Canziani, O. F., … Martino, D. (2007). IPCC, 2007: Summary for Policymakers. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, (April 2007), 7–22. http://doi.org/10.2134/jeq2008.0015br

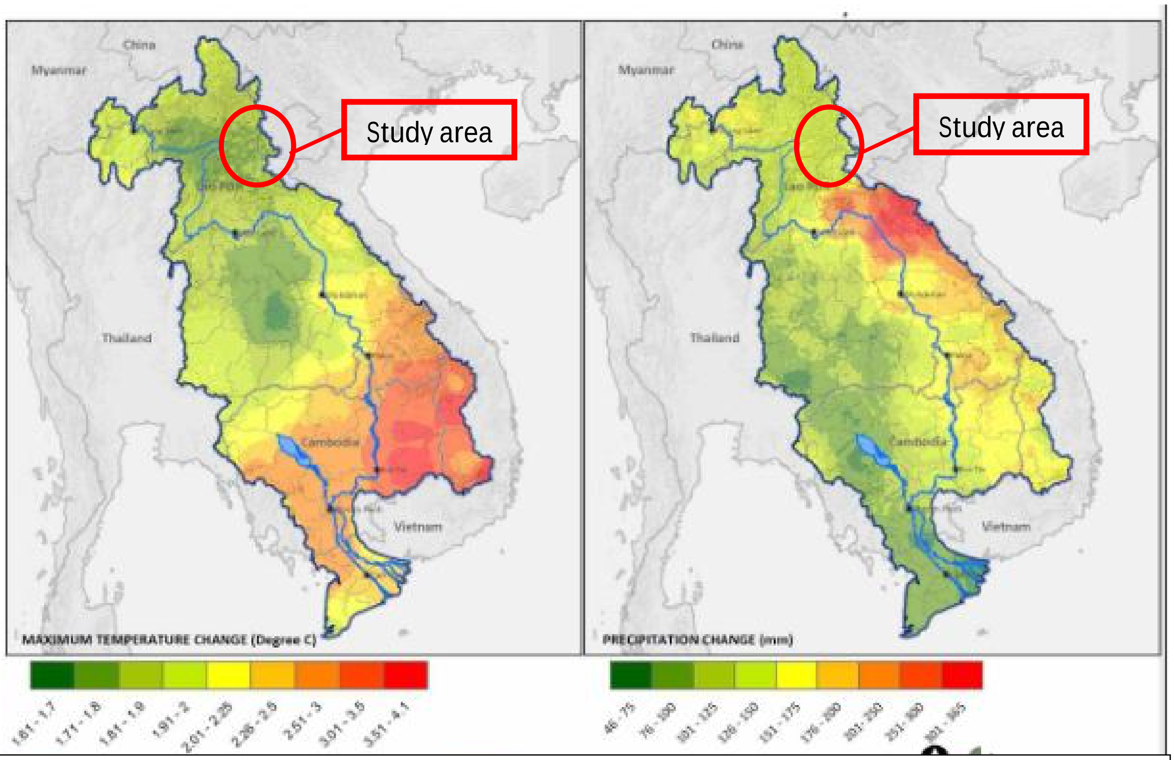
Van Ittersum, M. K., & Rabbinge, R. (1997). Concepts in production ecology for analysis and quantification of agricultural input-output combinations. *Field Crops Research*, *52*(3), 197–208. http://doi.org/10.1016/S0378-4290(97)00037-3

APPENDIX

APPENDIX LIST

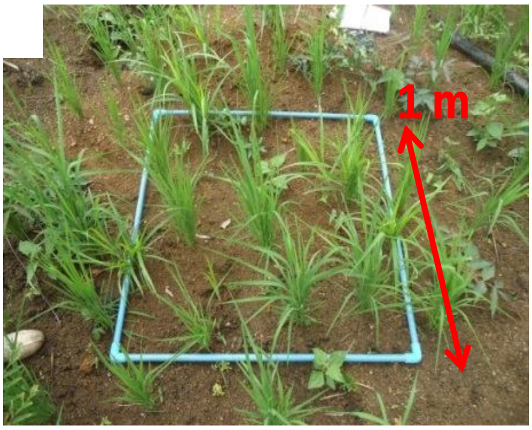
-APPENDIX 1: Previsions for climate change in the study area: map of the changes spatial variability for temperature and precipitations.
-APPENDIX 2: Plot sampling strategy
-APPENDIX 3: Specific protocol adjustment for LAI and biomass sampling considering crop type
-APPENDIX 4: cropping systems examples
-APPENDIX 5: Species and cultivar studied
-APPENDIX 6: Critical analysis of climatic data

APPENDIX 1: Previsions for climate change in the study area: map of the changes spatial variability for temperature and precipitations.



Projected annual average maximum daily temperature and annual precipitation changes in the Lower Mekong Basin. Source: ICEM, 2013

APPENDIX 2: Plot sampling strategy



a) Rice plot (1m²)

b) Maize plot (2m²)

c) Job's tear plot (2m²)

APPENDIX 3: Specific protocol adjustment for LAI and biomass sampling considering crop type

LAI measurement:

Maize leaves were taken back to the village then fixed on A1 sheets with transparent tape and picture was taken horizontally at ~1.30m height over the sheet. Rice and job's tear leaves were all taped on transparent tape in the field on A4 sheets because they quickly dried and fold after being cut (a). Pictures were taken horizontally at ~ 50cm height over the sheet (1st field trip) or scanned (2nd field trip) (a).

a)

Biomass measurement:

Maize plot biomass and plot leaves were weighted in a plastic bag hung to a dynamometer (capacity 18kg, precision 20 g) (b). Rice and job's tear total plot biomass were so low that the weight was directly measured with a small balance (capacity 500g, precision 0.1 g) (c).

b)

c)

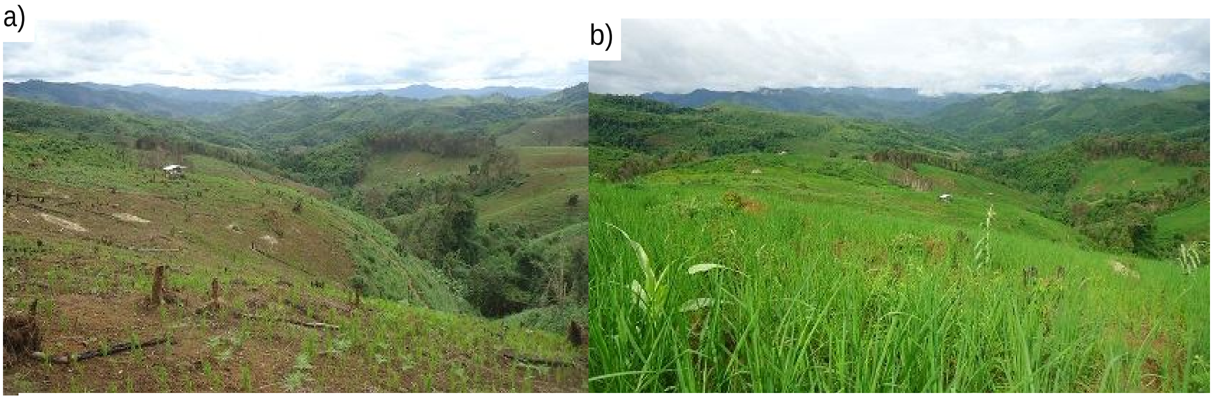
APPENDIX 4: cropping systems examples

1- A burnt field during the sowing period (April)

2- 8-year fallow with vegetation dominated by bamboo

a)

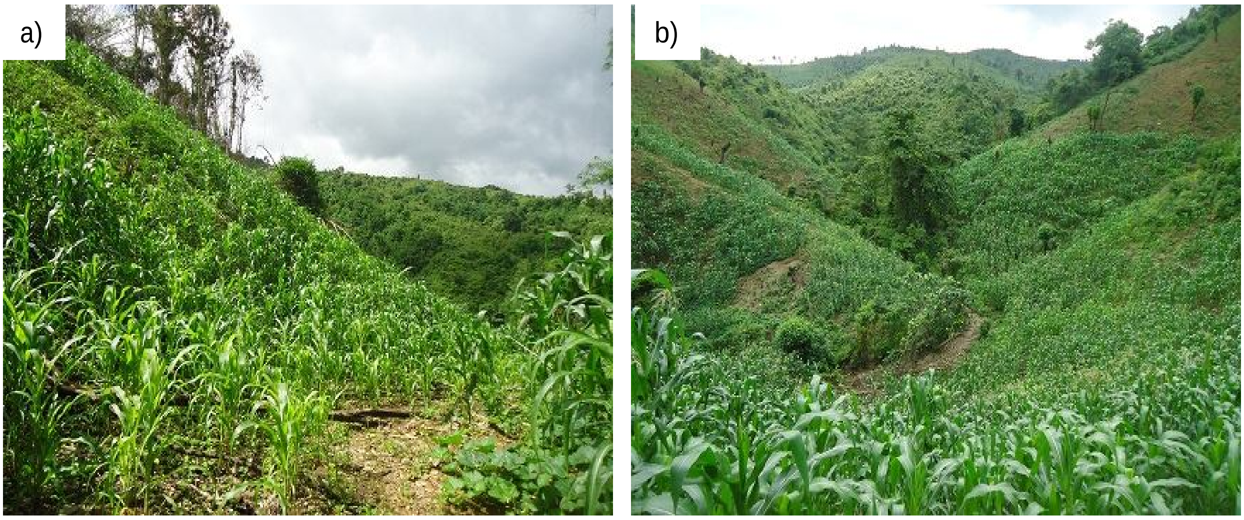
b)



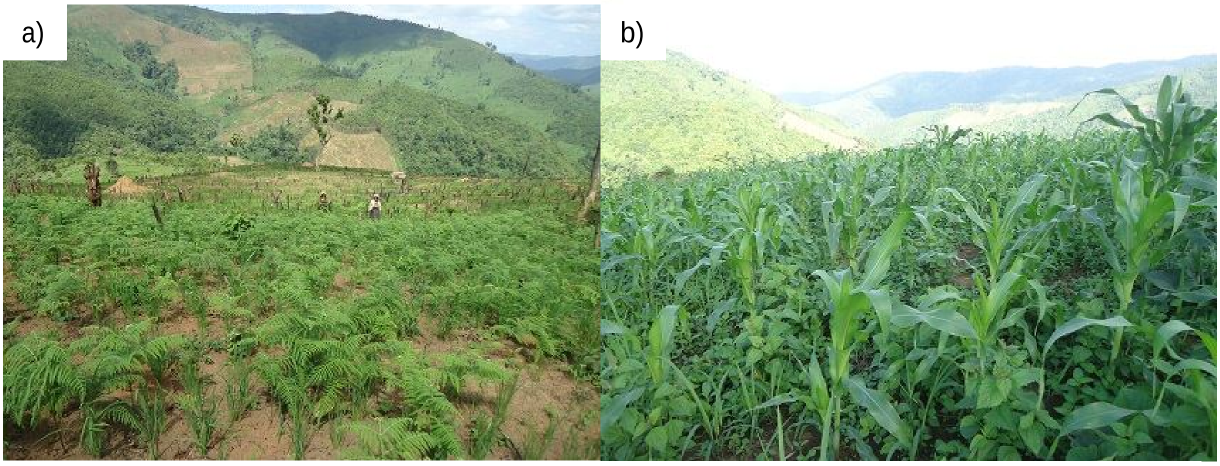
3- Landscape: Same upland rice field in June (1st sampling campaign, a) and in July (2nd sampling campaign, b)

a)

b)



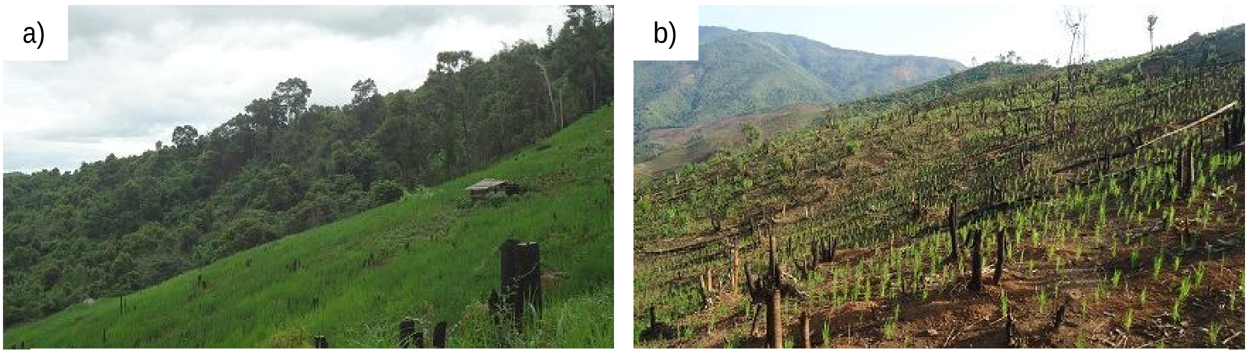
4- Local maize cultivated in small valley (July) (a) in Samsoum (b) in Phoutong



6- Weed infestation, a major concern. Example: a) in rice field (June)   b) in hybrid maize field (June)

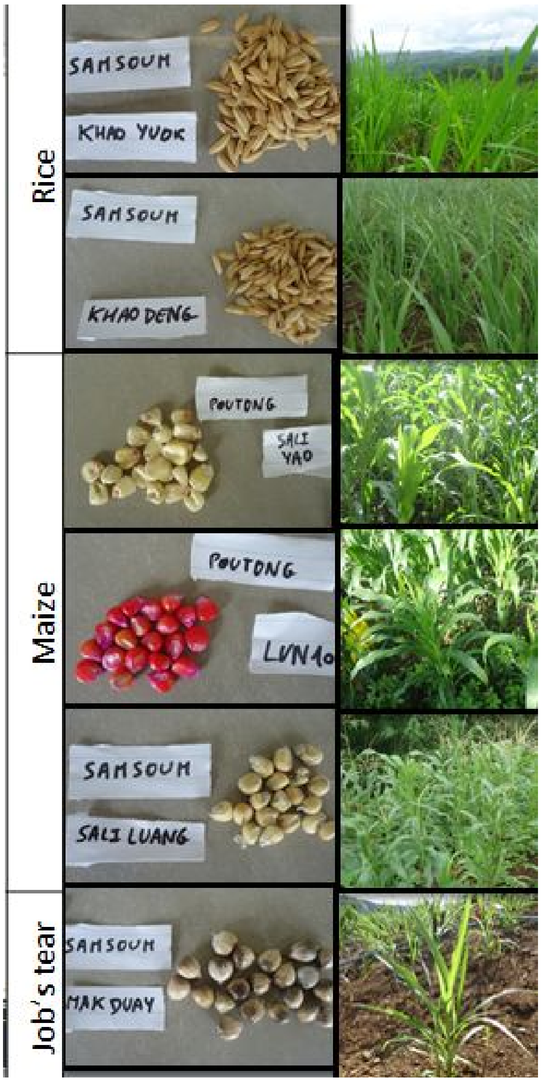
7- Job's tear field (July)

8- Intercropping example: Local maize and cucumber (June)



9- Cultivation on slopes, example of rice fields: a) Samsoum (July)   b) Phoutong (May)

APPENDIX 5: Species and cultivar studied



Main species and cultivars cultivated in the villages: names, seeds, cropping systems

APPENDIX 6: Critical analysis of climatic data

1. <u>Minimum & Maximum temperature</u>

a) Data collection/accuracy:

Data are provided on a daily scale and with integers from 1985 to 1988, but they are recorded as E (Estimated). From 1989 to 2001, monthly data are recorded but as O (observed), and with an accuracy of 0.1°C (fig.a1). No data series have been duplicated. Accuracy of data is questioned since we observed that minimum temperatures are higher than maximum temperature for a few dates (17 dates in December 1987 and 1 in April 1988, with minimum temperature higher than maximum temperatures from 1 to 4 degrees).

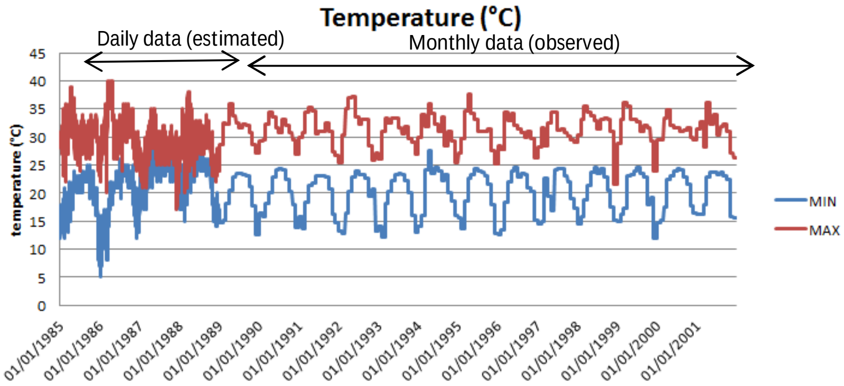


Figure a1: Temperature data series (min and max)

b) Data distribution: Table A1 gives average, maximum and minimum data for maximum and minimum temperature. Average temperature and daily temperature amplitude were calculated.

TabA1: Temperature data from Luang Prabang station

	Max temp	Min temp	Average temp	Daily Amplitude
Average	30.95°C	20.39°C	25.67°C	10.56°C
Min	17°C	5°C	13.5°C	-4°C (error)
Max	40°C	32°C	33.5°C	26°C

Maximum and minimum temperature varies differently throughout the year. Maximum temperature is maximum in April and minimum in December. Minimum temperature is at the lowest point in January and at the highest point in July but it is almost constant during rainy season months (May to September) (fig.a2). In general, daily amplitude of temperature is lower during the rainy season than during the dry season. Daily amplitude is maximum in February (average of 15.3 °C between maximum and minimum temperature) and minimum in July (average 7.1°C between maximum and minimum temperature). Variability in daily amplitude is maximal in March (fig.a3) Interannual average temperature varies between 20.6 in December and 28.2 in April. It varies more in the dry season months (maximum variation in February) and it is relatively constant in the rainy season (as well as amplitude).

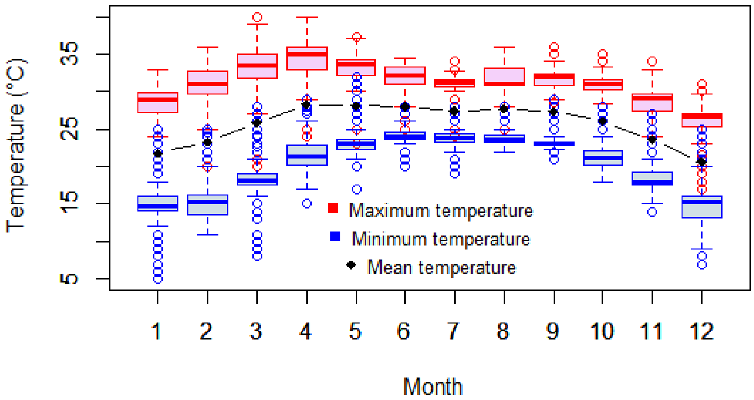


Figure a2: Minimum and maximum temperature variability (+ average temp) per month over the 17 years

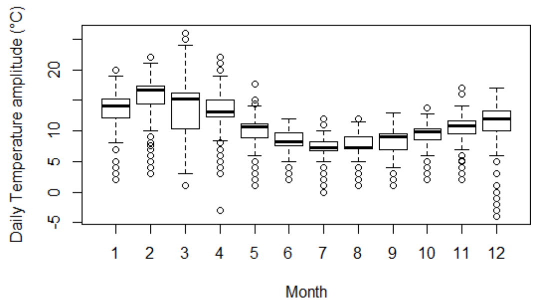


Figure a3: Daily amplitude variability for temperature

2. Windspeed

a) Data collection/accuracy: Wind speed data are recorded on a monthly scale. Data from 1985 to 1988, and also from 1999 to 2001 are defined as E (estimated). For those periods, data are copied yearly and data variation at year-scale is low (data vary between 0.5 and 0.8 m/s) (fig.a4). From 1989 to 1998, data are described as O (observed) and variation is higher (data vary between 0.1 and 1.3 m/s).

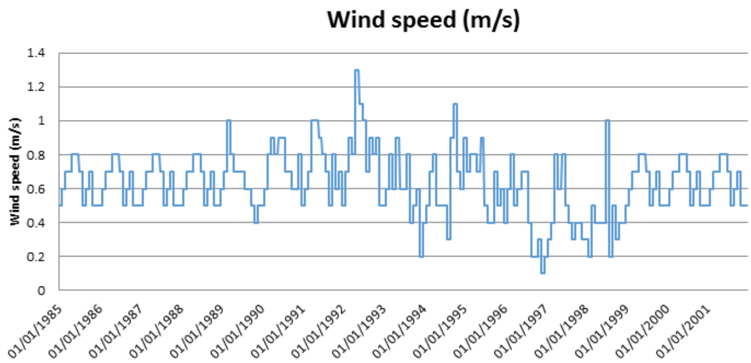


Figure a4 : Wind speed(m/s) from 1985 to 2001

b) Data distribution: Analysis of data distribution is biased by the numerous repeated data (7 years out of 16, so we choose not to represent the distribution with boxplots in this case). Wind speed is varying depending on the month of the year. Wind speed is higher between March and July. It is very low in August and increases again in October (fig.a5).

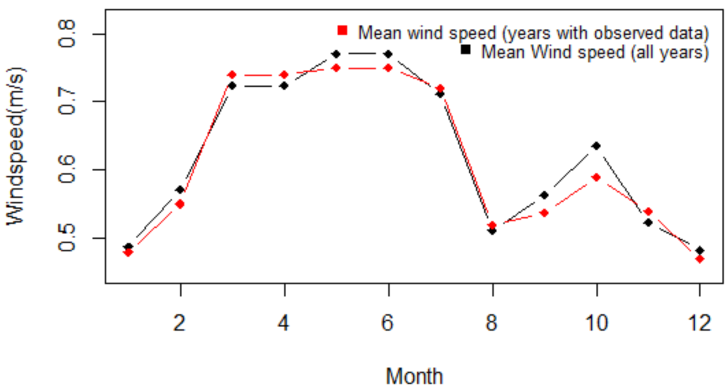


Figure a5: comparison between observed and estimated wind speed data

3. Relative humidity

a) Data collection/ accuracy: Relative humidity data are available on a monthly scale and with a low precision (integer) and data are classified as E (estimated). We can also observe that data series from 1997 to 2001 have been duplicated on a year scale (fig.a6).

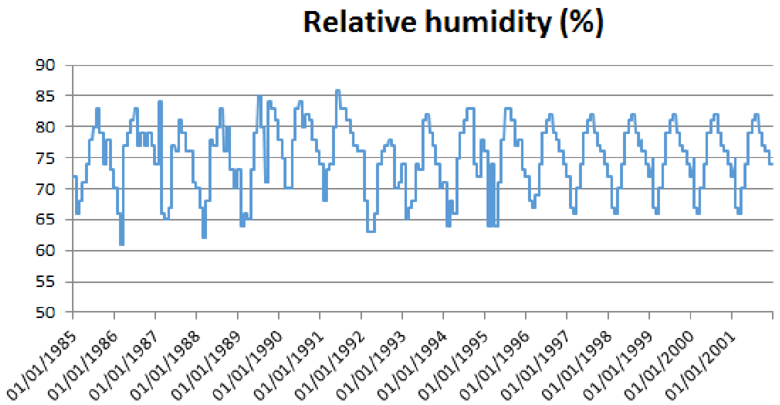


Figure a6: Relative humidity data series (%)

b) Data distribution: Average value of relative humidity is 74.9, minimum value of relative humidity is 61% and the maximum value is 86%. Relative humidity is varying throughout the year (fig.a7). It is at the lowest point in March (interannual average=66.7%). Relative humidity is maximum during August (interannual average=82.0%). Interannual variation within months is quite small, but this is certainly resulting from a bias induced by the year's duplicated data.

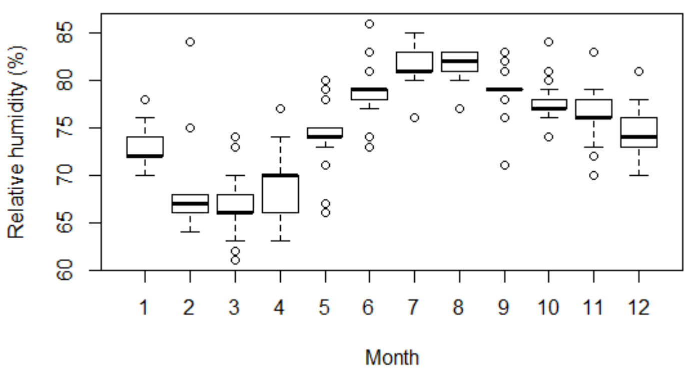


Figure a7: Monthly inertannual distribution of Relative Humidity (%)

4. Solar radiation

a) Data collection/ accuracy: Solar radiation data were daily recorded in MJ/m²/day. Data are strongly biased by series of 10-days periods artefacts at the beginning of each month (fig.a8). Even between months some artefacts are visible, as well as between years. Those data were not used to run the model and solar radiation was recalculated based on the sunshine duration data.

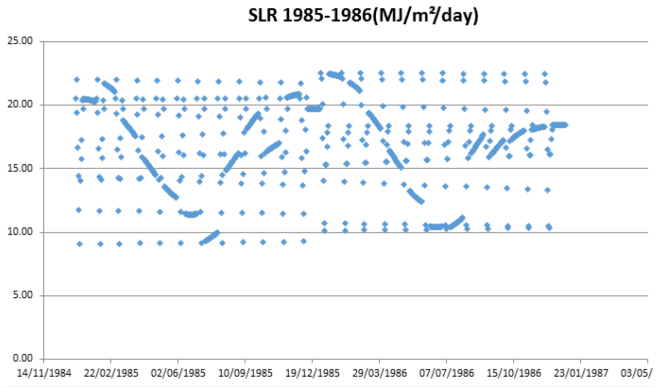


Figure a8: Example of solar radiation data at year-scale

5. Sunshine duration

a) Data collection/ accuracy: Sunshine duration is monthly recorded with accuracy of 0.01 hour, and all data are classified as E (Estimated). Some values are repeated at large scale: same data are recorded for years 1994 and 1995, as well as for years 2000 and 2001 (fig.a9).

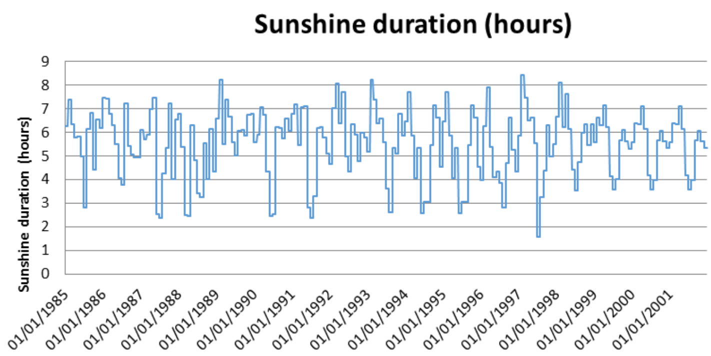


Figure a9: Data series for sunshine duration

b) Data distribution: Sunshine duration is spread between 1.55 hours and 8. 44 hours. During rainy season (especially June, July and August), sunshine duration is lower (In July, interannual sunshine duration average is 3.3 hours). During the dry season, sunshine duration is higher and highest values are in February (interannual sunshine duration average is 7.1). August is the month with the greatest variability for sunshine duration. Due to high variability of data per month and their probably low representativeness of daily data, we decided to use interannual averages to recalculate solar radiation based on the sunshine duration (fig.a10).

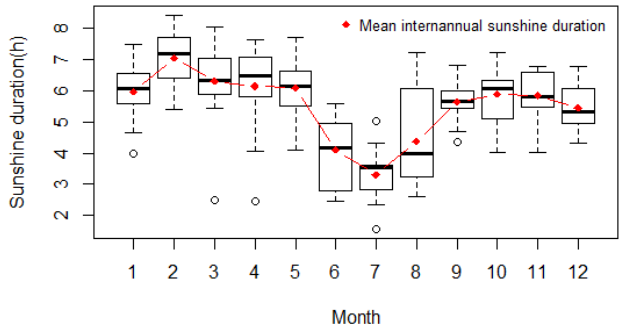


Figure a10: Sunshine duration variability throughout the year

6. Rainfall (observed)

a) Data collection/accuracy: Rainfall data are the most precise of all datasets because they have been recorded on a daily scale from 1961 to 2007 with an accuracy of 0.1 mm. We will discuss the accuracy of rainfall data when we will compare observed values to the predicted ones.

b) Data distribution: Daily rainfall average is 3.7 mm and maximum daily rainfall is 180.7mm. Daily data for precipitation do not bring much information on rainfall, so that we will study accumulation of rainfall on years, months and decades (10-days periods).

Interannual average for rainfall accumulation on the year scale is 1341mm. Minimum is 985mm in 1968 and maximum rainfall is 1840mm in 1986 (fig. a11).

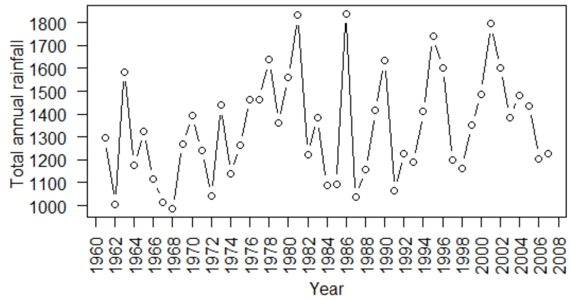


Figure a11: Total Annual rainfall (mm) (1961-2007)

On a month step, total rainfall amount is highly depending on the season. Monthly amounts of rainfall are low during the dry season (November-March) and higher during the rainy season (April-October) (fig.a12). Variability of monthly rainfall amount is also higher during the rainy season (especially in July). Highest amount of rainfall occurs in August (interannual average: 272mm)(Tab .A2).

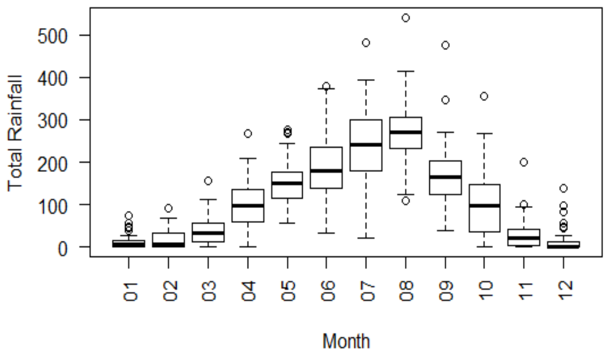


Figure a12: Monthly Rainfall variability (mm)

TabA2: Monthly interannual rainfall average (mm)

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
12.1	17.0	37.7	99.6	152.6	188.8	240.6	272.8	170.8	102.9	31.9	14.5

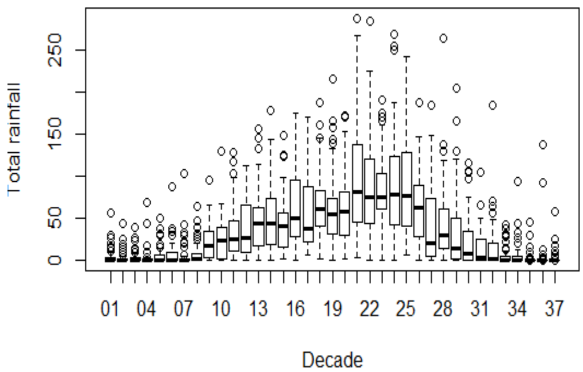


Figure a13: Rainfall variability per decade (mm)

Maximum value for total rainfall in one decade is 247mm. This same decade (N° 21, between 20/07 and 30/07) has a the maximal interannual average with 102.9 mm (fig.a13).

7. Rainfall (observed and predicted)

a) Data collection/ accuracy: This comparison was made from year 1961 to year 2007, excepted year 1994 for which predicted data were not available. Aphrodite data are predicted at a daily scale, and are set up with 5-decimals numbers. For some days, predicted data seem to be postponed from 1 or 2 days in comparison with observed data. For this reason we will try to assess the correlation between observed and predicted values on decades or monthly rainfall accumulations instead of daily rainfall data.

b) Data distribution:

c)

- Total annual scale rainfall analysis: We can observe the same trend between observed and predicted values (same distinction between dry and humid years) (fig.a14 (a)), but observed data are always higher than predicted data (except for year 1974). Difference at year scale varies between -153 and 385 mm, and annual difference average is 156mm, which is quite high. Correlation between observed and predicted data is good (r^2=0.71) (fig.a14 (b)).

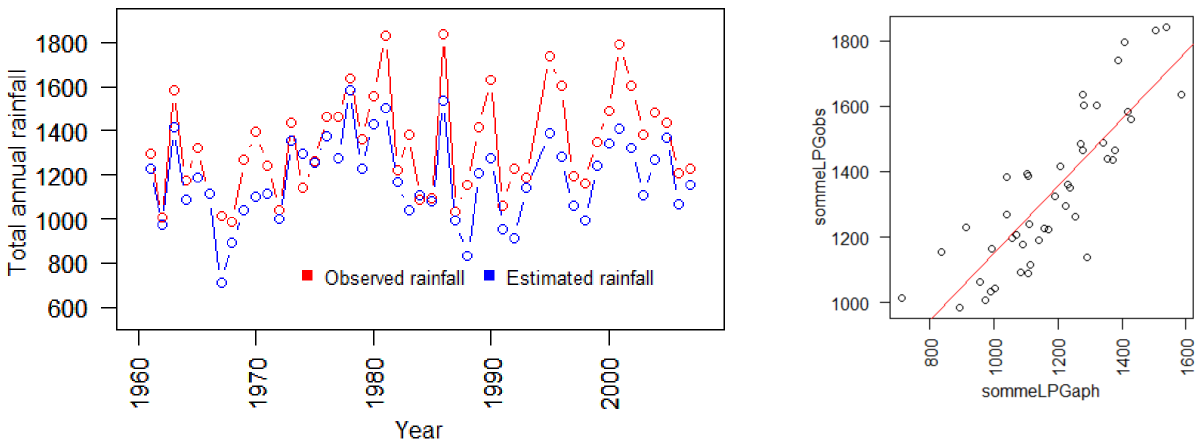


Figure a14: Comparison between observed and estimated total annual rainfall data (mm) (a) historical representation, (b) correlation

- Month- scale rainfall analysis

Monthly total rainfall has been calculated for observed and predicted data. Observed data are higher than estimated data but the difference varies among months (fig.a15(a)). During the dry season and in September, values are quite close, but June, July and August especially, difference in the monthly rainfall is higher (fig.a15(b)). This difference is also high in April, which is the beginning of rainy season. Average difference between observed and predicted values at the month scale is 13 mm, but it varies between -124mm and 204mm. Correlation between observed and estimated is good (R^2=0.92).

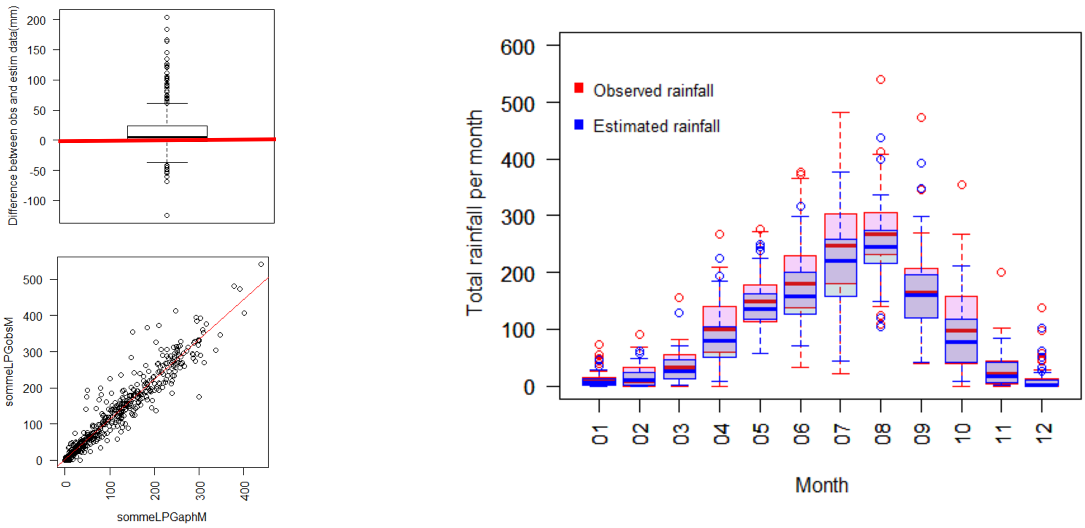


Figure a15: Comparison between observed and estimated monthly rainfall data (mm) (a) observed values – estimated value variation, (b) correlation plot, (c) variation of observed and estimated monthly rainfall data

- Decade scale analysis:

Calculating the total rainfall at 10 day-scale is a relevant way to observe trends inside rainy season. We can observe at which moments occur the highest differences between observed and estimated values and variations in both datasets. Variability follows the same trend in observed and estimated data (fig.a16(a)). Highest variability and also highest difference between observed and estimated data occurs in the 21th decade. Variability is greater for observed data. (There are more exceptional observed data than calculated ones). Average difference between observed and estimated data at the decade scale is 4mm (and is spread between -76 and 191 mm).

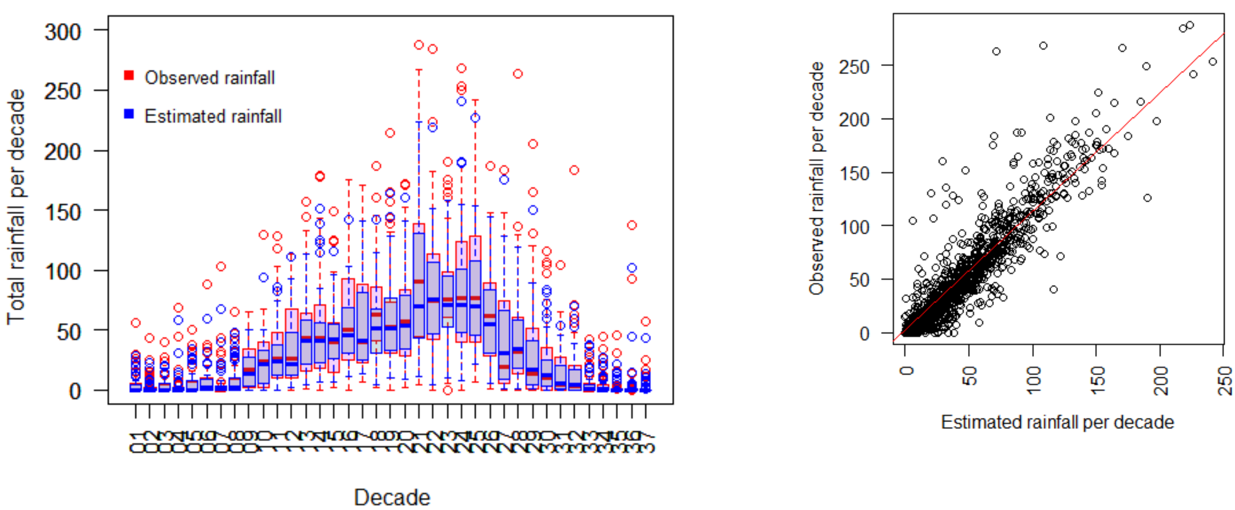


Figure a16: Comparison between observed and estimated monthly rainfall data (mm) (a) variation of observed and estimated rainfall data per decade (b) correlation plot

d) Rainfall spatial analysis (predicted values)

After comparison of observed and estimated values for Luang Prabang and Phonsavan (not presented in this study) weather stations, we can compare predicted data in spatial analysis to assess the possible differences between rainfall data from Luang Prabang weather station and real rainfall data in the upland areas where the villages are located. Rainfall values for Samsoum and Phoutong seem close, but Luang Prabang rainfall data seem to be always lower than Samsoum and Phoutong data. Rainfall data from Phonsavan are close to Samsoum and Phoutong data for some years but are higher for others (fig.a17).

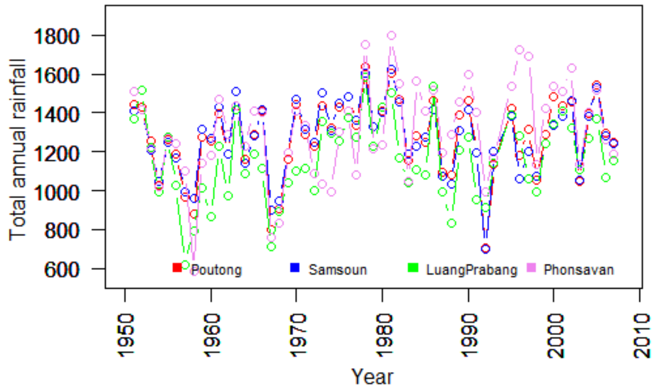


Figure a17: Spatial comparison between estimated data to assess the spatial variability of rainfall data

Résumé

Titre : Sensibilité des systèmes de culture des régions montagneuses du nord du Laos au climat actuel et futur.

Dans un contexte de transition agraire, l'agriculture de subsistance des régions montagneuses du nord du Laos est aussi amenée à faire face au changement climatique.
L'objectif de ce projet a été de décrire les systèmes de cultures pratiqués dans les régions montagneuses du nord du Laos puis d'évaluer leur sensibilité au climat.
Pour cela, des entretiens avec des agriculteurs ont été menés afin d'identifier les cultivars utilisés et la dynamique de leur cycle de culture. Des mesures en champs de producteurs et l'analyse de données de rendement ont servi à déterminer le niveau d'intensification des systèmes de culture pratiqués. La caractérisation des systèmes de culture a permis de paramétrer un modèle agro climatique simple, Potentiel Yield Estimator (PYE), afin de simuler la croissance de 4 cultivars (1 cultivar de riz glutineux, 2 cultivars de maïs et un cultivar de larmes de Job) dans des conditions potentielles ou limitées par l'eau. Puis une expérimentation virtuelle a été mise en place pour simuler la croissance de ces cultivars dans des systèmes de cultures conçus sur la base des informations récoltées sur le terrain. Plusieurs modalités ont été testées pour les paramètres d'entrée du modèle qui sont restés incertains (niveau de ruissellement, caractéristiques du sol, dates de semis). Cette expérimentation virtuelle, menée pour 16 années de données climatiques historiques (1985-2000) et pour 16 années fictives représentant une possibilité d'évolution du climat dans le futur, a permis d'évaluer la sensibilité des systèmes de culture au climat sous plusieurs aspects. Le rendement potentiel par cultivar a été analysé en fonction de la date de semis. Puis l'analyse de la sensibilité du rendement limité par l'eau par rapport au niveau de ruissellement et aux propriétés du sol a révélé l'existence d'une fenêtre de semis pour laquelle le rendement limité par l'eau est très proche du potentiel et dépend peu de l'année. D'une manière générale, le rendement limité par l'eau est peu sensible au ruissellement mais sa sensibilité (représentée par le niveau de rendement et sa variabilité interannuelle) à la réserve utile et la profondeur du sol est d'autant plus grande lorsque l'on s'éloigne des dates de semis optimales. Le changement climatique aurait pour conséquence d'abaisser le niveau de rendement potentiel mais n'affecterait pas outre-mesure le rendement relatif et sa variabilité en fonction des propriétés du sol et du ruissellement.
Le drainage, autre sortie du modèle, serait aggravé par le changement climatique, ce qui amène à considérer avec prudence l'usage de fertilisants minéraux pour palier la baisse de fertilité des sols due au raccourcissement du temps de jachère.

Mots clés
Modélisation, riz pluvial, maïs, changement climatique, systèmes de culture, rendement potentiel, rendement limité par l'eau, fenêtre de semis, drainage, réserve utile, ruissellement

Pour citer cet ouvrage : [Lechevallier, Esther, (2015). Sensibilité des systèmes de culture des régions montagneuses du nord du Laos au climat actuel et futur. Mémoire, diplôme d'ingénieur agronome, option Production Végétale Durable, Montpellier SupAgro. 40p.]

Montpellier SupAgro, Centre international d'études supérieures en sciences agronomiques de Montpellier, 2 place Pierre Viala, 34060 Montpellier cedex 02. http://www.supagro.fr