MEKONG RIVER COMMISSION

TECHNICAL REPORT

CROP YIELD MODELING

BASIN-WIDE ASSESSMENT OF CLIMATE CHANGE IMPACT AND ADAPTATION OPTIONS IN LOWER MEKONG BASIN

A joint activity between Agriculture and Irrigation Team and Climate Change Adaptation Imitative Team

Country: Thailand

Prepared by

Thai national consultant of crop modeling

Reporter name

Yuthasart Anuluxtipun

June 30, 201

Contents

Introduction

1.1 Background and justification

The population of the Lower Mekong River Basin [LMB] has been estimated at 60 million people. A large proportion of this population have livelihoods that are closely linked to the river system, with over 60% of the economically-active population having water-related occupancies that are vulnerable to water-related shocks and degradation.

With more than 20% of the population living below the poverty line - and 15% undernourished - the agriculture and fisheries sectors are vital for food security.

Agriculture is the single most important economic activity, providing livelihoods for approximately 60% of the basin population while Mekong fisheries are among the largest inland fisheries in the world, and provide most of the protein for the basin population.

Both agriculture and fisheries in turn depend on the availability of water in sufficient quantity and quality to sustain productivity. Food production and security are therefore intimately linked to water security and management. However, over past decade population and urbanization are increasingly rapidly in the LMB, farming practices are dynamic and also changing rapidly

Since flood and drought affected areas are considered more vulnerable in terms of food security, the particularly focus will be placed on the relationship between flood, drought and food security.

At the same time, there is a growing concern about the potential impacts of climate change on natural ecosystems, socio-economic characteristics and food security in the LMB. Such impacts also exacerbate the problems associated with supplying the region's increased demand for food. The impacts of climate change are likely to be particularly severe on LMB communities, given their strong reliance on natural resources for their livelihoods. It is thus important for the MRC to provide a more informed understanding of the impacts of climate change on food security in the LMB, which is a part of the overall basin-wide assessment of the climate change impacts in the LMB.

This assessment aims to provide a comprehensive report to answer the questions: (i) How will climate change impact on food security within the basin? (ii) Which areas and communities are most vulnerable in this regard, (iii) How different food-producing sectors are impacted? And (vi) what adaptation options should be prioritized to ensure food security in the whole basin?. The results of this assessment will provide sound information for MRC to formulate the Mekong Climate Change Adaptation Strategy and Action Plan [MASAP] in the next step.

In late 2003, the CCAI together with Future Water had conducted a literature review and rapid assessment which lead to a draft report on "Past and Future Trends in Crop Production and Food Demand and Supply in the LMB" in which AquaCrop model and Food Balance Sheets were used as tools for analyzing and modeling the available data at MRCS and FAO. The results showed the varieties of basin-wide impacts and across different AR5 emission scenarios (updated), however, the spatial resolution based on BDP sub-areas is too coarse for planning purpose. In addition, the result shows that AquaCrop model can be an effective tool to assess climate change impact to crops production under Mekong Basin context. On the other hand, the current impact to crops assessments such as assessment on ecosystems, flood and drought and hydropower will be incorporated into the assessment of food security to draw the whole picture of the impact of climate change to LMB.

In 2003, AIP conducted a study on "Assessment of the conditions necessary to achieve the long-term food security and poverty reduction in the LMB under climate change conditions". The study aims to facilitate the long-term planning and policy-making in the crop production sector towards a food secured and poverty alleviated future for the LMB under climate change. In this study, the baseline of crop production and poverty situation of MCs were analyzed. Besides, crop modeling in climate change context and gross margin analysis were conducted in pilot areas. Taking into account climate change scenarios, the future yields of rice, maize, cassava and soybean in Thailand are projected as a case study. The results indicate that yields of rice, maize and cassava in Thailand will decrease by 2025 and 2050 under climate change scenarios while the yield of soybean will slightly increase by 2025 and 2050. The impact of climate change on rice yield in Northeast Thailand was assessed via SWAT model and PRECIS dynamic downscaling. The SWAT model simulates the water availability in the study area and the crop production using the Erosion-Productivity Impact calculator (EPIC) plant growth model. It predicted that rice yield would decrease up to 30 percent in the future.

Another activity of AIP 2.1.1 - Prepare and analyze the inventory of irrigation projects under development has been done with a paper titled Irrigation for Food Security, Poverty Alleviation and Rural Development in the LMB. This paper provides data and information to assess the pros and cons of future irrigation development potential, their social, economic and environmental implications, and the implications for water balance, increased food production, food security, poverty alleviation, environmental considerations and climate change. Furthermore, the irrigation database improvement is the on-going activity of AIP in which line agencies collect data and improve irrigation database under regional coordination and supervision. This database can provide significant input to the basin-wide assessment of food security.

CCAI and AIP have conducted a number of working sessions and discussion and revealed a clear need for more substantial study with finer resolution and at least provisional level data and information, at the same time considering the limited availability of data, especially in fisheries and livestock components.

1.2 Objective of the assignment

- To assess the vulnerability of area and sectors related to food security that is vulnerable to the impacts of changing climate on food security throughout in the LMB.
- To identify and prioritize vulnerable areas and communities and propose adaptation options with relation to food security under climate change projections
- To provide the key findings and lesson learned of the assessment for further mainstreaming climate change adaptations to the Mekong Adaptation Strategy and Action Plan [MASAP]; and.
- To enhance understanding and capacity of the member countries to adapt to the impacts of climate change on key components of food security throughout facilitating and mentoring the whole process of assessment.
- To conduct crop modeling in the country for Basin-wide Assessment of Climate Change Impacts on Food Security and Adaptation Options in the Lower Mekong River Basin, and produce a report to regional office (AIP).

1.3 Summary of the implementation process of the assignment

The purpose of this study is to projection dry yield of rice and maize on three extreme climate change condition in 2030, 2060 and baseline years (1980-2008) such as wet condition, dry condition and extreme wet and dry condition. The crop model simulation is AquaCrop version 5 that is a tool to forecast rice and maize production. The experimental units are 1,008 which are the combinations factors such as three years, three climate conditions, four representative concentration pathways and twenty-eight sites of paddy rice and Corn Belt. Thailand consists of eight provinces such as Chiang Rai, Amnat Charoen, Bueng Kan, Loei, Mukdahan, Nakhon Phanom, Nong Khai and Ubon Ratchathani which connect the Mekong River but there are twenty-one provinces involve Mekong River Basin.

The results show that Rice yield production increases 23.07% (2.32 ton/ha) and 29.96% (2.45 ton/ha) from the baseline yielding (1.89 ton/ha) in wet condition 2030, 2060 respectively. In the dry condition, rice yield production increases 24.19% (2.38 ton/ha) and 34.57% (2.58 ton/ha) from the baseline yielding (1.92 ton/ha) in 2030, 2060 respectively. In the extreme wet and dry condition, rice yield production slightly increases 4.34% (1.95 ton/ha) in 2030 and slightly decreases 3.53% (1.80 ton/ha) in 2060 from the baseline yielding (1.87 ton/ha).

Maize yield production as the same direction of rice yield production shows that increases 6.99% (3.59 ton/ha) and 8.32% (3.63 ton/ha) from the baseline yielding (3.35 ton/ha) in wet condition 2030, 2060 respectively. In the dry condition, maize yield production increases 8.65% (3.43 ton/ha) and 8.93% (3.44 ton/ha) from the baseline yielding (3.16 ton/ha) in 2030, 2060 respectively. In the extreme wet and dry condition, maize yield production increases 9.82% (2.61 ton/ha) in 2030 and increases 9.61% (2.60 ton/ha) in 2060 from the baseline yielding (2.37 ton/ha). The conclusion that Rice and Maize production in the North and Northeast of Thailand may have increased yielding more decreased yielding level if they are not lost the production from drought, flood, landslide, seasonal shifting and land use change.

2. Overview of Crop Production and Climate Change Impact

2.1 Natural characteristics and socio-economic conditions of rice and maize production

Rice Situation in 2014 Production The major rice planted area in year 2014/15 decreased from last year due to the change of government policy, declining price, and farmers' decision making to switch to plant sugarcane which provided higher returns and market certainty. However, the yield slightly increased because the level of rainfall was sufficient to progress. The second rice planted area also decreased from last year due to lower water level in major dams being not enough to cultivate, and declining price. The yield also slightly decreased because of insufficient rainfall. For the world production, it was found in year 2014/15 that harvested areas were 160.87 million hectare, and came with 476.96 million tons of rice production with average yield about 4.42 ton per hectare. Harvested area and production increased from 158.17 million hectare and 471.88 million tons respectively in the year 2012/13, or increased by 1.71 percent and 1.08 percent respectively. The increasing productivity countries were India, Bangladesh, Vietnam, Myanmar, Philippines, Brazil, Japan, Nigeria, Pakistan, Cambodia, and Thailand, for example. In contrast, the countries with decreased productivity were China and Indonesia.

Trade In 2014, Thailand exported 10.97 million tons of rice and total value of 174,853 million baht, comparing with 6.61 million tons of rice and total value of 133,839 million baht in 2013. The volume and value increased 65.96 percent and 30.64 percent respectively because export price of Thai rice was approximated to competitors such as India and Vietnam, with the average price of 425 US dollars per tons. As a result, some rice importing countries reverted to import rice from Thailand as usual.

Rice production is forecast at 19.8 million metric tons up 1.6 percent from the previous year (2015/16) in anticipation of improvement in average yield. Meanwhile, planted area is expected to decline around 0.6 percent as farmers will likely shift some area to sugarcane crop because of the government incentive under the 5-year Agricultural Restructuring Program (2015 – 2019). In 2015-2016, rice farmers will likely shift around 32,000 hectares to sugarcane based on the registration of rice farmers with sugar mills, particularly in the northeastern and western regions. However, overall rice harvested area is expected to increase by 0.4 percent in anticipation of the recovery of the off-season rice crop from severe drought in 2014-2015.

The Thai Meteorological Department (TMD) reported normal precipitation in 2015, compared to precipitation in 201. This is based on the International Research Institute for Climate and Society's latest estimate of the higher probability of neutral weather phenomenon during the monsoon season in Thailand. Consequently, the average yield of 2.8 metric tons per hectare in 2015-2016 is expected, compared to 2.762 metric tons per hectare in the 2014-2015.

Maize situation in 2014 Production The maize production area gradually decreased due to the higher return of other agricultural products such as cassava, sugar cane, potatoes and vegetables. In spite of this, the production yield per hectare increased because of the suitable weather and adequate rain to be flourishing. However, the total production declined due to the decreasing area of production. The maize production in the world crop year 2014/15 was estimated at 988.08 million tons, which increased around 0.04 percent from 987.69 million tons in the year 2013/14 because of the increasing production in major producing countries such as U.S.A., European Union, Mexico, and Russia. In crop year 2013/14, the world maize production increased 13.79 percent from the year 2012/13. The main increasing occurred in U.S.A. from 273.19 in the year 2013/14 to 351.27 million tons in the year 2014/15 or about 28.58 percent.

Trade the maize demand in Thailand for the year 2014 was 5.00 million tons, a slightly increased 5.93 percent from the year 2013 which was 4.72 million tons due to the increase in demand of feed industry and expansion of livestock industry. The maize export from Thailand in the year 2014 slightly increased 12.48 percent for the production and 24.55 percent of the value from the year 2013 or increased from 0.561 million tons to 0.631 million tons and from 4,138.61 million baht to 5,154.83 million baht, respectively. A result showed that the increasing demand from major export market including Philippines, China and Vietnam.

Maize production is forecast to increase slightly to 4.8 million metric tons in anticipation of yield improvement (2015-2016). Average yield is expected to increase to around 4.4 metric tons per hectare, up 2 percent from the previous year when crop was adversely affected by below normal precipitation. The increase in average yield will likely more than offset anticipated acreage reduction. Sources expect Maize acreage to decline as farmers are likely to shift to cassava crop due to relatively higher attractive returns. Average farm-gate prices of Maize declined by around 1 percent in 2014, compared to approximately 4 percent increase in cassava prices.

2.2 Characteristic of crop production

Thailand is the world's largest exporter of rice, accounting for approximately 30% of the world market. Rice accounts for 30% of the total value of agricultural production in Thailand and 12% of the value of all Thai agricultural exports. Rice-growing households constitute 75% of the 5 million Thai farming families, accounting for nearly 50% of the agricultural labor force. Thai rice can be divided into four main types: (1) white, (2) cargo, (3) white glutinous, and (4) parboiled. Each rice type contains different grades. Rice primarily grows in four regions of Thailand: (1) Central, (2) Northeast, (3) Northern, and (4) Southern. The Central Region has perhaps the greatest advantage in production due to the high productivity of the land and the advanced technology used. In general, paddy rice production in the Central region accounted for about 30% of total production. The Northeast, however, is where the most production occurs, especially of glutinous and jasmine rice. Almost 40% of total rice production comes from the Northeast region. Paddy rice can be categorized into four types as well: (1) irrigated with regional surface water, (2) irrigated with local groundwater drawn from shallow aquifers, (3) rainfed lowland, and (4) rainfed upland rice. Most of the rice in Thailand is directly affected by rainfall with rainfed lowlands accounting for approximately 75% of the wet season rice area and 68% of production. Groundwater and rainfed upland areas account for a further 1.92% and 0.58% of the wet season rice area and about 1.17% and 0.32% of production, respectively. Typically, the Thai rice growing season starts in May and ends in September but in the Northeast starts in August and harvested in December. The three critical requirements for rice production in Thailand are: (1) constant and uniform flooding; (2) even but slightly sloped land with a good irrigation system for continual cycles of water flow, and (3) the ability of the soil to provide 90% of the rice field with a constant water depth of 2-3 inches of water for the entire growing season. A number of other factors are also necessary for efficient rice production. As noted, dependable and consistent rainfall is needed. However, rainfall is also captured and used for irrigating the fields as needed when rainfall is less than expected. A good irrigation system is necessary because most rice varieties cannot produce if moisture levels vary dramatically.

Thai farmers usually plant maize as their major farm enterprise. In addition, most maize is grown in the uplands, where there is limited opportunity to pursue any other enterprise. Some minor or secondary crops can be grown either before or after maize, but they would provide an even lower income than maize. Other sources, including wage employment, contribute about 30% of maize farmers’ incomes. After maize, Central Plains and Lower North farmers commonly plant sunflower, sorghum, or mung bean, and Upper North farmers grow groundnut, black bean, or garlic. In Phichit (Lower North), farmers grow dry season irrigated maize after their wet season paddy rice, a practice that is being promoted by the District Agricultural Office. Other crops grown after maize include soybean, chili, cotton, cassava, Job’s tears, and rice-beans. In Chiang Mai (Upper North), farmers plant both maize and groundnut in the early and late rainy seasons. Maize is less risky than groundnut but is grown primarily to feed backyard animals because its market price is often low and unprofitable. Groundnut, meanwhile, tends to have more variable yields but better prices. To fully exploit field moisture and shorter growth periods, farmers sometimes plant the new crop while maize is still standing in the fields. This was observed especially in late season rice, beans, cotton, and mung bean.

Most maize areas surveyed in this study had two cropping seasons, but only six (out of 31) sub-districts planted maize in both seasons. In most of the Lower Northeast, Upper Northeast, and some parts of the Lower North, farmers planted only one crop of maize per year during the early rainy season from April to June. In Chiang Rai, dry season maize was planted after wet season paddy rice. In Loei province (Upper Northeast), farmers planted only one crop of maize in the rainy season, but some would plant it between rows of fruit trees. Some farmers also integrated maize into young banana plantations or rotated it with cassava. In Kamphangphet (Lower North), farmers planted the first maize crop in the early rainy season, followed by second and third maize crops when there was sufficient water. In Uthai Thani (Lower North) and a few other areas, maize is grown in the late rainy season. In Thailand, the first crop of maize is usually grown in May. Land preparation and sowing begins in April/May after the first rain, and harvesting is done beginning in August and through September. The second maize crop starts in September and ends by December. The rainy season starts in April and lasts until October, after which there is very little rain. The second season of maize gets only a few weeks of rain, and crop production is often subject to high risk of drought. Farmers harvest their product dry in the fields in either December or January. The third maize season, from January to April, is only possible in paddy fields with irrigation. Since only a limited area can be planted with third season maize, the small output often fetches a relatively high price.

2.3 Overview of climate change impact in Thailand

The most recent severe drought happened almost 20 years ago during El Niño, the phenomenon caused by shifts in Pacific trade winds and ocean temperatures. El Niño is back this year; its full force is still to be felt and has the potential to be strong and last until next March. Thai people, therefore, should become more aware of climate change and its interaction with cyclical weather patterns to better adapt to current and future hazards. Since the last rainy season in 2014, Thailand has had far less precipitation than usual. That was worry as at the end of 2014, when the last rainy season ended, large dams were at already at a level considered critically low. Since then international and national experts have warned that drought will affect the important rice growing areas of Thailand's central plain. The Royal Irrigation department has announced it is stopping water supply for double-crop field planting until October 7 2015. This is because the priorities for water allocation are now human and industrial consumption, and environmental protection. This is to meet increasing demand from urban populations, and the economically critical tourism and manufacturing industries. As a result, the agrarian sector and farmers' livelihoods lose out. Thailand's winter ends in January. The rainy season usually begins in the middle of May, sometimes as late as the beginning of June. But this year rain only began lightly falling in August. Most of this year's rain has fallen below the dams, which means they are not recharging and water still remains largely inaccessible to water managers attempting to alleviate drought response. Farmers are therefore often unable to grow rice, water stresses across the country continue, and desiccated river banks are collapsing silting up rivers. Effects or the drought are also felt in cities. There is insufficient water supply to meet demand in Bangkok and its peripheries. The Metropolitan Waterworks Authority has had to reduce water pressure at night. In some places consumers complain of a brackish taste to tap water because of sea water infiltration. Thailand is experiencing the worst drought in decades, with seven out of 67 provinces affected and water rationing taking place in almost a third of the country. Thailand's Irrigation Department said that the amount of usable water in dams across the country, except in the West, have dwindled to below 10 percent and in the capital Bangkok tap water production has been slowing down since May, reports the Associated Press. Meanwhile the drought is taking its toll on the country's farmers. Rice farmers usually plant their paddy in June or July but because of critical water shortages, the Agriculture Ministry has asked farmers to delay planting their crop until August. According to the Office of Agricultural Economics, the delay could cost farmers in Thailand's central plains 60 billion baht ($1.8 billion) in losses and straddle them with significant debt. Thailand is one of the world's top producers of rice, exporting more than 10 million tons annually. As a result of the drought, the Thai government has lowered its forecast rice exports for this year by 2 million tons. Fearing the drought could mean a rise in rice prices, African countries have increased their imports, the Nation reports. The African market remains an important market for Thailand especially rice and parboiled rice. In an effort to support farmers affected by drought, Thailand's Finance Ministry approved loans of up to 60 billion baht ($1.77 billion) for emergency funds and long-term assistance to increase farm productivity. In preparation for the next possible drought, Thai government suggests more careful planning of crop rotation and switching to crops that need less water such as corn, kale and watermelon in drier years. Farmers are encouraged to use water-efficient technologies such as drip irrigation. A form of irrigation that saves water and fertilizer by allowing water to drip slowly to the roots of many different plants through a network of valves, pipes, tubing and emitters.

In contrast, The flooding in Thailand during the second half of 2011 was enhanced by and likely the result of persistent monsoonal rains combining with the remnants of a series of tropical cyclones beginning in late July and lasting through the month of October. (Monsoon rains are defined as occurring due to a shift in wind direction from the ocean to land. In some cases, this pattern can cause significant rainfall.) The presence of an active La Niña phase of the El Niño-Southern Oscillation (ENSO) also contributed to the excessive nature of the rainfall. The heaviest rains occurred across northern and central sections of Thailand, before swollen rivers and floodwaters began to shift southward towards the greater Bangkok metropolitan area. The following pages will help outline what is typical during a normal meteorological year in Thailand and will provide insights on what made the floods so devastating and how they unfolded. Due to the abundance of rainfall, widespread flooding occurred across southern sections of the country in March and April. The Disaster Prevention and Mitigation Department declared eight provinces (Nakhon Si Thammarat, Phatthalung, Surat Thani, Trang, Chumphon, Songkhla, Krabi and Phang Nga) as disaster zones after the floods killed at least 61 people and saw upwards of 600,000 homes damaged from the worst flooding in a decade. Damage from the flooding and landslides was also extensive to businesses and the transportation and electrical infrastructures. The University of the Thai Chamber of Commerce estimated economic losses of at least THB27.2 billion (USD880.0 million). It should be noted that the above normal rains in the north would essentially lay the groundwork for the substantial floods in the coming months as soils were oversaturated and river levels elevated. In addition to Thailand, excessive rainfall was prevalent throughout much of Southeast Asia that also led to flood inundation in multiple countries during the second half of 2011. Both of them cause agriculture production and harmful for Thai people. Severe flooding 0occurred during the 2011 monsoon season in Thailand. The flooding began at the end of July triggered by the landfall of Tropical Storm. These floods soon spread through the provinces of northern, northeastern, and central Thailand along the Mekong and Chao Phraya river basins. In October floodwaters reached the mouth of the Chao Phraya and inundated parts of the capital city of Bangkok. Flooding persisted in some areas until mid-January 2012, and resulted in a total of 815 deaths (with 3 missing) and 13.6 million people affected. Sixty-five of Thailand's 77 provinces were declared flood disaster zones, and over 20,000 km^2 of farmland was damaged. The disaster has been described as the worst flooding yet in terms of the amount of water and people affected. The World Bank has estimated 1,425 billion baht (US$45.7 billion) in economic damages and losses due to flooding, as of 1 December 2011. Most of this was due to the manufacturing industry, as seven major industrial estates were inundated in water as much 3 meters deep during the floods. Disruptions to manufacturing supply chains affected regional automobile production and caused a global shortage of hard disk drives which lasted throughout 2012. The World Bank's estimate for this disaster means it ranks as the world's fourth costliest disaster as of 2011 surpassed only by the 2011 earthquake and tsunami in Japan, 1995 Kobe earthquake, and Hurricane Katrina in 2005. A 2015 study suggested increasing odds for potential flooding similar to the 2011 flood intensity to occur in the near future.

In Thailand, the world's largest rice exporter, rice constitutes a major export on which the economy of the whole country depends. Climate change could affect rice growth and development and thus jeopardize Thailand's wealth. Current climatic conditions in Thailand are compared to predictions from four general circulation models (GCMs). Temperature predictions correlate well with the observed values. Predictions of monthly rainfall correlate poorly. Virtually all models agree that significant increases in temperature (from 1 to 7 °C) will occur in the region including Thailand following a doubling of atmospheric carbon dioxide (CO2) concentration. The regional seasonality and extent of the rise in temperature vary with each model. Predictions of changes in rainfall vary widely between models. Global warming should in principle allow a northward expansion of rice-growing areas and a lengthening of the growing season now constrained by low temperatures. The expected increase in water-use efficiency due to enhanced CO2 might decrease the water deficit vulnerability of dryland rice areas and could make it possible to slightly expand them. The ongoing prolonged summer of 2015 and El Niño has affected the entire country. Thailand needs to take lessons from the current drought and to prepare for similar events in the future. The country needs to understand that climate change is going to cause more crises and it needs to learn and adapt

3. Methodology

3.1 Introduction of AquaCrop

Much progress has been made in quantifying and understanding crop growth in relation to water in the last 30 years. This led to the development of AquaCrop, the FAO’s crop water productivity simulation model. For this development, FAO organized consultations with recognized authorities and experts from major scientific and academic institutions, national and international research centers and governmental organizations worldwide. The outcome is a revised framework that treats herbaceous crops and tree crops separately. The herbaceous crops are to be simulated by the model AquaCrop, parameterized for each crop species. The model is to strike a balance among accuracy, simplicity and robustness. It is to be used for irrigation management, project planning, and scenario simulations at different scales. The tree crops present additional complexities which are not easy to simulate. Hence, only guidelines regarding water management and yield estimation are being written for important tree crop species.

AquaCrop Conceptual Briefs

In the FAO Irrigation and Drainage Paper No. 33 "Yield Response to Water", the fundamental relation of the yield estimate in response to water is expressed through the following equation,

$$\left(\frac{Yx - Ya}{Yx}\right) = Ky \left(\frac{ETx - ET}{ETx}\right) \qquad \textbf{(Eq. 3.1a)}$$

Where Yx and Ya are the maximum and actual yield, ETx and ET are the maximum and actual evapotranspiration, and Ky is the proportionality factor between relative yield loss and relative evapotranspiration reduction.

AquaCrop evolves from Eq. (3.1a) by (i) dividing the ET in soil evaporation (Es) and crop transpiration (Tr), (ii) obtaining biomass (B) from the product of water productivity (WP) and cumulated crop transpiration, as reported in Eq. (3.1b), (iii) expressing the final yield (Y) as the product of B and Harvest Index (HI), (iv) normalizing Tr with reference evapotranspiration (ETo), and (v) calculating crop water use, growth and production in daily time steps instead of only as the final ET and Y.

$$B = WP \cdot \Sigma Tr \qquad \textbf{(Eq. 3.1b)}$$

The division of ET into Es and Tr avoids the confounding effect of the non-productive consumptive use of water (Es). This is important for growing periods when canopy cover is incomplete. The expression of Y in terms of B and HI allows a distinction of the basic functional relations between environmental conditions and B, and environmental conditions and HI. The normalization of Tr makes the B-Tr relationship general, applicable to different climatic regimes. The simulation of water use and production in daily time steps permits a more realistic accounting of the dynamic nature of water stress effects and crop responses. A schematic representation of these evolutionary steps is reported in Figure 3.1a.

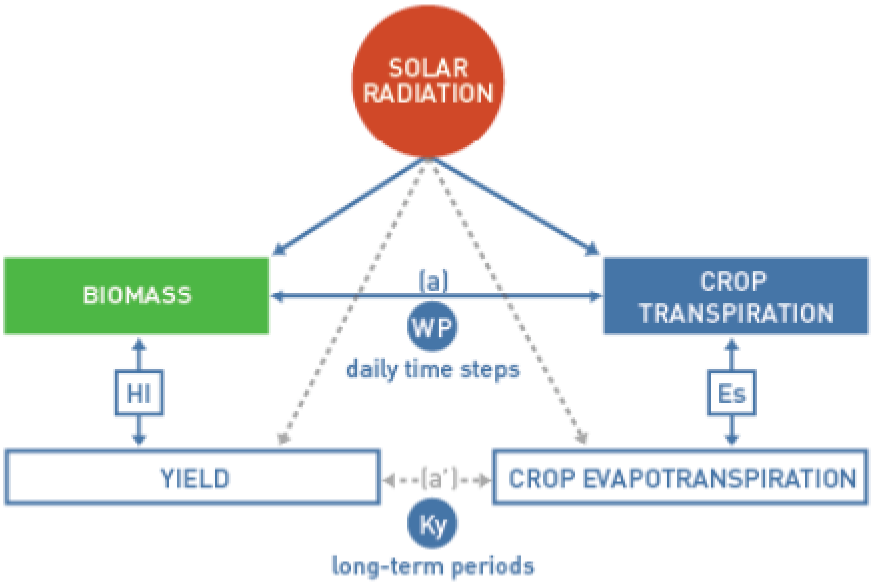


Figure 3.1a. Evolution of AquaCrop from Eq (3.1a), based on the introduction of two intermediary steps: the separation of soil evaporation (Es) from crop transpiration and the attainment of yield from biomass and Harvest Index (HI). The relationship a', linking yield to crop evapotranspiration is expressed through Eq. (3.1a) via the Ky parameter and normally applies to long periods. The relationship a, linking biomass to crop transpiration, is expressed by Eq. (3.1b) via the WP parameter and has a daily time step.

As Eq. (3.1a) of Paper No. 33, AquaCrop is water-driven, meaning that the crop growth and production are driven by the amount of water consumptively used (Tr). AquaCrop focuses on the fundamental relation between B and Tr (Eq.3.1b) rather than Y and ET (Eq.1), relying on the conservative behavior of WP. Similarly to many other crop-growth models, AquaCrop further develops a structure (sub-model components) that includes: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration (CO2); and the management, with its major agronomic practice such as irrigation and fertilization.

Simulation runs of AquaCrop are executed with daily time steps, using either calendar days or growing degree days. Several features distinguish AquaCrop from other crop growth models achieving a new level of simplicity, robustness and accuracy.

These key features include

- canopy development expressed as canopy cover (CC) of the ground and not through leaf area index (LAI). This offers a significant simplification in the simulation by reducing canopy development with time to a sigmoid function using a canopy growth coefficient. Senescence of the canopy is simulated with a decline function

- root development is expressed in terms of effective rooting depth as a function of time (either calendar or thermal). A functional relationship is also established between root and shoot development

- B is calculated using WP and Tr. WP is normalized for climate (atmospheric evaporative demand and carbon dioxide) so that it can be used in different climatic zones in space and time. WP is also partially affected by fertility levels

- Y is calculated as the product of B and HI. HI increases mostly linearly with time (either calendar or thermal) starting after pollination and until near physiological maturity. Other than for the yield, there is no biomass partitioning into the various organs. This choice avoids the majority of uncertainties linked to this fundamental process that remains among the most difficult to model

- water stress is expressed through stress coefficients (Ks) specific of each basic growth expression. These are canopy expansion, stomatal control of transpiration (gs), canopy senescence and harvest index. Different Ks accommodate for different crop species sensitivities to water stress

- ET division in Es and Tr approximates the Ritchie approach (1972), but using CC rather than LAI as the crop parameter

- AquaCrop uses a relatively small number of explicit and mostly-intuitive parameters and input variables requiring simple methods for their determination. The overall structure of AquaCrop's main components is shown in the flowchart of Figure 3.1b.

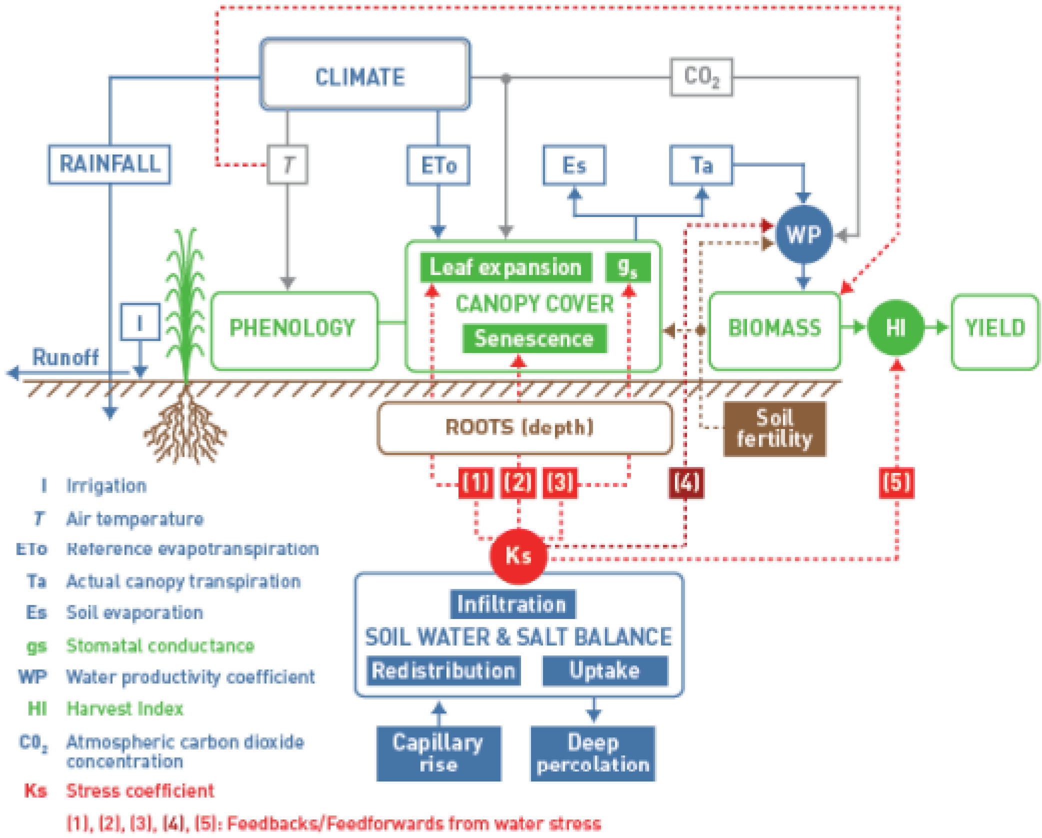


Figure 3.1b. AquaCrop flowchart indicating the main components of the soil-plant-atmosphere continuum. AquaCrop is mainly intended for practitioners such as those working for extension services, governmental agencies, NGOs and various kinds of farmers associations. It is useful for developing irrigation strategies under water deficit, finding the most suitable crop calendar under rainfed agriculture and obtaining yield estimates for field crops under a variety of environmental conditions (including salinity and climate change). AquaCrop should also be of interest to scientists and for teaching purposes. (FAO, 2016)

3.2 Modeling process

3.2.1 Calculation scheme

A general calculation scheme of AquaCrop is depicted in Figure 3.2.1 with a daily time step the model simulates successively the following processes:

1. Soil water balance. The amount of water stored in the root zone is simulated by accounting for the incoming and outgoing water fluxes at its boundaries. The root zone depletion determines the magnitude of a set of water stress coefficients (Ks) affecting: (a) green canopy (CC) expansion, (b) stomatal conductance and hence transpiration (Tr) per unit CC, (c) canopy senescence and decline, (d) the harvest index (HI) and (e) the root system deepening rate;

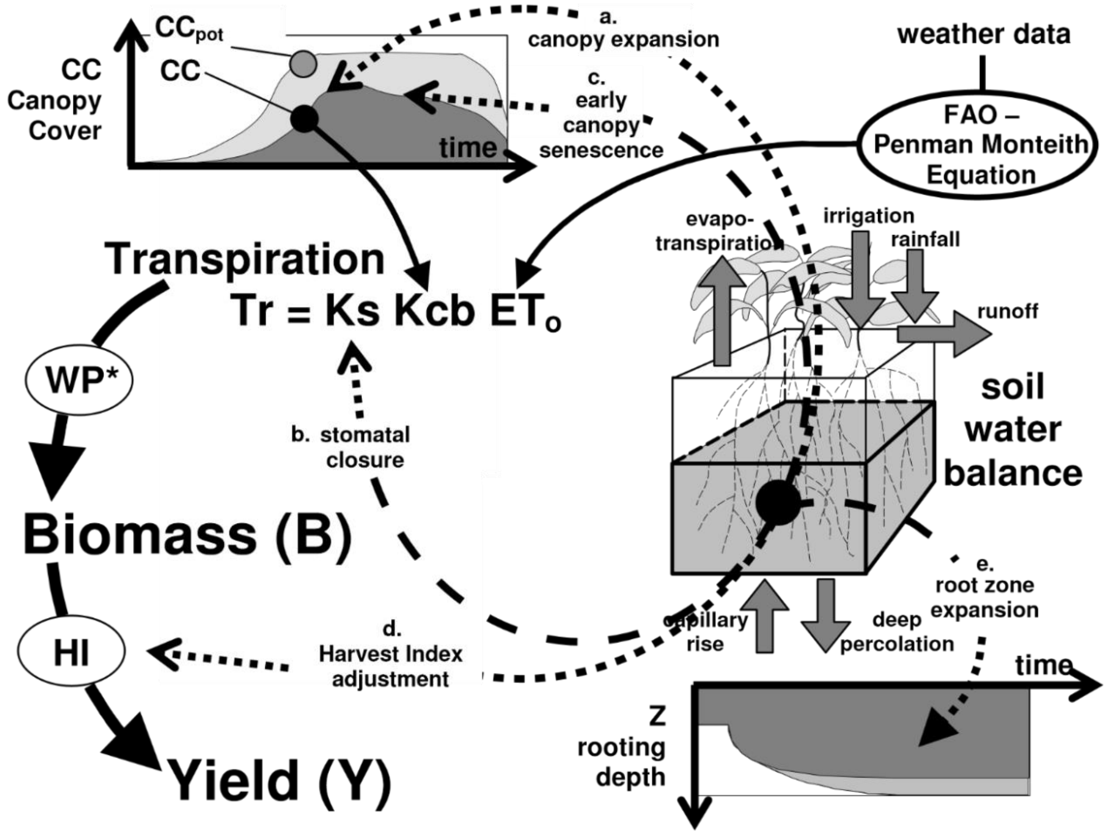


Figure 3.2.1 Calculation scheme of AquaCrop with an indication (dotted arrows) of the processes (a to e) affected by water stress. CC is the simulated canopy cover, CC_{pot} the potential canopy cover, Ks the water stress coefficient, Kcb the crop coefficient, ETo the reference evapotranspiration, WP* the normalized crop water productivity, and HI the Harvest Index

2. Crop development. In the simulation of crop development, the canopy expansion is separated from the expansion of the root zone. The interdependence between shoot and root is indirect via water stress. AquaCrop uses canopy cover to describe crop development. The canopy is a crucial feature of AquaCrop. Through its expansion, aging, conductance and senescence, it determines the amount of water transpired (Tr), which in turns determines the amount of biomass produced (B) and the final yield (Y). If water stress occurs, the simulated CC will be less than the potential canopy cover (CC_{pot}) for no stress conditions and the maximum rooting depth might not be reached (dark shaded areas in Fig. 3.2.1);

3. Crop transpiration (Tr). Crop transpiration is obtained by multiplying the evaporating power of the atmosphere (ET_o) with a crop coefficient. The crop coefficient (Kcb) is proportional to CC and hence continuously

adjusted. The evaporating power is expressed by the reference grass evapotranspiration (ET_o) as determined by the FAO Penman-Monteith equation. If water stress induces stomatal closure, the water stress coefficient for stomatal conductance (Ks) reduces transpiration accordingly. Green canopy cover and duration represent the source for transpiration, stomatal conductance represents transpiration intensity;

4. Above ground biomass (B). The cumulative amount of water transpired (Tr) translates into a proportional amount of biomass produced through the biomass water productivity. In AquaCrop the water productivity normalized for atmospheric demand and air CO_2 concentrations (WP*) is used. It expresses the strong relationship between photosynthetic CO_2 assimilation or biomass production and transpiration independently of the climatic conditions. Beyond the partitioning of biomass into yield (Step 5), there is no partitioning of above-ground biomass among various organs. This choice avoids dealing with the complexity and uncertainties associated with the partitioning processes, which remain among the least understood and most difficult to model;
5. Partitioning of biomass into yield (Y). Given the simulated aboveground biomass (B), crop yield is obtained with the help of the Harvest Index. In response to water and/or temperature stresses, HI is continuously adjusted during yield formation.

3.2.2 Step 1 – simulation of the soil water balance

In a schematic way, the root zone can be considered as a reservoir (Fig. 3.2.2a). By keeping track of the incoming (rainfall, irrigation and capillary rise) and outgoing (runoff, evapotranspiration and deep percolation) water fluxes at the boundaries of the root zone, the amount of water retained in the root zone, and the root zone depletion can be calculated at any moment of the season by means of a soil water balance.

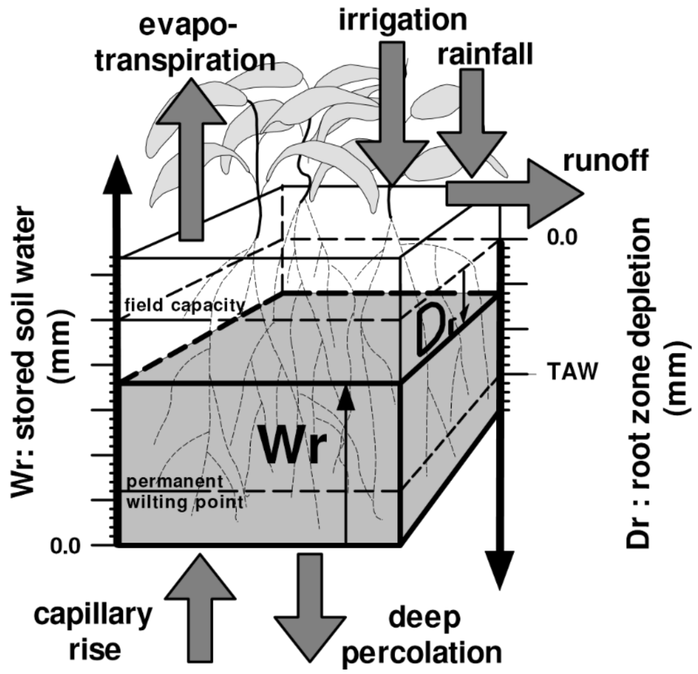


Figure 3.2.2a The root zone as a reservoir with indication of the fluxes at its boundaries affecting the water stored in the root zone (Wr) and the root zone depletion (Dr)

To accurately describe surface run-off, water infiltration and retention, water and salt movement, and to separate soil evaporation from crop transpiration, AquaCrop divides both the soil profile and time axis into small fractions. The simulations run with a daily time step (Δt) and the soil profile is divided into 12 compartments (Δz), which size is adjusted to cover the entire root zone.

The effect of water stress is described by stress coefficients (Ks). Above an upper threshold of root zone depletion, water stress is non-existent (Ks is 1) and the process is not affected. Soil water stress starts to affect a particular process when the stored soil water in the root zone drops below an upper threshold level (Fig. 3.2.2b). Below the lower threshold, the effect is maximum (Ks is 0) and the process is completely halted. Between the thresholds, the shape of the Ks curve determines the magnitude of the effect of soil water stress on the process. Since the effect of water stress might differ along the processes, each process has its own Ks coefficient and threshold values.

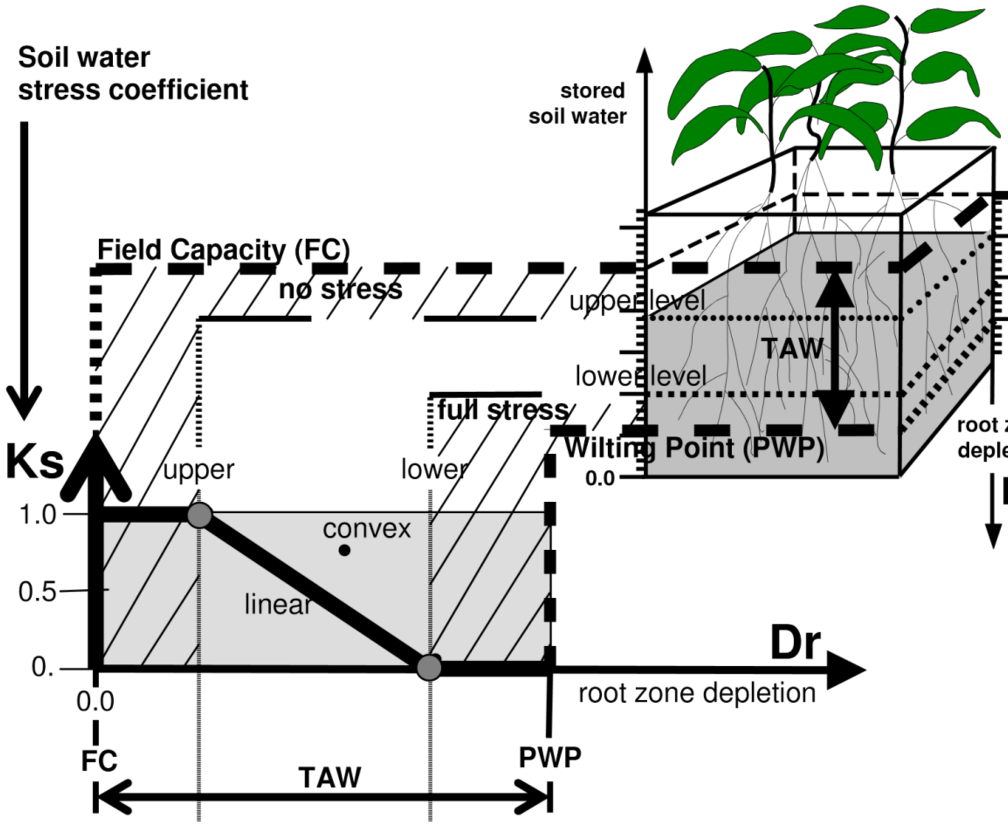


Figure 3.2.2b The water stress coefficient (Ks) for various degrees of root zone depletion (Dr). TAW is the Total Available soil Water in the root zone which is the difference between the water content at Field Capacity and Permanent Wilting Point

3.2.3 Step 2 – simulation of green canopy development (CC)

Instead of leaf area index (LAI) AquaCrop uses green canopy cover (CC) to express foliage development. CC is the fraction of the soil surface covered by green canopy cover. Canopy development under optimal conditions is described by only a few crop parameters which are retrieved from the cropped file at the start of the simulation:

- initial canopy cover at 90 % emergence (CC_o);
- maximum canopy cover when the canopy is fully developed (CC_x);
- canopy growth coefficient (CGC), used to describe the canopy expansion between cop emergence and full development;
- canopy decline coefficient (CDC), used to describe the declining phase due to leaf senescence as the crop approaches maturity.

In figure 3.2.3, the variation of green canopy cover throughout a crop cycle under no stress conditions is represented.

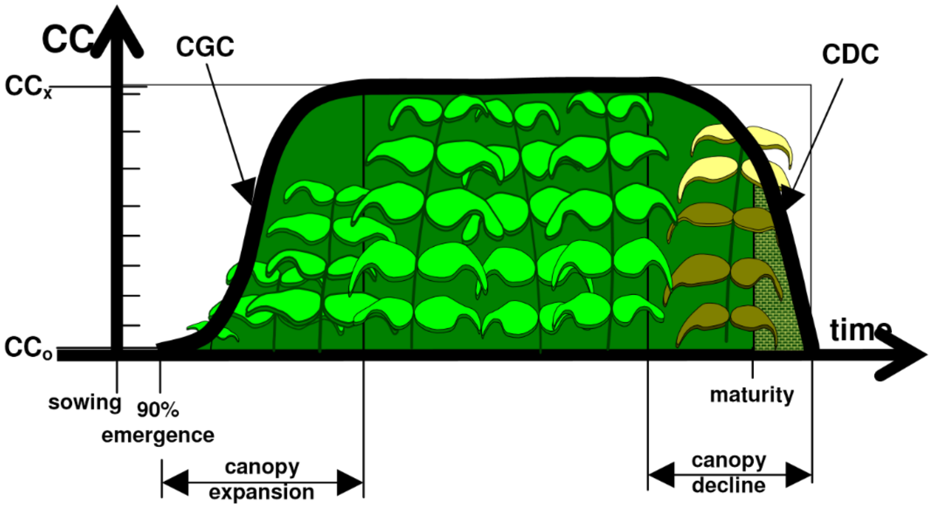


Figure 3.2.3a Variation of the green canopy cover (CC) throughout the crop cycle under non-stress conditions. CC_o and CC_x are the initial and maximum green canopy cover, respectively; CGC is the green canopy growth coefficient; CDC is the green canopy decline coefficient

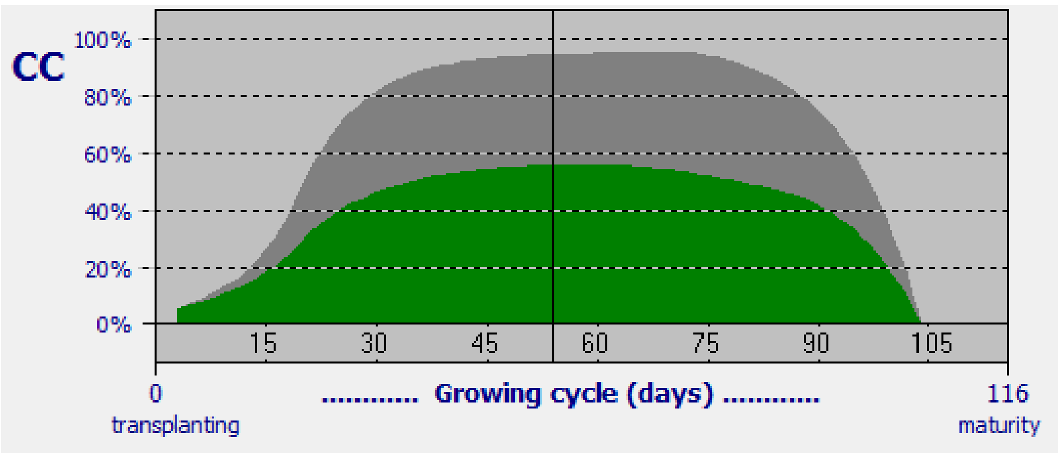


Figure 3.2.3b Effect of soil fertility and poor biomass production to rice canopy cover NE of Thailand.

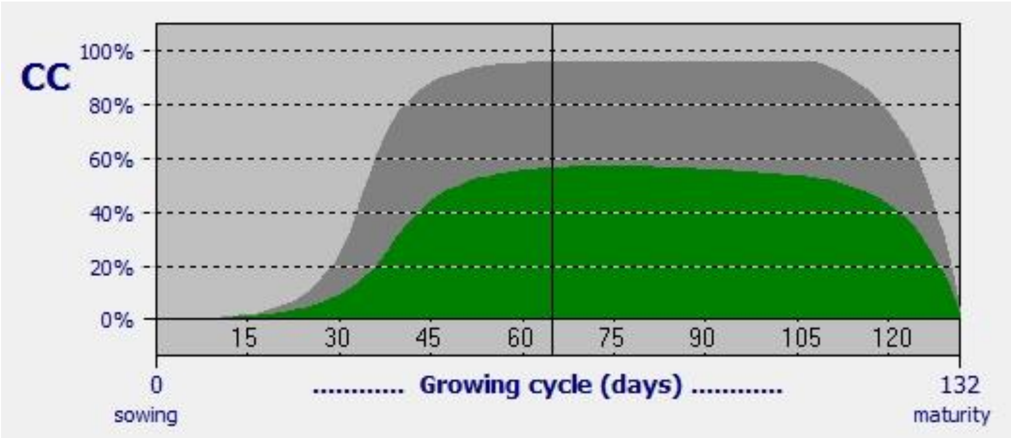


Figure 3.2.3b Effect of soil fertility and poor biomass production to maize canopy cover in NE of Thailand.

The effect of water stress on canopy expansion is simulated by multiplying the Canopy Growth Coefficient (CGC) with the water stress coefficient for canopy expansion ($Ks_{exp,w}$). As root zone depletion increases and drops below the upper threshold, the stress coefficient becomes smaller than 1 and the canopy expansion starts to be reduced (Fig. 3.2.2b). When the lower threshold of root zone depletion is reached, $Ks_{exp,w}$ is zero, and the process is completely halted. As a result, CC_x might not be reached or much later in the season than described in Fig. 3.2.3a for non-stressed conditions.

Early canopy senescence is triggered when water stress becomes severe. As a consequence, the upper threshold of root zone depletion for senescence is much lower in Fig. 3.2.2b and close to the permanent wilting point. The degree of senescence is described by the value of the water stress coefficient for early canopy senescence (Ks_{sen}) which modifies the canopy decline coefficient (CDC). Due to the induced early canopy senescence, the crop life might become much shorter than for non-stressed conditions. The simulation of the green canopy cover (CC) during the building up of water stress during the crop cycle is presented in Figure 3.2.3b

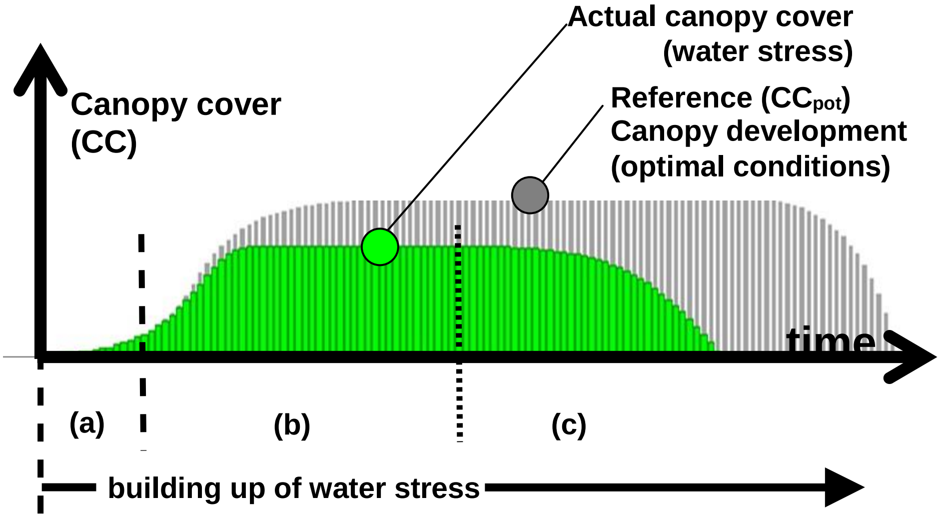


Figure 3.2.3b Simulation of the green canopy cover (CC) when water stress builds during the crop cycle with reference to the canopy development for non-stressed conditions (CC_{pot}). With indication of periods (a) no effect of water stress on canopy development; (b) water stress affecting leaf expansion; (c) water stress triggering early canopy decline

Other stresses considered by Aquacrop affecting CC are:

- air temperature stress. The effect of air temperature on canopy development is simulated by running AquaCrop in growing degree days (GDD). For the purpose of GDD calculations, a base temperature (below which crop development does not progress) and an upper temperature (above which the crop development no longer increases) are required;
- soil salinity stress. Since soil salinity reduces the availability of the water in the root zone reservoir, the presence of dissolved salts increases the effect of soil water stress. This is simulated in AquaCrop by moving the thresholds in Fig. 3.2.2b closer to Field Capacity;
- Mineral nutrient stress. AquaCrop does not simulate nutrient cycles and balance but provides a set of soil fertility stress coefficients (Ks), to simulate the effect of soil fertility on the growing capacity of the crop and the maximum canopy cover (CC_x) that can be reached at mid-season. A distinction is made between a soil fertility coefficient for leaf expansion ($Ks_{exp,f}$) which reduces CGC and a soil fertility coefficient for maximum canopy cover (Ks_{CCx}) which reduces CC_x. Next to the effect on leaf expansion and maximum canopy cover, AquaCrop simulates a steady decline of the canopy cover once CC_x is reached (Fig. 1.2f). The average daily decline is given by a decline factor ($f_{CDecline}$).

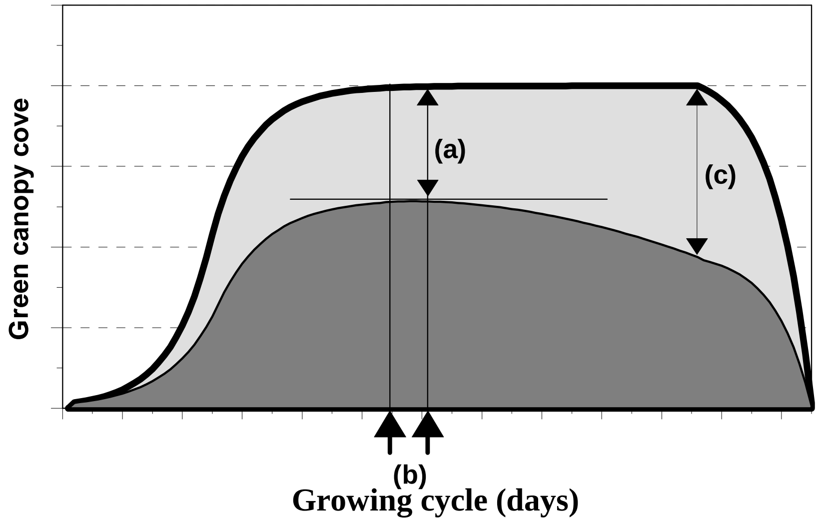


Figure 3.2.3c Green canopy cover (CC) for unlimited (light shaded area) and limited (dark shaded area) soil fertility with indication of the processes resulting in (a) a less dense canopy cover, (b) a slower canopy development, and (c) a steady decline of CC once the maximum canopy cover is reached

3.2.4 Step 3 – simulation of crop transpiration (Tr)

Crop transpiration (Tr) is calculated by multiplying the evaporating power of the atmosphere with the crop coefficient (Kcb) and by considering water stresses (Ks):

$$Tr = Ks\ (Kcb_x\ CC\ ^*)\ ETo \qquad \text{(Eq. 3.2.4)}$$

where the evaporating power (ET_o) is expressed by the reference grass evapotranspiration as determined by the FAO Penman-Monteith equation. The crop transpiration coefficient (Kcb) is proportional to the fractional canopy cover (CC) and as such continuously adjusted to the simulated canopy development. The proportional factor (Kcb_x) integrates all the effects of characteristics that distinguish the crop transpiration from the grass reference surface. As the crop develops, Kcb_x is adjusted for aging and senescence effects. In Eq. 1.2a, CC is replaced by CC^* to account for interrow micro advection which makes extra energy available for crop transpiration. When canopy cover is not complete the contribution is substantial (Fig. 3.2.4a).

Either a shortage or an excess of water in the root zone might reduce crop transpiration. This is simulated by considering water stress coefficients (Ks). When water shortage in the root zone provokes stomatal closure a stress coefficient for stomata closure (Ks_{sto}) is considered. When the excess of water results in anaerobic conditions, the effect of stress on transpiration is expressed by the coefficient for water logging (Ks_{aer}). According to the general rule in AquaCrop, the water stress coefficients range between 1, when water stress is non-existent and 0, when the stress is at its full strength and crop transpiration is completely halted. The simulation of crop transpiration affected by water stress during the crop cycle is presented in Figure 3.2.4b

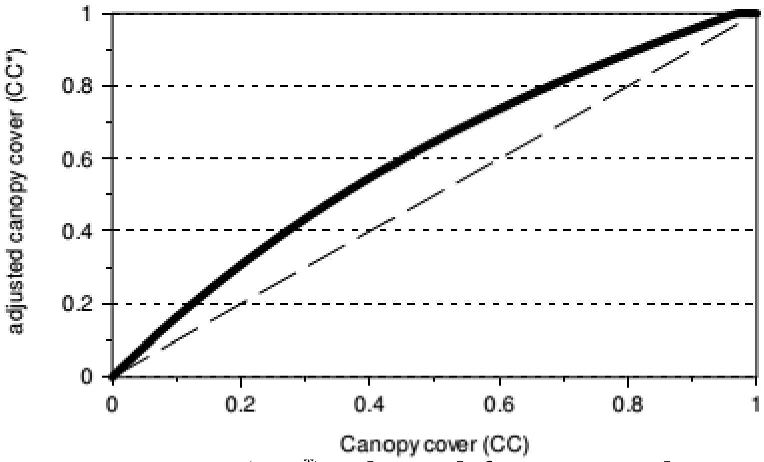


Figure 3.2.4a Canopy cover (CC^{*}) adjusted for micro-advective effects (bold line) for various fractions of green canopy cover (CC)

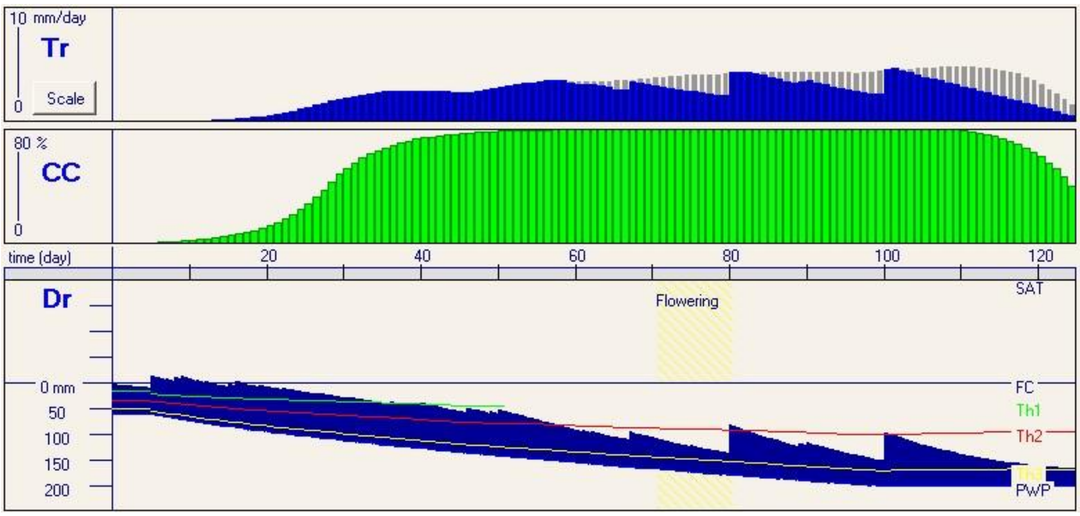


Figure 3.2.4b Simulated root zone depletion (Dr), green canopy cover (CC) and crop transpiration (Tr) throughout the crop cycle with indication of the soil water thresholds affecting canopy development (Th1), inducing stomata closure (Th2), and triggering early canopy senescence (Th3)

3.2.5 Step 4 – simulation of the above-ground biomass (B)

The crop water productivity (WP) expresses the aboveground dry matter (g or kg) produced per unit land area (m^2 or ha) per unit of water transpired (mm). Many experiments have shown that the relationship between biomass produced and water consumed by a given species is highly linear for a given climatic condition (Eq. 3.2.5).

$$B = WP \cdot \Sigma Tr \qquad \text{Eq. 3.2.}$$

To correct for the effect of the climatic conditions, AquaCrop uses the normalized water productivity (WP^*) for the simulation of aboveground biomass. The goal of the normalization is to make WP applicable to diverse location and seasons, including future climate scenarios. The normalization consists in a normalizing for:

- the atmospheric CO_2 concentration. The normalization for CO_2 consists in considering the crop water productivity for an atmospheric CO_2 concentration of 369.41 ppm (parts per million by volume). The reference value of 369.41 is the average atmospheric CO_2 concentration for the year 2000 measured at Mauna Loa Observatory in Hawaii (USA);
- the evaporative demand of the atmosphere. The normalization for climate is obtained by dividing the daily amount of water transpired (Tr) with the reference evapotranspiration (ET_o) for that day:

After normalization, recent findings indicate that crops can be grouped in classes having a similar WP^*, which are depicted in Fig. 1.2i. Distinction can be made between C4 crops with a WP^* of about 30 to 35 g/m^2 (or 0.30 to 0.35 ton per ha) and C3 crops with a WP^* of about 15 to 20 g/m^2 (or 0.15 to 0.20 ton per ha).

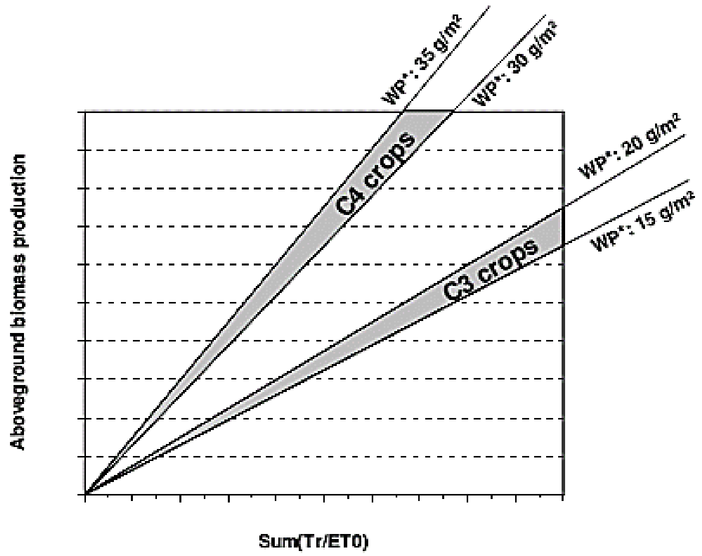


Figure 3.2.5a The relationship between the aboveground biomass and the total amount of water transpired for C3 and C4 crops after normalization for CO_2 and ET_o

The aboveground biomass production for every day of the crop cycle is obtained by multiplying the WP* with the ratio of crop transpiration to the reference evapotranspiration for that day (Tr/ET_o). The production of biomass might be hampered when the air temperature is too cool irrespectively of the transpiration rate and ETo on that day. This is simulated in AquaCrop by considering a temperature stress coefficient (Ks_b):

$$B = Ks_b \, WP^* \sum_i \frac{Tr_i}{ETo_i} \qquad \text{(Eq. 3.2.5)}$$

If the growing degrees generated in a day drops below an upper threshold, full conversion of transpiration to biomass production can no longer be achieved and Ks_b becomes smaller than 1 and might even reach zero when it becomes too cold to generate any growing degrees. The simulated biomass production throughout the crop cycle for the canopy development and crop transpiration in Fig. 3.2.5a is presented in Figure 3.2.5b.

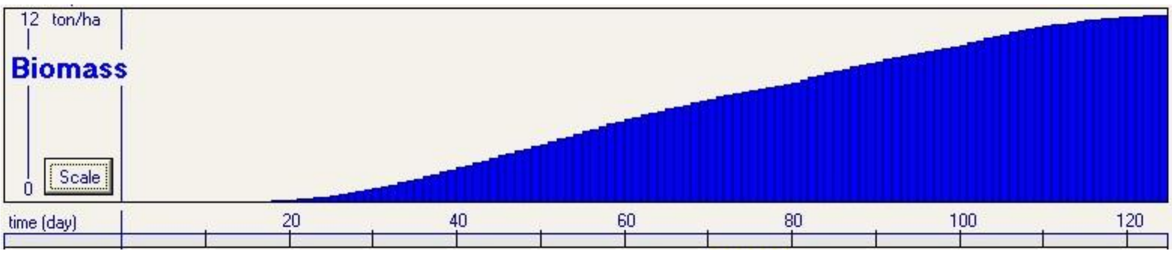


Figure 3.2.5b Simulated biomass production throughout the crop cycle for the canopy development and crop transpiration presented in Fig. 3.2.4a

During the simulation, the normalized WP^* might be adjusted to consider:

- atmospheric CO_2 concentration different from its 369.41 ppm reference value (i.e. the concentration for the year 2000 at Mauna Loa Observatory in Hawaii). This is simulated by multiplying WP* with a correction factor. The correction factor is larger than 1 for CO_2 concentrations above 369.41 ppm, and smaller than 1 for CO_2 concentrations below the reference value;
- the type of products that are synthesized during yield formation. If they are rich in lipids or proteins, considerable more energy per unit dry weight is required then for the synthesis of carbohydrates. As a consequence, the water productivity during yield formation needs to be reduced. This is simulated by multiplying WP* with a reduction coefficient for the products synthesized;
- limited soil fertility. Since soil fertility stress might decrease the crop water productivity, the effect of stress is simulated with the help of the soil fertility stress coefficient for crop water productivity (Ks_{WP}) which varies between 1 and 0. As long as soil fertility does not affect the process, Ks_{WP} is 1 and WP* is not adjusted.

3.2.6 Step 5 – partitioning of biomass (B) into yield (Y)

Starting from flowering or tuber initiation the Harvest Index (HI) gradually increases to reach its reference value (HI_o) at physiological maturity (Fig. 3.2.6). A too short grain/fruit filling stage or tuber formation stage as a result of early canopy senescence might result in inadequate photosynthesis and a reduction of the reference Harvest Index. For leafy vegetable crops, HI builds up right after germination and reaches quickly HI_o.

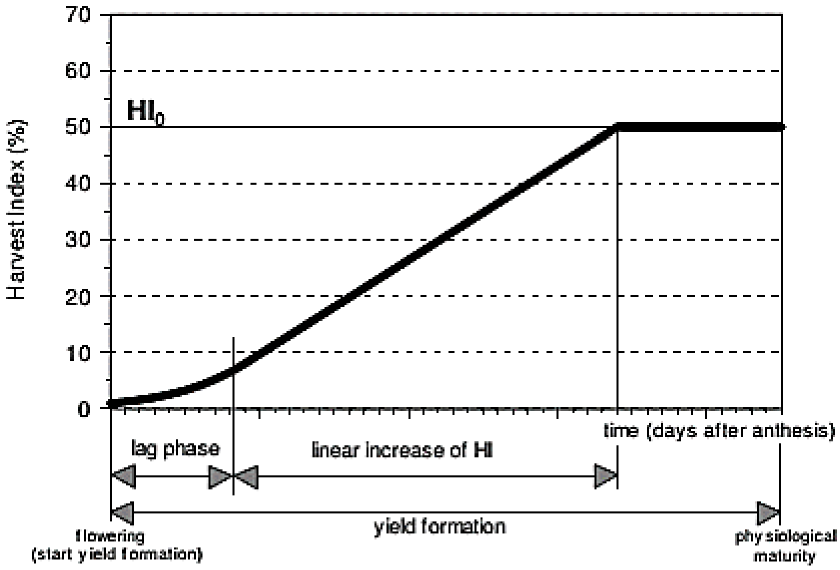


Figure 3.2.6 Building up of Harvest Index from flowering till physiological maturity for fruit and grain producing crops

Yield (Y) is obtained by multiplying the above ground biomass (B) with the adjusted reference Harvest Index:

$$Y = f_{HI}\, HI_o\, B \qquad \text{(Eq. 3.2.6)}$$

Where f_{HI} is a multiplier which considers the stresses that adjust the Harvest Index from its reference value. The adjustment of the Harvest Index to water deficits and air temperature depends on the timing and extent of stress during the crop cycle. The effect of stress on the Harvest Index can be positive or negative. The distinction is made between stresses before the start of the yield formation, during flowering which might affect pollination, and during yield formation.

3.2.7 Input requirement

AquaCrop uses a relatively small number of explicit parameters and largely intuitive input variables, either widely used or requiring simple methods for their determination. Input consists of weather data, crop and soil characteristics, and management practices that define the environment in which the crop will develop (Figure 3.2.7) The inputs are stored in climate, crop, soil and management files and can be easily adjusted through the user interface.

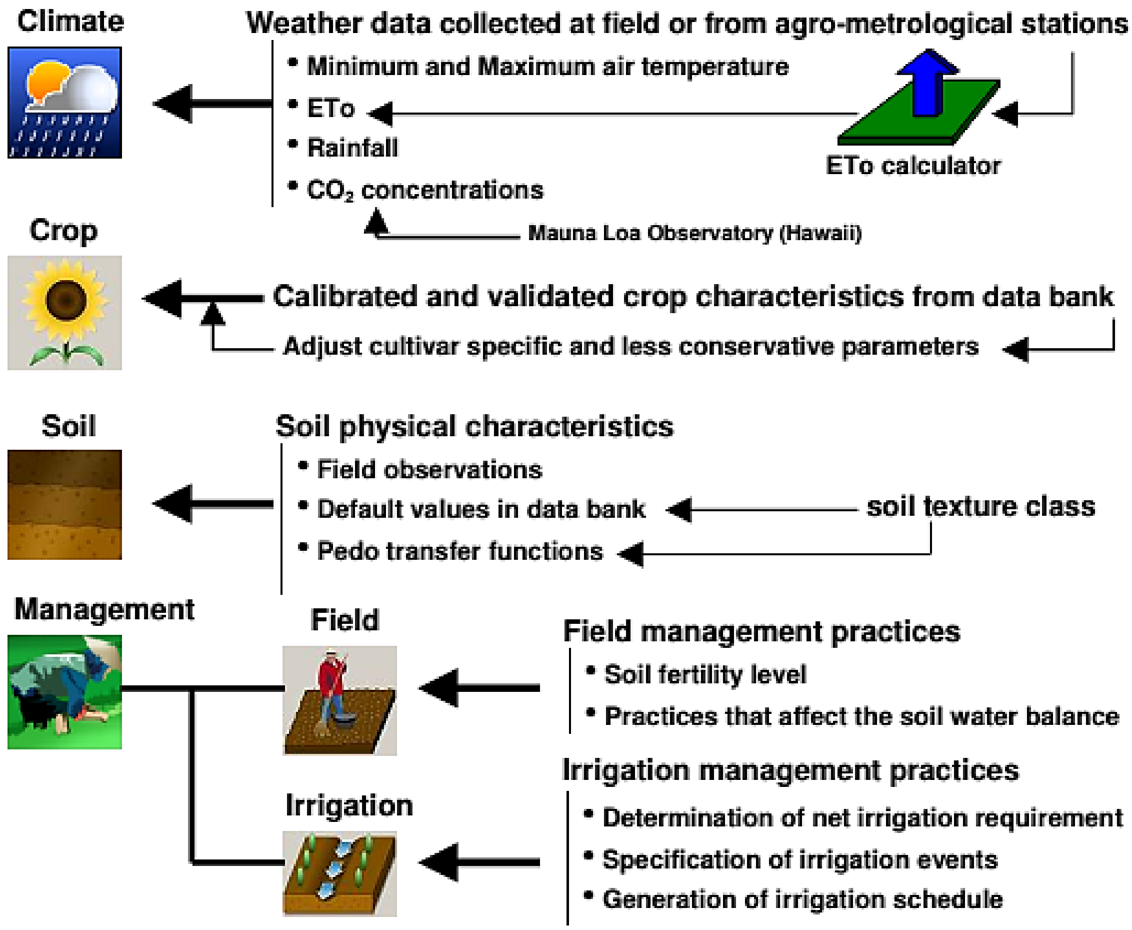


Figure 3.2.7 Input data defining the environment in which the crop will develop.

3.2.7.1 Weather data

For each day of the simulation period, AquaCrop requires minimum (T_n) and maximum (T_x) air temperature, reference evapotranspiration (ET_o) as a measure of the evaporative demand of the atmosphere, and rainfall. Additional the mean annual CO_2 concentration has to be known. Temperature affects crop development (phenology), and when limiting, growth and biomass accumulation. Rainfall and ET_o are determinants for the water balance of the root zone and air CO_2 concentration affects crop water productivity.

ET_o is derived from weather station data by means of the FAO Penman-Monteith equation (as defined in the Irrigation and Drainage Paper N° 56). An ETo calculator is available for that purpose. The calculator, which is public domain software, can be downloaded from the FAO website. The climatic data can be given in a wide variety of units, and procedures are available in the calculator to estimate missing climatic data.

The daily, 10-daily or monthly air temperature, ET_o and rainfall data for the specific environment are stored in climate files from where the program retrieves data at run time. In the absence of daily weather data, the program invokes built-in approximation procedures to derive daily temperature, ET_o and rainfall from the 10-daily or monthly means. For rainfall, with its extremely heterogeneous distribution over time, the use of 10-daily or monthly total rainfall data might reduce the accuracy of the simulations.

Additionally, a historical time series of mean annual atmospheric CO_2 concentrations measured at Mauna Loa Observatory in Hawaii, as well as the expected concentrations for the near future are provided in AquaCrop. The data is used to adjust the WP* to the CO_2 concentration of the year for which the simulation is running. The user can enter other future year's CO_2 for prospective analysis of climate change.

3.2.7.2 Crop characteristics

Although grounded in basic and complex biophysical processes, AquaCrop uses a relatively small number of crop parameters describing the crop characteristics. FAO has calibrated crop parameters for major agriculture crops and provides them as default values in the model. When selecting a crop its crop parameters are downloaded. Distinction is made between conservative, cultivar-specific and less conservative parameters:

- The conservative crop parameters do not change materially with time, management practices, or geographical location. They were calibrated with data of the crop grown under favorable and non-limiting conditions and remain applicable for stress conditions via their modulation by stress response functions. As such the conservative parameters require no adjustment to the local conditions and can be used as such in the simulations;
- The cultivar specific crop parameters might require an adjustment when selecting a cultivar-different from the one considered for crop calibration. Less-conservative crop parameters are affected by field management, conditions in the soil profile, or the weather (especially when simulating in

calendar day mode). These parameters might require an adjustment after downloading to account for the local variety and or local environmental conditions.

When a crop is not available in the data bank, a crop file can be created by specifying only the type of crop (fruit or grain producing crops; root and tuber crops; leafy vegetables, or forage crops) and the length of its growth cycle. On the basis of this information, AquaCrop provides defaults or sample values for all required parameters. In the absence of more specific information, these values can be used. Through the user interface the defaults can be adjusted.

3.2.7.3 Soil characteristics

The soil profile can be composed of up to five different horizons of variable depth, each with their own physical characteristics. The considered hydraulic characteristics are the hydraulic conductivity at saturation (K_{sat}) and the soil water content at saturation (θ_{sat}), field capacity (θ_{FC}), and at permanent wilting point (θ_{PWP}). The user can make use of the indicative values provided by AquaCrop for various soil texture classes, or import locally determined or derived data from soil texture with the help of pedo-transfer functions. If a layer blocks the root zone expansion, its depth in the soil profile has to be specified as well.

3.2.7.4 Management practices

Management practices are divided into two categories: field management and irrigation management practices:

- Under field management practices are choices of soil fertility levels, and practices that affect the soil water balance such as mulching to reduce soil evaporation, soil bunds to store water on the field, and tillage practices such as soil ridging or contours reducing run-off of rain water. The fertility levels range from non-limiting to poor, with effects on WP, on the rate of canopy growth, on the maximum canopy cover, and on senescence;
- Under irrigation management, the user chooses whether the crop is rainfed or irrigated. If irrigated, the user can select the application method (sprinkler, drip, or surface), the fraction of surface wetted, and specify for each irrigation event, the irrigation water quality, the timing and the applied irrigation amount. There are also options to assess the net irrigation requirement and to generate

irrigation schedules based on specified time and depth criteria. Since the criteria might change during the season, the program provides the means to test deficit irrigation strategies by applying chosen amounts of water at various stages of crop development. (Dirk RAES, Pasquale STEDUTO, Theodore C. HSIAO, and Elias FERERES. , 2011)

3.3 Modeling zones and sites selection

The study area focuses on Lower Mekong Basin(LMB), especially Northeastern Thailand and Chiang Rai province in the Northern as shown in Figure 3.3.Figure 3.3 is the locations of the total number of Agro-Ecological Zone and the samplings points. There are five zones in LMB and five target areas in the Northeast and the Northern Thailand. There are twenty-eight site selections and consist of 14 paddy rice and 14 corn belt table 2

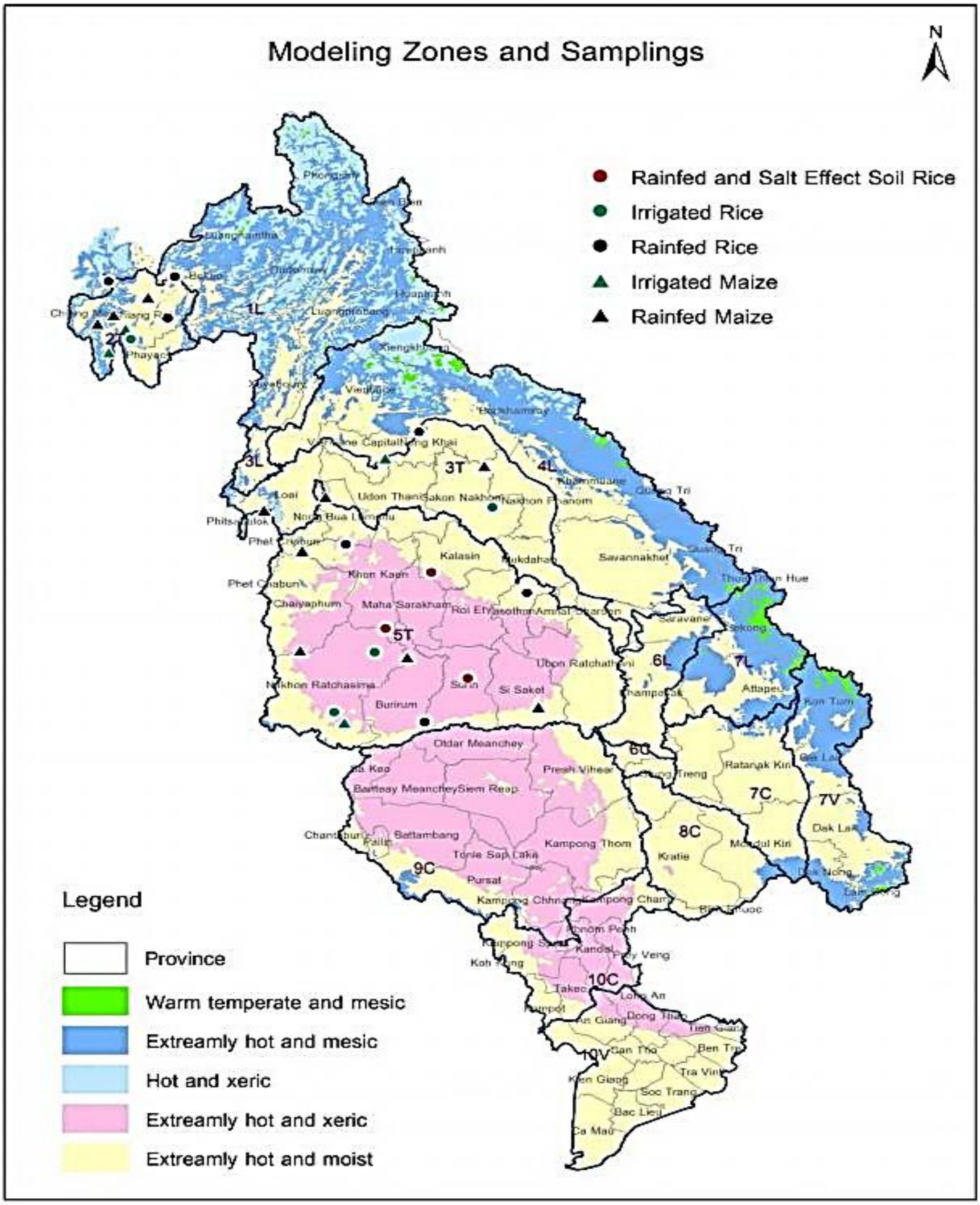


Figure 3.3 Lower Mekong Basin

Table 3.3 14 paddy rice site selections and 14 corn belt site selections.

Rice							
X	**Y**	**District**	**Province**	**UTM WGS 1984**	**Zone_name**	**Sub area code**	**Areas**
838319	1617215	Muang	Nakhon Ratchasima	Zone 47	Extreamly hot and xeric	5T	Irrigated
889563	1704991	Muang	Nakhon Ratchasima	Zone 47	Extreamly hot and xeric	5T	Irrigated
1038710	1916064	Muang Sakon Nakhon	Sakon Nakhon	Zone 47	Extreamly hot and moist	3T	Irrigated
581852	2160296	Phan	Chiang Rai	Zone 47	Extreamly hot and moist	2T	Irrigated
1007231	1666922	Srikhoraphum	Surin	Zone 47	Extreamly hot and xeric	5T	Salt Effect Soil
903584	1739263	Nong Song Hong	Khon Kaen	Zone 47	Extreamly hot and xeric	5T	Salt Effect Soil
960819	1820832	Yang Talat	Kalasin	Zone 47	Extreamly hot and xeric	5T	Salt Effect Soil
952854	1602916	Bankruat	Burirum	Zone 47	Extreamly hot and xeric	5T	Rainfed
1081947	1790900	Thaicharoen	Yasothon	Zone 47	Extreamly hot and moist	5T	Rainfed
853774	1861927	King Nong Na	Khon Kaen	Zone 47	Extreamly hot and xeric	5T	Rainfed
945649	2025083	King Rattana Wapi	Nong Khai	Zone 47	Extreamly hot and moist	3T	Rainfed
628630	2190862	Khun Tan	Chiangrai	Zone 47	Extreamly hot and moist	2T	Rainfed
553935	2244187	Mae Faluang	Chiangrai	Zone 47	Hot and xeric	2T	Rainfed
637619	2251511	Chiang Khong	Chiangrai	Zone 47	Extreamly hot and mesic	2T	Rainfed
Maize							
X	**Y**	**District**	**Province**	**UTM WGS 1984**	**Zone_name**	**Sub area code**	**Areas**
1096443	1624413	Khunhan	Sisaket	Zone 47	Extreamly hot and moist	5T	Rainfed
930976	1696738	Khu Muang	Burirum	Zone 47	Extreamly hot and xeric	5T	Rainfed
795862	1706492	Bamnetnarong	Chaiyaphum	Zone 47	Extreamly hot and xeric	5T	Rainfed
798388	1851864	Phu Phaman	Khon Kaen	Zone 47	Extreamly hot and moist	5T	Rainfed
750424	1910694	Dan Sai	Loei	Zone 47	Hot and xeric	3T	Rainfed
828053	1930068	Na Wang	Nong Bua Lamphu	Zone 47	Extreamly hot and moist	5T	Rainfed
1028379	1974909	Seka	Nong Khai	Zone 47	Extreamly hot and moist	3T	Rainfed
540601	2181995	Mae Saluai	Chiangrai	Zone 47	Extreamly hot and mesic	2T	Rainfed
560959	2194647	Muang Chiang Mai	Chiangrai	Zone 47	Hot and xeric	2T	Rainfed
603995	2220262	King Wiang Chiang Rung	Chiangrai	Zone 47	Extreamly hot and moist	2T	Rainfed
851922	1601441	Khonburi	Nakhon Ratchasima	Zone 47	Extreamly hot and xeric	5T	Irrigated
903252	1986364	Muang Nong Khai	Nong Khai	Zone 47	Extreamly hot and moist	3T	Irrigated
554765	2140847	Wiang Papao	Chiangrai	Zone 47	Extreamly hot and moist	2T	Irrigated
575937	2174621	Phan	Chiangrai	Zone 47	Extreamly hot and moist	2T	Irrigated

3.4 Data collection and preparation

Soil moisture contents were determined by means of pressure membrane apparatus and calculate Field Capacity (FC) and Permanent Wilting Point (PWP) then get Available Water Content (AWC) in soil.

Crop parameters such as time from sowing to germination, full canopy cover, beginning and end of flowering and start of senescence, complete drying, and plant density at harvest were observed and recorded throughout the entire season. Other observations included maximum rooting depth and plant population per hectare at planting based on spacing. Above ground biomass yields were determined on dry weight basis after harvesting and sun drying until constant weight. Grain yield quantities were measured at 14 % moisture content. Daily values of rainfall and minimum and maximum air temperature were recorded with an automatic weather station at each field.

Climate data, the daily ETo was calculated with the Penman-Monteith equation using the FAO ETo calculator (Version 3.1) with daily values of minimum, mean and maximum air temperature as inputs. The missing meteorological data were handled as follows; for wind speed, the ETo calculator default value for light to moderate winds was specified. The calculator handles missing humidity data through estimation by assuming that the minimum air temperature (Tmin) is a good estimate for the mean dew point temperature (Tdew). Soil data, Soil sampling was carried out horizon-wise from 0 to 1 m depth. Horizons were delineated based on homogeneity of color, texture (feel method) and the general appearance. In the laboratory are analyzed soil texture (hydrometer method), organic carbon (Walkley black method). Saturated hydraulic conductivity and water content at saturation, field capacity and wilting point of individual soil horizons was estimated from soil texture and organic carbon content using pedo-transfer functions available in the hydraulic properties calculator. The planting dates presented more possibilities and scenarios for simulation leading to enriched understanding of rainfall onset, planting date and rainfall cessation interactions and effect on both the observed and simulated yields. These included; planting dates, seedling emergence, duration of the various maize physiological periods from sowing date and harvesting dates. Plant population was based on the recommended plant spacing for each site. Given that there were no obvious and significant maize variety differences recommended for each site in their growth and development, all varieties were treated uniformly within each site because of the differences in crop cycle lengths. Canopy cover development of the crop was monitored fortnightly by taking photographs and the shading effect/ground cover analyzed using ERDAS imagine image processing software by percent of shading.

SimCLIM is a software tool designed to facilitate the assessment of risks from climate change for sustainability officers, consultants, policy makers, academics, non-governmental and governmental organizations and students.

SimCLIM uses the latest CMIP5 climate data. Maps, graphs and charts of various aspects of climate change can be generated spatially and for sites, for cities, provinces/states, nations, and the world. The flexibility of SimCLIM is limitless. Now the power to model past and future climate can be in your hands. All of AR5 which includes: Global included (0.5°x0.5° or ca. 50 km x 50km; sea level rise 0.25°x0.25° or ca. 25x25km) All countries/regions/sub regions available (resolution dependent on country area, most 1kmx1km) Specific countries with states are available on request. Downscaled data that is derived from virtually any statistical or dynamical method can be post-processed and added to SimCLIM so it can drive the generation of spatial scenarios as a member of a multi model ensemble.

Outputs can be exported to GIS programs such as ArcGIS and tabular data can be quickly exported to Excel for further analysis and graphing. Data Management: Work areas functionality to ease the management of multiple study areas.

Data: Climate scenarios including minimum, maximum and mean temperature now available with 40 general circulation models to choose from and to apply in ensembles for virtually a place on Earth. Extreme Events: Updated extreme daily precipitation analysis AR5 dataset now with 22 general circulation model patterns.

3.5 Model calibration and validation

Statistical analysis, Model performance was evaluated using the index of agreement root mean square error (RMSE) the coefficient of efficiency (E) and the coefficient of determination (R2). The RMSE represents a measure of the overall mean, deviation between observed and simulated values, that is, a synthetic indicator of the absolute model uncertainty. It takes the same units of the variable being simulated. Values of mean residual and mean relative error close to zero indicate small differences between simulated and observed mean thus indicating little systematic deviation or bias in the entire data set hence the better the model's fit. Values of RMSE close to zero rather express precision and reliability of the simulation for observed estimation points.

The added value of this statistical indicator (E) as compared to RMSE, is in its ability to capture how well the model performs over the whole simulation span, for example, along the season. RMSE does not distinguish between large deviations occurring in some part of the season and small deviations in another part of the season.

AquaCrop calibration was performed with AquaCrop version 5. We mainly focused on total biomass and grain yields, with some attention to canopy cover and soil moisture availability. Canopy cover development over time was considered in order to determine the initial canopy cover immediately after seedling emergence and the maximum canopy cover necessary as input parameters to the model. Further details on the nature of the experiments used on calibration are expected to test in the near future. Soil fertility properties were considered during simulation since blanket fertility management was applied throughout the experiments over the period under consideration. More focus 1,008 experimental unit areas. Model validation from all experiments is expecting to check. These experiments provided sufficient data especially due to the variations in planting dates and the replications in the two or three different agro-climatic regions were considered. The results are presented and discussed by agro-climatic region. For each site, comparisons were made between simulated and measured values of the final grain and biomass yields, canopy cover and SWC at intervals over the growing season.

Evaluation of simulation results in menu

When running a simulation, users can evaluate the simulation results with the help of field data stored in an observation file. The user gets access to the *Evaluation of simulation results* menu by selecting the <Field data> command in the command panel of the *Simulation run* menu (Fig. 3.5a).

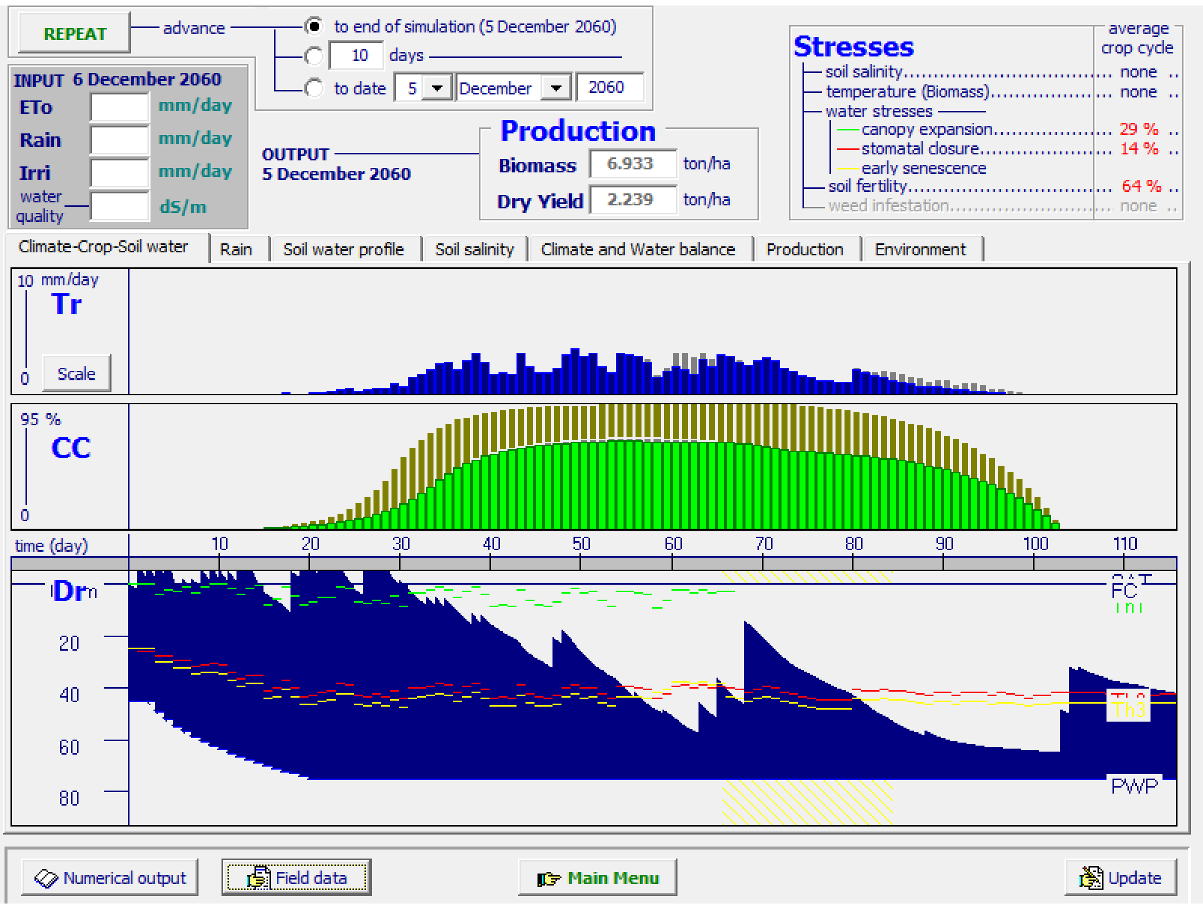


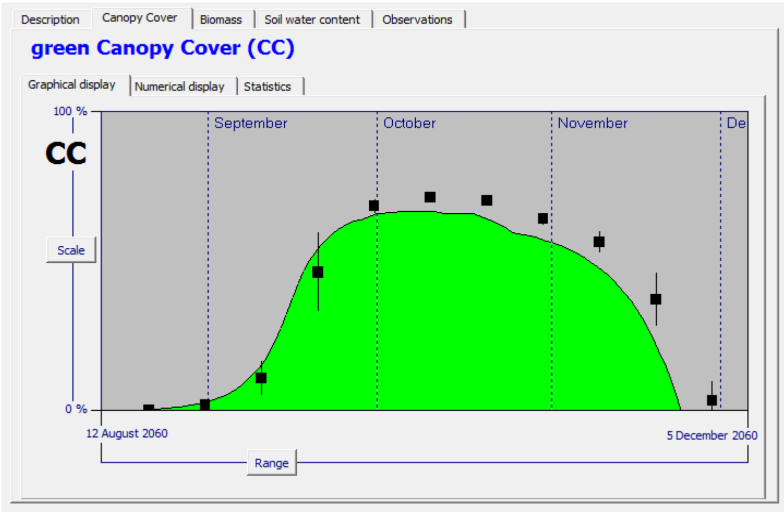
Figure 3.5a The *Simulation run* menu with the <Field data> command in the command panel

- Graphical and numerical
  displays for each of the 3 sets of field observations (Canopy Cover, Biomass and Soil water content) the user finds in the *Evaluation of simulation results* menu:
  1. A graphical display where the simulated and observed (with their standard deviations) values are plotted (Fig. 3.5b);
  2. A numerical display where the simulated and observed values (with their standard deviations)are displayed; and
  3. Statistical indicators evaluating the simulation results (Fig. 3.5c).

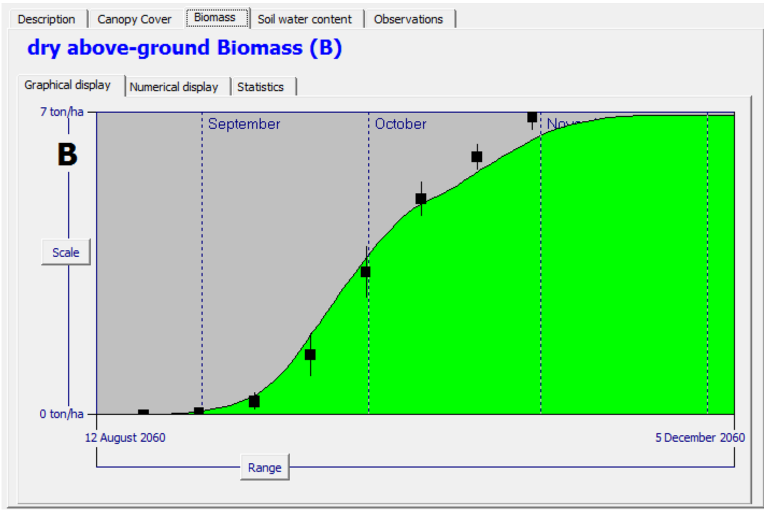
- Save results
  On exit of the Simulation Run menu, the option is available to save the evaluation of the simulation results in 2 output files (Fig. 3.5d): Data output file: which contain for each day of the simulation period the simulated green canopy cover (CC), biomass (B) and soil water content (SWC), and the observed field data (with their standard deviation); Statistics output file: which contain the statics of the evaluation of the simulation results for Canopy Cover, biomass and soil water content (see section 3.5b).

• Statistical indicators
The statistical indicators (see section 3.5b) available to assess the simulation results with field data
are:

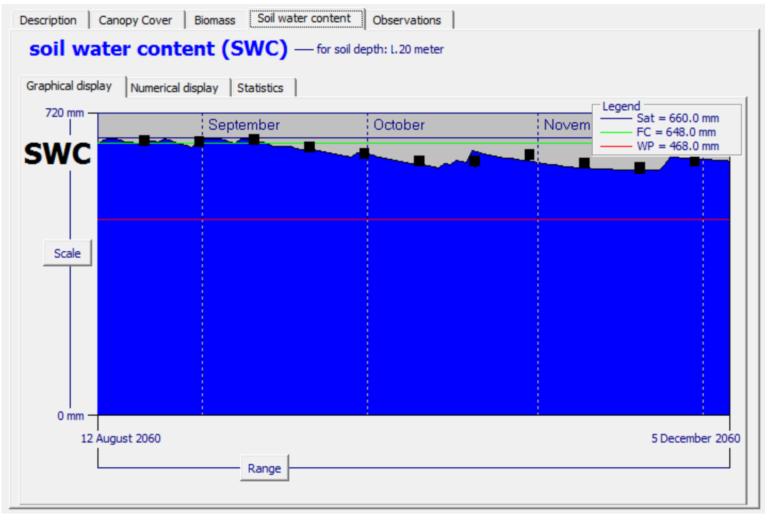
− Pearson correlation coefficient (r);
− Root mean square error (RMSE);
− Normalized root means square error (CV(RMSE));
− Nash-Sutcliffe model efficiency coefficient (EF);
− Wilmott's index of agreement (d).



A.



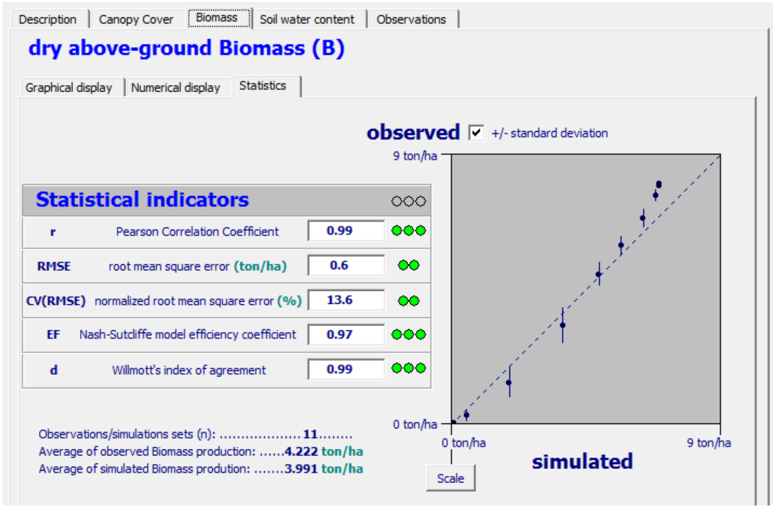
B.



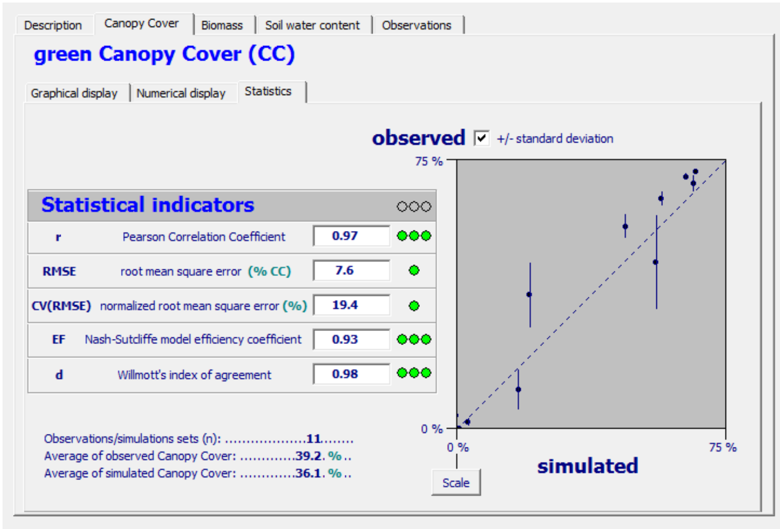
C.

Figure 3.5b Simulated (line) and observed (dots) **A.** green canopy cover **B.** dry above-ground Biomass **C.** soil water content with their standard deviations (vertical lines) in the *Evaluation of simulation results* menu.

A.



B.



C.

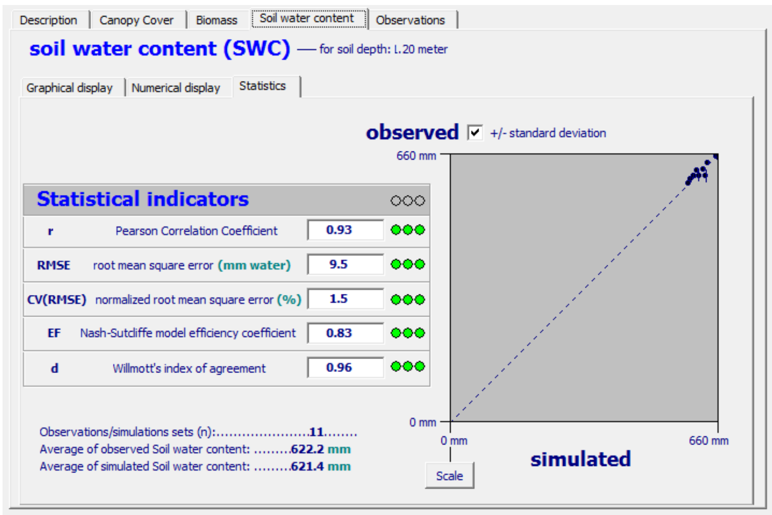


Figure 3.5c Statistical indicators for the assessment of the simulated **A.** green canopy cover **B.** dry above-ground Biomass **C.** soil water content dry above-ground Biomass in the *Evaluation of simulation results* menu

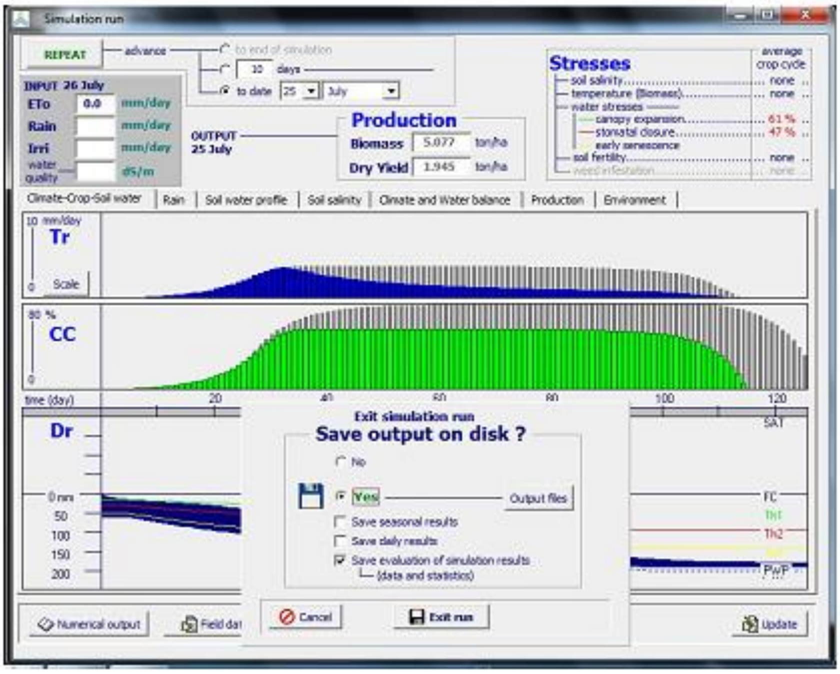


Figure 3.5d Presented options for saving output on disk when exiting the *Simulation run* menu.

Statistical indicators

Evaluation of model performance is important to provide a quantitative estimate of the ability of the model to reproduce an observed variable, to evaluate the impact of calibrating model parameters and compare model results with previous reports (Krause et al., 2005). Several statistical indicators are available to evaluate the performance of a model (Loague and Green,1991). Each has its own strengths and weaknesses, which means that the use of an ensemble of different indicators is necessary to sufficiently assess the performance of the model (Willmott,1984; Legates and McCabe, 1999). In the equations 15a to 15e, Oi and Pi are the observations and predictions respectively, $\bar{O}$ and $\bar{P}$ their averages and n the number of observations.

Pearson correlation coefficient (r)

The Pearson correlation coefficient ranges from -1 to 1, with values close to 1 indicating a good agreement:

$$= \left[\frac{\sum(O_i-\bar{O})(P_i-\bar{P})}{\sqrt{\sum(O_i-\bar{O})^2\sum(P_i-\bar{P})^2}}\right] \qquad \text{(Eq. 3.5a)}$$

A major drawback of r and its squared value (r^2) is that only the dispersion is quantified, which means that a model which systematically overestimates (or underestimates) the observations can still have a good r^2 value (Krause et al., 2005). Willmott (1982) also stated that within the context of atmospheric sciences both r and r^2 are insufficient and often misleading when used to evaluate model performance. Analysis of the residual error (the difference between model predictions and observations: Pi – Oi) is judged to contain more appropriate and insightful information.

The correlation coefficient (r) ranges from -1 to 1, with values close to 1 indicating a good agreement. The following interpretation for r is used in AquaCrop. It is somewhat arbitrary and hence should be regarded as an indication.

Value for r	Interpretation	Color code
≥ 0.90	Very good	●●●
0.80 – 0.89	Good	●●
0.70 – 0.79	Moderate good	●
0.50 – 0.69	Moderate poor	●
0 – 0.49	Poor	●●
< 0	Very poor	●●●

Root Mean Square Error (RMSE)

The root mean square error or RMSE is one of the most widely used statistical indicators (Jacovidesand Kontoyiannis, 1995) and measures the average magnitude of the difference between predictions and observations. It ranges from 0 to positive infinity, with the former indicating good and the latter poor model performance. A big advantage of the RMSE is that it summarizes the mean difference in the units of P and O. It does however not differentiate between over- and underestimation.

$$RMSE = \sqrt{\frac{\sum (P_i - O_i)^2}{n}} \qquad \text{(Eq. 3.5b)}$$

A disadvantage of RMSE is the fact that the residual errors are calculated as squared values, which has the result that higher values in a time series are given a larger weight compared to lower values (Legates and McCabe, 1999) and that the RMSE is overly sensitive to extreme values or outliers (Moriasi et al., 2007). This is in fact a weakness of all statistical indicators where the residual variance is squared, including EF and Willmott's d which are discussed below. Normalized Root Mean Square Error (CV(RMSE)) Because RMSE is expressed in the units of the studied variable, it does not allow model testing under a wide range of meteo-climatic conditions (Jacovides and Kontoyiannis, 1995). Therefore, RMSE can be normalized using the mean of the observed values (). The normalized RMSE (CV(RMSE)) is expressed as a percentage and gives an indication of the relative difference between model and observations.

$$CV(RMSE) = \frac{1}{\bar{O}} \sqrt{\frac{\sum (P_i - O_i)^2}{n}} \, 100$$

(Eq. 3.5c)

A simulation can be considered excellent if CV(RMSE) is smaller than 10%, good if between 10 and 20%, fair if between 20 and 30% and poor if larger than 30% (Jamieson, 1991).

The following interpretation for CV(RMSE) (and the corresponding RMSE) is used in AquaCrop. It is somewhat arbitrary and hence should be regarded as an indication.

Value for NRMSE	Interpretation	Color code
$\leq 5\%$	Very good	●●●
6 – 15%	Good	●●
16 – 25%	Moderate good	●
26 – 35%	Moderate poor	●
36 – 45%	Poor	●●
$> 46\%$	Very poor	●●●

Nash-Sutcliffe model efficiency coefficient (EF)

The Nash-Sutcliffe model efficiency coefficient (EF) determines the relative magnitude of the residual variance compared to the variance of the observations (Nash and Sutcliffe, 1970). Another way to look at it is to say that EF indicates how well the plot of observed versus simulated data fits the 1:1 line (Moriasi et al., 2007). EF can range from minus infinity to 1. An EF of 1 indicates a perfect match between the model and the observations, an EF of 0 means that the model predictions are as accurate as the average of the observed data and a negative EF occurs when the mean of the observations is a better prediction than the model.

$$EF = 1 - \frac{\sum (P_i - O_i)^2}{\sum (O_i - \bar{O})^2}$$

(Eq. 3.5d)

EF is very commonly used, which means that there is a large number of reported values available in literature (Moriasi et al., 2007). However, like r^2, EF is not very sensitive to systematic over- or underestimations by the model (Krause et al., 2005).

The Nash-Sutcliffe efficiency coefficient (EF) can range from minus infinity to 1. An EF of 1 indicates a perfect match between the model and the observations, an EF of 0 means that the model predictions are as accurate as the average of the observed data and a negative EF occurs when the mean of the observations is a better prediction the model. The following interpretation for EF is used in AquaCrop. It is somewhat arbitrary and hence should be regarded as an indication.

Value for EF	Interpretation	Color code
≥ 0.80	Very good	●●●
0.60 – 0.79	Good	●●
0.40 – 0.59	Moderate good	●
0 – 0.39	Moderate poor	●
(-10) – 0	Poor	●●
< (-10)	Very poor	●●●

Willmott’s index of agreement (d)

The index of agreement was proposed by Willmott (1982) to measure the degree to which the observed data are approached by the predicted data. It represents the ratio between the mean square error and the “potential error”, which is defined as the sum of the squared absolute values of the distances from the predicted values to the mean observed value and distances from the observed values to the mean observed value (Willmott, 1984). It overcomes the insensitivity of r^2 and EF to systematic over- or underestimations by the model (Legates and McCabe, 1999; Willmott, 1984). It ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the predicted and observed data.

$$d = 1 - \frac{\sum (P_i - O_i)^2}{\sum \left(|P_i - \bar{O}| + |O_i - \bar{O}| \right)^2} \qquad \text{(Eq. 3.5e)}$$

A disadvantage of d is that relatively high values may be obtained (over 0.65) even when the model performs poorly and that despite the intentions of Willmott (1982) d is still not very sensitive to systemic over- or underestimations (Krause et al., 2005).

The Wilmott's index of agreement (d) ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the predicted and observed data. The following interpretation for d is used in AquaCrop. It is somewhat arbitrary and hence should be regarded as an indication.

Value for d	Interpretation	Color code
≥ 0.9	Very good	●●● (green)
0.80 – 0.89	Good	●● (green)
0.65 – 0.79	Moderate good	● (green)
0.50 – 0.64	Moderate poor	● (red)
0.25 – 0.49	Poor	●● (red)
< 0.25	Very poor	●●● (red)

3.6 Climate change scenarios and the impact assessment

This project focused on: Synthesize climate change trends in Thailand from available climate scenarios; Review existing state of knowledge on climate change impacts and risks in Thailand; Summarize climate scenario data in an easy-to-use format which was made available for further studies on climate change impacts; Establish a mechanism to disseminate data and information to support climate change studies and assessments on the impact of climate change in Thailand.

The results of these analyses suggest that the future climate in Thailand and surrounding countries will get warmer, have a longer summer time, a shorter and warmer wintertime and a rainy season with higher intensity of rainfall resulting in higher annual total precipitation. These changes are unlikely to be irreversible and would have an impact on various systems and sectors. High-resolution climate scenarios from long-term climate projections can be used to assess the impact of climate change in various sectors as well as to support long-term planning. However, a climate scenario is only a reliable future and cannot be taken as a long-term forecast. There is a certain degree of uncertainty in this method. One way to cope with the uncertainty of long-term climate projections is the use of multiple scenarios, which are developed using various climate models or under different conditions. Climate Change Data Distribution System has been developed and opens for technical users, who need future climate data for their research purposes, to extract data and download via the internet. That is the best way to subscribe by everyone who needs data.

4. AquaCrop modeling for representative sites

4.1Data collection and model setup

Table 4.1 Data collection and model setup

Plant	X	Y	Province	District	Areas	crop					
						Name	Mode	Initial canopy cover	Fertillity stress	calendar	
									Biomass	Day 1 aftertransplanting	Maturity
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	Paddyrice	calendar days	small	poor	12 August	5 december
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	Paddyrice	calendar days	small	poor	12 August	5 december
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	Paddyrice	calendar days	small	poor	12 August	5 december
	581852	2160296	Chiang Rai	Phan	Irrigated	Paddyrice	calendar days	small	poor	12 August	5 december
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	Paddyrice	calendar days	small	poor	12 August	5 december
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	Paddyrice	calendar days	small	poor	12 August	5 december
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	Paddyrice	calendar days	small	poor	12 August	5 december
	952854	1602916	Burirum	Bankruat	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
	628630	2190862	Chiangrai	Khun Tan	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	Paddyrice	calendar days	small	poor	12 August	5 december
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	930976	1696738	Burirum	Khu Muang	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	750424	1910694	Loei	Dan Sai	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	1028379	1974909	Nong Khai	Seka	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	Maize	calendar days	good	poor	1 April	10 August
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	Maize	calendar days	good	poor	1 April	10 August
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	Maize	calendar days	good	poor	1 April	10 August
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	Maize	calendar days	good	poor	1 April	10 August
	575937	2174621	Chiangrai	Phan	Irrigated	Maize	calendar days	good	poor	1 April	10 August

Table 4.1 cont. Data collection and model setup

Plant	X	Y	Province	District	Areas	Irrigation					
						Mode	Irrigation method	Time and depth criteria			
								Day no.	Interval days	Depth (mm.)	Water quality (dS/m)
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	for going cycle	Furrow	1	10	50	0.5
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	for going cycle	Furrow	1	10	50	0.5
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	for going cycle	Furrow	1	10	50	0.5
	581852	2160296	Chiang Rai	Phan	Irrigated	for going cycle	Furrow	1	10	50	0.5
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	-	-	-	-	-	-
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	-	-	-	-	-	-
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	-	-	-	-	-	-
	952854	1602916	Burirum	Bankruat	Rainfed	-	-	-	-	-	-
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	-	-	-	-	-	-
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	-	-	-	-	-	-
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	-	-	-	-	-	-
	628630	2190862	Chiangrai	Khun Tan	Rainfed	-	-	-	-	-	-
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	-	-	-	-	-	-
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	-	-	-	-	-	-
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	-	-	-	-	-	-
	930976	1696738	Burirum	Khu Muang	Rainfed	-	-	-	-	-	-
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	-	-	-	-	-	-
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	-	-	-	-	-	-
	750424	1910694	Loei	Dan Sai	Rainfed	-	-	-	-	-	-
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	-	-	-	-	-	-
	1028379	1974909	Nong Khai	Seka	Rainfed	-	-	-	-	-	-
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	-	-	-	-	-	-
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	-	-	-	-	-	-
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	-	-	-	-	-	-
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	for going cycle	Furrow	1	7	30	0.5
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	for going cycle	Furrow	1	7	30	0.5
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	for going cycle	Furrow	1	7	30	0.5
	575937	2174621	Chiangrai	Phan	Irrigated	for going cycle	Furrow	1	7	30	0.5

Table 4.1 cont. Data collection and model setup

Plant	X	Y	Province	District	Areas	Field manage		
						Soil fertility	Mulches	
						Biomass product	Soil cover by mulches	Type of surface mulches
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	poor	significant	organic plant maturials
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	poor	significant	organic plant maturials
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	poor	significant	organic plant maturials
	581852	2160296	Chiang Rai	Phan	Irrigated	poor	significant	organic plant maturials
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	poor	significant	organic plant maturials
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	poor	significant	organic plant maturials
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	poor	significant	organic plant maturials
	952854	1602916	Burirum	Bankruat	Rainfed	poor	significant	organic plant maturials
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	poor	significant	organic plant maturials
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	poor	significant	organic plant maturials
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	poor	significant	organic plant maturials
	628630	2190862	Chiangrai	Khun Tan	Rainfed	poor	significant	organic plant maturials
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	poor	significant	organic plant maturials
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	poor	significant	organic plant maturials
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	poor	significant	organic plant maturials
	930976	1696738	Burirum	Khu Muang	Rainfed	poor	significant	organic plant maturials
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	poor	significant	organic plant maturials
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	poor	significant	organic plant maturials
	750424	1910694	Loei	Dan Sai	Rainfed	poor	significant	organic plant maturials
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	poor	significant	organic plant maturials
	1028379	1974909	Nong Khai	Seka	Rainfed	poor	significant	organic plant maturials
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	poor	significant	organic plant maturials
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	poor	significant	organic plant maturials
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	poor	significant	organic plant maturials
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	poor	significant	organic plant maturials
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	poor	significant	organic plant maturials
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	poor	significant	organic plant maturials
	575937	2174621	Chiangrai	Phan	Irrigated	poor	significant	organic plant maturials

Table 4.1 cont. Data collection and model setup

Plant	X	Y	Province	District	Areas	Soil profile	Groundwater		Initial condition
							Groundwater table		Soil salinity profile
							Depth below soil surface (m)	Salinity (dS/m)	Ece (dS/m)
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	Sandy Loam	-	-	-
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	Sandy Loam	-	-	-
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	Sandy Loam	-	-	-
	581852	2160296	Chiang Rai	Phan	Irrigated	Clay	-	-	-
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	Sandy Loam	0.3	8	12
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	Sandy Loam	0.5	10	12
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	Sandy Loam	0.7	16	12
	952854	1602916	Burirum	Bankruat	Rainfed	Sandy Loam	-	-	-
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	Sandy Loam	-	-	-
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	Sandy Loam	-	-	-
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	Loam	-	-	-
	628630	2190862	Chiangrai	Khun Tan	Rainfed	Clay	-	-	-
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	Clay	-	-	-
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	Clay	-	-	-
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	Clay	-	-	-
	930976	1696738	Burirum	Khu Muang	Rainfed	Sand	-	-	-
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	Clay	-	-	-
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	Clay	-	-	-
	750424	1910694	Loei	Dan Sai	Rainfed	Loam	-	-	-
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	Sandy Loam	-	-	-
	1028379	1974909	Nong Khai	Seka	Rainfed	Clay	-	-	-
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	Clay	-	-	-
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	Clay	-	-	-
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	Loam	-	-	-
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	Sandy Loam	-	-	-
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	Sandy Loam	-	-	-
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	Clay	-	-	-
	575937	2174621	Chiangrai	Phan	Irrigated	Clay	-	-	-

4.2 Result of crop modeling under climate change scenarios

Table 4.2a Representative sites and dry yield projection in the wet condition.

Plant	X	Y	Province	District	Areas	Wet (ton/ha)											
						BL				2030				2060			
						RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5	RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5	RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	1.967	1.967	1.967	1.967	2.404	2.419	2.397	2.463	2.439	2.628	2.632	2.827
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	1.967	1.967	1.967	1.967	2.404	2.419	2.397	2.463	2.439	2.628	2.632	2.827
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	1.969	1.969	1.969	1.969	2.407	2.422	2.399	2.466	2.442	2.631	2.636	2.831
	581852	2160296	Chiang Rai	Phan	Irrigated	1.966	1.966	1.966	1.966	2.402	2.417	2.394	2.458	2.434	2.623	2.627	2.822
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	1.769	1.769	1.769	1.769	2.135	2.148	2.128	2.189	2.102	2.266	2.270	2.442
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	1.731	1.731	1.731	1.731	2.164	2.178	2.157	2.218	2.098	2.262	2.266	2.438
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	1.794	1.794	1.794	1.794	2.254	2.268	2.247	2.312	2.159	2.329	2.332	2.509
	952854	1602916	Burirum	Bankruat	Rainfed	1.967	1.967	1.967	1.967	2.404	2.419	2.396	2.463	2.438	2.627	2.631	2.827
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	1.816	1.816	1.816	1.816	2.385	2.401	2.377	2.447	2.327	2.527	2.531	2.746
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	1.983	1.983	1.983	1.983	2.431	2.446	2.423	2.491	2.403	2.604	2.609	2.822
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	1.672	1.672	1.672	1.672	1.984	1.998	1.977	2.039	1.786	1.948	1.952	2.128
	628630	2190862	Chiangrai	Khun Tan	Rainfed	1.937	1.937	1.937	1.937	2.304	2.319	2.296	2.367	2.202	2.399	2.404	2.622
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	1.930	1.930	1.930	1.930	2.287	2.302	2.279	2.350	2.183	2.379	2.383	2.601
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	1.935	1.935	1.935	1.935	2.298	2.313	2.290	2.361	2.196	2.392	2.397	2.615
			Average			1.886				2.321				2.451			
			Increase (%)							23.069				29.957			
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	2.122	2.122	2.122	2.122	2.524	2.526	2.523	2.535	2.429	2.448	2.449	2.451
	930976	1696738	Burirum	Khu Muang	Rainfed	5.825	5.825	5.825	5.825	6.113	6.122	6.109	6.150	6.134	6.225	6.226	6.294
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	2.122	2.122	2.122	2.122	1.952	1.954	1.952	1.959	1.849	1.861	1.861	1.862
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	0.672	0.672	0.672	0.672	0.782	0.783	0.781	0.786	0.697	0.706	0.706	0.713
	750424	1910694	Loei	Dan Sai	Rainfed	5.863	5.863	5.863	5.863	6.179	6.188	6.175	6.216	6.199	6.290	6.292	6.359
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	5.862	5.862	5.862	5.862	6.176	6.185	6.172	6.212	6.197	6.289	6.290	6.357
	1028379	1974909	Nong Khai	Seka	Rainfed	0.915	0.915	0.915	0.915	0.991	0.993	0.991	0.997	1.023	1.034	1.034	1.042
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	1.927	1.927	1.927	1.927	2.307	2.309	2.306	2.314	2.384	2.408	2.408	2.412
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	2.069	2.069	2.069	2.069	2.455	2.458	2.454	2.465	2.554	2.578	2.578	2.581
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	5.865	5.865	5.865	5.865	6.181	6.190	6.177	6.218	6.203	6.295	6.296	6.364
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	5.866	5.866	5.866	5.866	6.179	6.187	6.175	6.215	6.203	6.295	6.296	6.364
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	5.866	5.866	5.866	5.866	6.183	6.192	6.179	6.219	6.206	6.297	6.299	6.366
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	0.974	0.974	0.974	0.974	1.052	1.054	1.051	1.058	1.062	1.077	1.077	1.087
	575937	2174621	Chiangrai	Phan	Irrigated	0.974	0.974	0.974	0.974	1.051	1.053	1.050	1.057	1.061	1.076	1.076	1.086
			Average			3.352				3.586				3.630			
			Increase (%)							6.994				8.321			

Table 4.2b Representative sites and dry yield projection in the dry condition.

Plant	X	Y	Province	District	Areas	Dry (ton/ha)											
						BL				2030				2060			
						RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5	RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5	RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	1.967	1.967	1.967	1.967	2.406	2.421	2.399	2.463	2.437	2.625	2.630	2.824
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	1.967	1.967	1.967	1.967	2.406	2.421	2.398	2.463	2.437	2.625	2.630	2.824
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	1.978	1.978	1.978	1.978	2.418	2.433	2.411	2.477	2.451	2.640	2.645	2.840
	581852	2160296	Chiang Rai	Phan	Irrigated	1.966	1.966	1.966	1.966	2.402	2.417	2.395	2.459	2.435	2.624	2.628	2.823
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	1.769	1.769	1.769	1.769	2.194	2.207	2.187	2.250	2.215	2.389	2.393	2.572
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	1.731	1.731	1.731	1.731	2.209	2.223	2.202	2.265	2.159	2.327	2.330	2.503
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	1.960	1.960	1.960	1.960	2.400	2.415	2.393	2.459	2.436	2.625	2.629	2.824
	952854	1602916	Burirum	Bankruat	Rainfed	1.967	1.967	1.967	1.967	2.403	2.418	2.396	2.462	2.412	2.603	2.607	2.806
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	1.984	1.984	1.984	1.984	2.452	2.467	2.444	2.512	2.486	2.679	2.683	2.878
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	1.983	1.983	1.983	1.983	2.411	2.426	2.404	2.470	2.443	2.631	2.636	2.830
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	1.665	1.665	1.665	1.665	2.189	2.204	2.181	2.248	2.222	2.418	2.423	2.637
	628630	2190862	Chiangrai	Khun Tan	Rainfed	1.967	1.967	1.967	1.967	2.404	2.418	2.396	2.460	2.436	2.625	2.629	2.824
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	1.966	1.966	1.966	1.966	2.404	2.418	2.396	2.460	2.436	2.625	2.629	2.824
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	1.967	1.967	1.967	1.967	2.404	2.418	2.396	2.460	2.436	2.625	2.629	2.824
			Average			1.917				2.381				2.580			
			Increase (%)							24.189				34.568			
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	2.102	2.102	2.102	2.102	2.277	2.279	2.276	2.285	2.031	2.051	2.051	2.043
	930976	1696738	Burirum	Khu Muang	Rainfed	5.825	5.825	5.825	5.825	6.112	6.121	6.108	6.149	6.134	6.225	6.226	6.294
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	1.550	1.550	1.550	1.550	1.998	1.999	1.997	2.004	1.852	1.859	1.859	1.849
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	0.605	0.605	0.605	0.605	0.640	0.641	0.639	0.643	0.601	0.610	0.610	0.616
	750424	1910694	Loei	Dan Sai	Rainfed	5.863	5.863	5.863	5.863	6.179	6.188	6.175	6.216	6.199	6.290	6.292	6.359
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	5.862	5.862	5.862	5.862	6.176	6.185	6.172	6.213	6.197	6.288	6.290	6.357
	1028379	1974909	Nong Khai	Seka	Rainfed	0.933	0.933	0.933	0.933	1.100	1.101	1.099	1.106	1.090	1.105	1.105	1.115
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	1.612	1.612	1.612	1.612	1.754	1.756	1.753	1.764	1.774	1.799	1.799	1.816
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	2.057	2.057	2.057	2.057	2.439	2.442	2.438	2.449	2.550	2.572	2.572	2.577
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	2.069	2.069	2.069	2.069	2.456	2.458	2.454	2.466	2.558	2.581	2.581	2.587
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	5.865	5.865	5.865	5.865	6.181	6.189	6.176	6.217	6.199	6.291	6.292	6.36
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	5.866	5.866	5.866	5.866	6.179	6.188	6.175	6.216	6.203	6.295	6.297	6.364
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	2.000	2.000	2.000	2.000	2.235	2.238	2.233	2.248	2.090	2.125	2.125	2.145
	575937	2174621	Chiangrai	Phan	Irrigated	2.000	2.000	2.000	2.000	2.234	2.237	2.232	2.247	2.088	2.122	2.123	2.143
			Average			3.158				3.431				3.440			
			Increase (%)							8.650				8.929			

Table 4.2c Representative sites and dry yield projection in the extreme wet and dry condition.

Plant	X	Y	Province	District	Areas	Extream wet/dry (ton/ha)											
						BL				2030				2060			
						RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5	RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5	RCP_2.6	RCP_4.5	RCP_6.0	RCP_8.5
Rice	838319	1617215	Nakhon Ratchasima	Muang	Irrigated	1.966	1.966	1.966	1.966	2.405	2.419	2.397	2.463	2.444	2.633	2.637	2.832
	889563	1704991	Nakhon Ratchasima	Muang	Irrigated	1.966	1.966	1.966	1.966	2.405	2.419	2.397	2.463	2.444	2.633	2.637	2.832
	1038710	1916064	Sakon Nakhon	Muang Sakon Nakhon	Irrigated	1.978	1.978	1.978	1.978	2.421	2.436	2.414	2.481	2.421	2.436	2.414	2.481
	581852	2160296	Chiang Rai	Phan	Irrigated	1.967	1.967	1.967	1.967	2.408	2.423	2.400	2.464	2.450	2.640	2.644	2.840
	1007231	1666922	Surin	Srikhoraphum	Salt Effect Soil	1.631	1.631	1.631	1.631	1.958	1.970	1.952	2.007	1.915	2.067	2.070	2.228
	903584	1739263	Khon Kaen	Nong Song Hong	Salt Effect Soil	1.654	1.654	1.654	1.654	1.999	2.012	1.993	2.048	1.957	2.111	2.115	2.276
	960819	1820832	Kalasin	Yang Talat	Salt Effect Soil	1.660	1.660	1.660	1.660	2.004	2.017	1.998	2.057	1.963	2.119	2.123	2.286
	952854	1602916	Burirum	Bankruat	Rainfed	1.967	1.967	1.967	1.967	2.198	2.213	2.190	2.257	1.567	1.704	1.707	1.925
	1081947	1790900	Yasothon	Thaicharoen	Rainfed	1.984	1.984	1.984	1.984	2.126	2.141	2.119	2.184	1.606	1.746	1.750	1.969
	853774	1861927	Khon Kaen	King Nong Na	Rainfed	1.972	1.972	1.972	1.972	2.192	2.207	2.184	2.250	1.164	1.272	1.274	1.455
	945649	2025083	Nong Khai	King Rattana Wapi	Rainfed	1.665	1.665	1.665	1.665	1.185	1.193	1.181	1.217	0.937	1.028	1.030	1.128
	628630	2190862	Chiangrai	Khun Tan	Rainfed	1.902	1.902	1.902	1.902	1.256	1.265	1.252	1.294	0.777	0.899	0.901	1.039
	553935	2244187	Chiangrai	Mae Faluang	Rainfed	1.902	1.902	1.902	1.902	1.234	1.243	1.229	1.270	0.777	0.899	0.901	1.039
	637619	2251511	Chiangrai	Chiang Khong	Rainfed	1.898	1.898	1.898	1.898	1.256	1.265	1.252	1.294	0.777	0.899	0.901	1.039
			Average			1.865				1.946				1.799			
			Increase (%)							4.336				-3.533			
Maize	1096443	1624413	Sisaket	Khunhan	Rainfed	2.102	2.102	2.102	2.102	2.488	2.489	2.487	2.492	2.302	2.308	2.308	2.302
	930976	1696738	Burirum	Khu Muang	Rainfed	2.102	2.102	2.102	2.102	2.488	2.489	2.488	2.492	2.304	2.311	2.310	2.304
	795862	1706492	Chaiyaphum	Bamnetnarong	Rainfed	1.550	1.550	1.550	1.550	2.488	2.489	1.936	1.941	2.304	2.311	2.310	2.304
	798388	1851864	Khon Kaen	Phu Phaman	Rainfed	0.605	0.605	0.605	0.605	0.643	0.643	0.641	0.646	0.622	0.630	0.630	0.636
	750424	1910694	Loei	Dan Sai	Rainfed	5.863	5.863	5.863	5.863	6.181	6.189	6.176	6.217	6.203	6.295	6.296	6.363
	828053	1930068	Nong Bua Lamphu	Na Wang	Rainfed	5.862	5.862	5.862	5.862	6.179	6.187	6.174	6.215	6.202	6.293	6.295	6.362
	1028379	1974909	Nong Khai	Seka	Rainfed	0.915	0.915	0.915	0.915	0.977	0.978	0.976	0.982	0.994	1.006	1.006	1.014
	540601	2181995	Chiangrai	Mae Saluai	Rainfed	1.927	1.927	1.927	1.927	2.093	2.095	2.092	2.101	2.037	2.052	2.052	2.052
	560959	2194647	Chiangrai	Muang Chiang Rai	Rainfed	1.941	1.941	1.941	1.941	2.108	2.110	2.107	2.115	2.061	2.078	2.078	2.078
	603995	2220262	Chiangrai	King Wiang Chiang Rung	Rainfed	1.903	1.903	1.903	1.903	2.066	2.068	2.066	2.074	2.014	2.029	2.029	2.026
	851922	1601441	Nakhon Ratchasima	Khonburi	Irrigated	5.866	5.866	5.866	5.866	6.179	6.188	6.175	6.216	6.203	6.295	6.296	6.363
	903252	1986364	Nong Khai	Muang Nong Khai	Irrigated	0.650	0.650	0.650	0.650	0.746	0.747	0.745	0.750	0.712	0.722	0.722	0.729
	554765	2140847	Chiangrai	Wiang Papao	Irrigated	0.974	0.974	0.974	0.974	1.046	1.047	1.045	1.052	1.057	1.072	1.072	1.082
	575937	2174621	Chiangrai	Phan	Irrigated	0.974	0.974	0.974	0.974	1.045	1.047	1.044	1.051	1.056	1.070	1.070	1.080
			Average			2.374				2.607				2.602			
			Increase (%)							9.819				9.611			

5. Climate Change Impact on Crop Production

5.1 Rice production

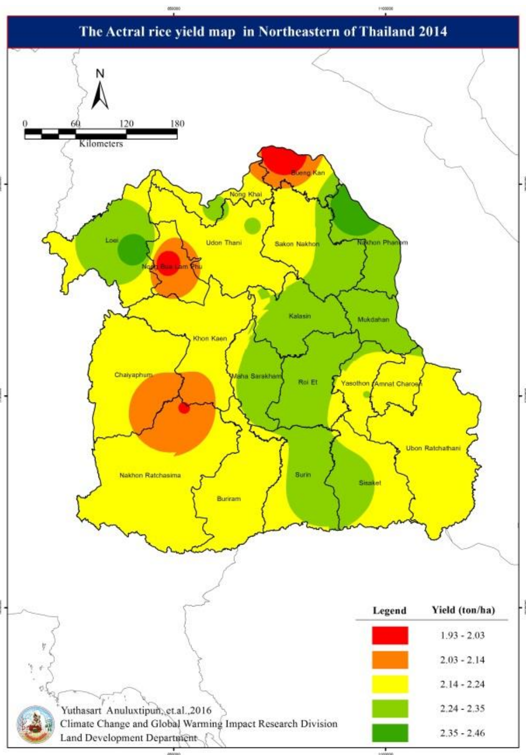
The results show that Rice yield production increases 23.07% (2.32 ton/ha) and 29.96% (2.45 ton/ha) from the baseline yielding (1.89 ton/ha) in wet condition 2030, 2060 respectively. In the dry condition, Rice yield production increases 24.19% (2.38 ton/ha) and 34.57% (2.58 ton/ha) from the baseline yielding (1.92 ton/ha) in 2030, 2060 respectively. In the extreme wet and dry condition, rice yield production slightly increases 4.34% (1.95 ton/ha) in 2030 and slightly decreases 3.53% (1.80 ton/ha) in 2060 from the baseline yielding (1.87 ton/ha). In the extreme wet and dry condition, Not only Nong Khai and Chiang Rai province may have impacted on the yield decreasing in 2030 and 2060, but also Khon Kaen, Yasothon and Burirum province may have impacted on the yield decreasing in 2060 as shown in Table 4.2a, 4.2b and 4.2c.

5.2 Maize production

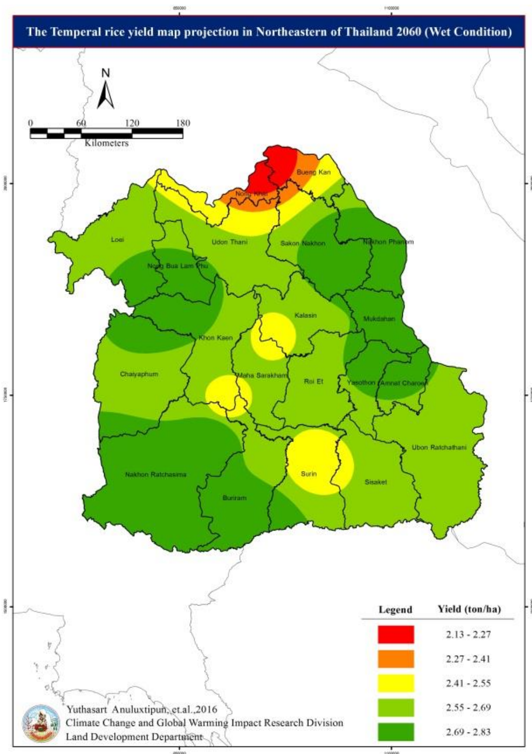
Maize yield production as the same direction of rice yield production shows that increases 6.99% (3.59 ton/ha) and 8.32% (3.63 ton/ha) from the baseline yielding (3.35 ton/ha) in wet condition 2030, 2060 respectively. In the dry condition, Maize yield production increases 8.65% (3.43 ton/ha) and 8.93% (3.44 ton/ha) from the baseline yielding (3.16 ton/ha) in 2030, 2060 respectively. In the extreme wet and dry condition, Maize yield production increases 9.82% (2.61 ton/ha) in 2030 and increases 9.61% (2.60 ton/ha) in 2060 from the baseline yielding (2.37 ton/ha). The conclusion that Rice and Maize production in the North and Northeast of Thailand may have increased yielding more decreased yielding level if they are not lost the production from drought, flood, landslide and land use change. In the wet condition, Chaiyaphum province may have impacted on the yield decreasing in 2030 and 2060. In the dry condition, Sisaket province may have impacted on the yield decreasing in 2060 as shown in Table 4.2a, 4.3b, 4.2c and Figure 5a, 5b, 5c and 5d respectively.

Table 5 Actual yield in 2014 of Thailand

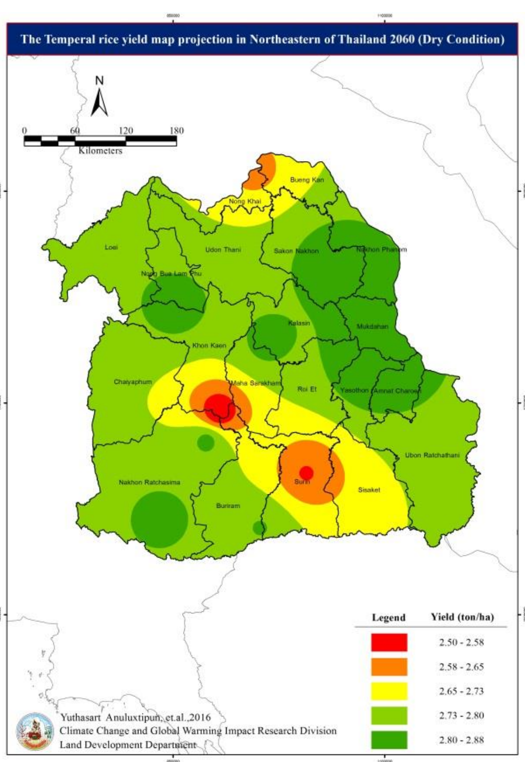
Rice				Maize	
PROVINCE	YIELD2014 (ton/ha)	PROVINCE	YIELD2014 (ton/ha)	PROVINCE	YIELD2014 (ton/ha)
Bueng Kan	1.925	Nong Khai	2.256	Nong Khai	3.525
Nong Bua Lamphu	1.950	Mukdahan	2.269	Khon Kaen	3.925
Nakhon Ratchasima	2.019	Kalasin	2.269	Kalasin	3.944
Khon Kaen	2.119	Sisaket	2.269	Chaiyaphum	4.031
Amnat Charoen	2.131	Yasothon	2.281	Udon Thani	4.125
Chaiyaphum	2.150	Surin	2.288	Nakhon Ratchasima	4.138
Ubon Ratchathani	2.156	Maha Sarakham	2.338	Loei	4.250
Sakon Nakhon	2.175	Roi Et	2.338	Nong Bua Lamphu	4.256
Buriram	2.206	Loei	2.450	Sisaket	4.888
Udon Thani	2.250	Nakhon Phanom	2.456	Ubon Ratchathani	5.475



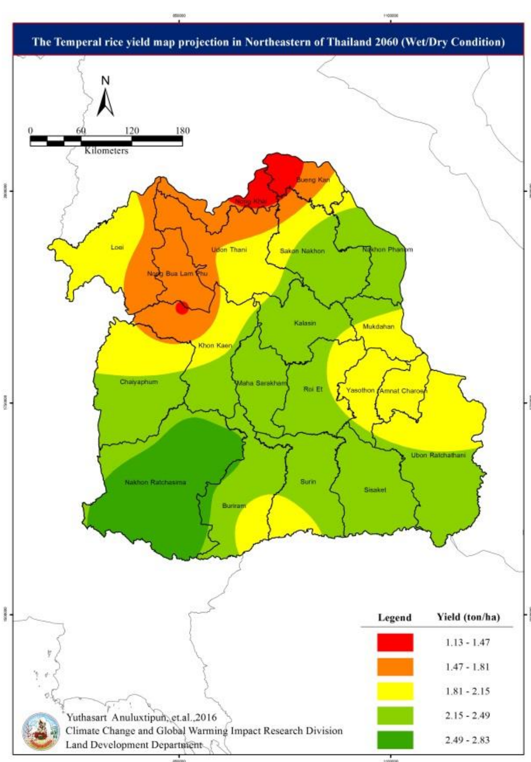
A. Actual yield in 2014



B. Temporal yield in 2060(Wet)

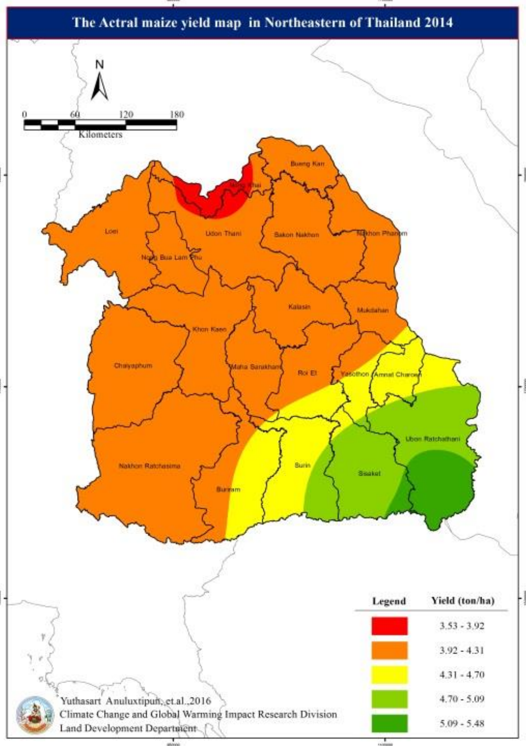


C . Temporal yield in 2060(Dry)

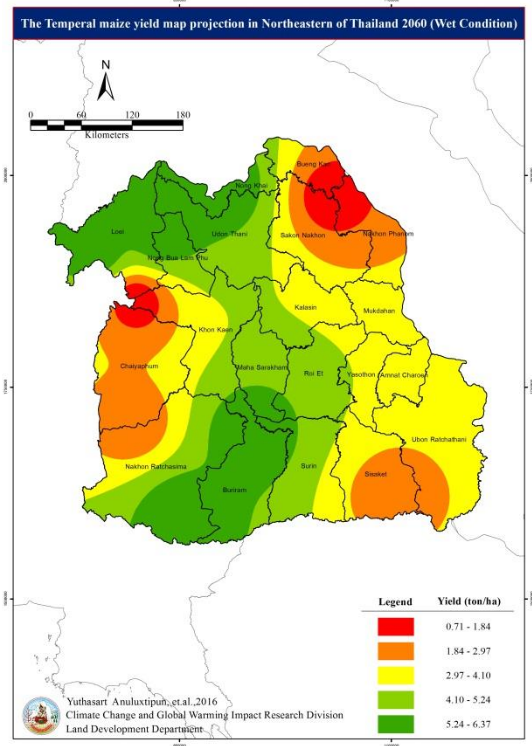


D. Temporal yield in2060(Extreme)

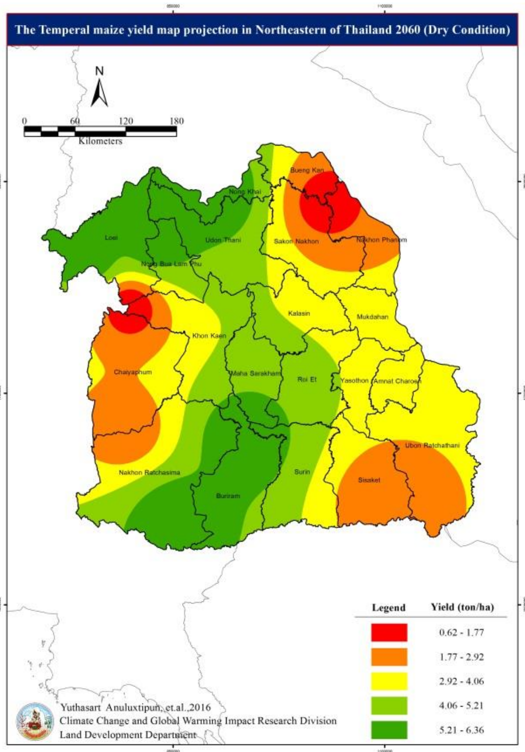
Figure 4a. The actual and temporal rice yield map in Northeastern of Thailand .



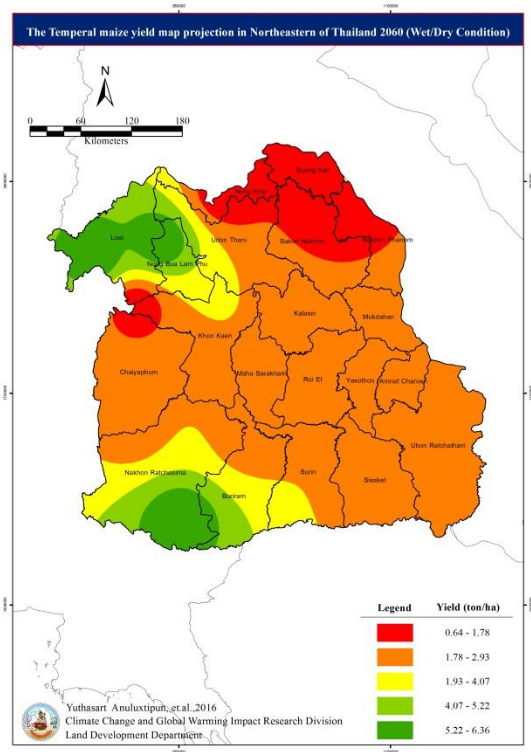
A. Actual yield in 2014



B. Temporal yield in 2060(Wet)

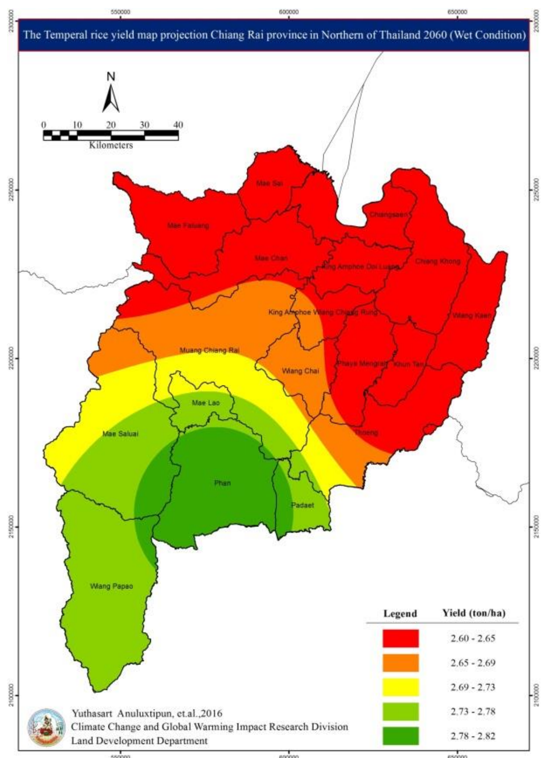


C. Temporal yield in 2060(Dry)

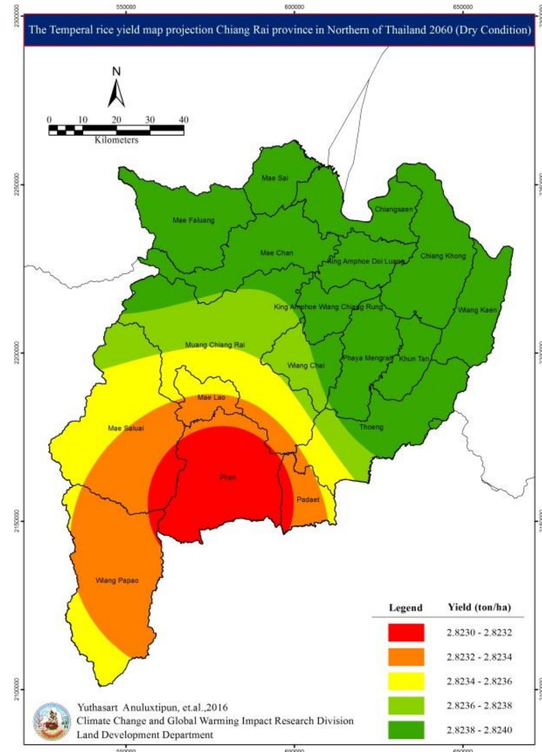


D. Temporal yield in 2060(Extreme)

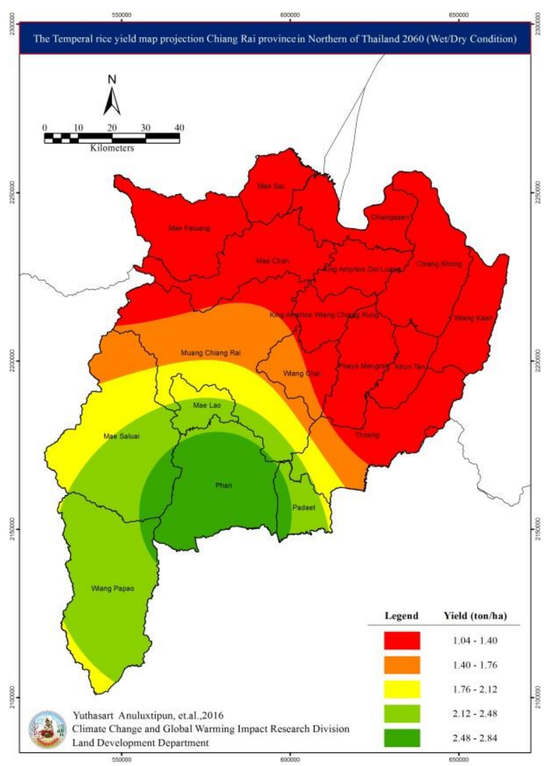
Figure 5b. The actual and temporal maize yield map in Northeastern of Thailand



A. Temporal yield in 2060(Wet)

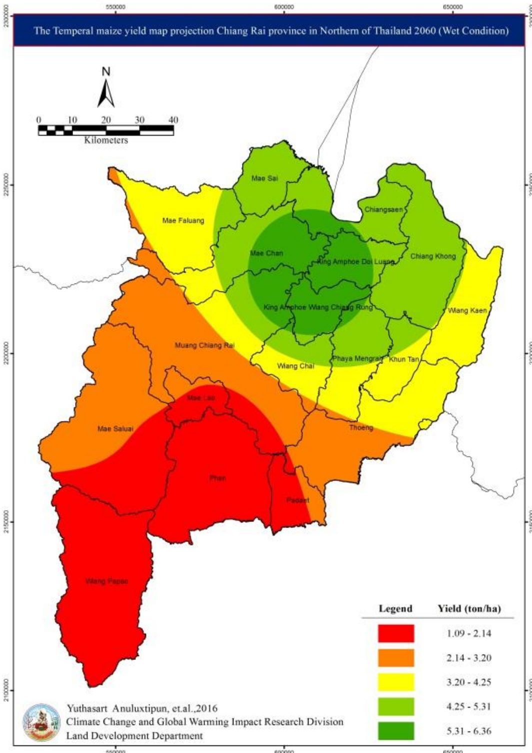


B. Temporal yield in 2060(Dry)

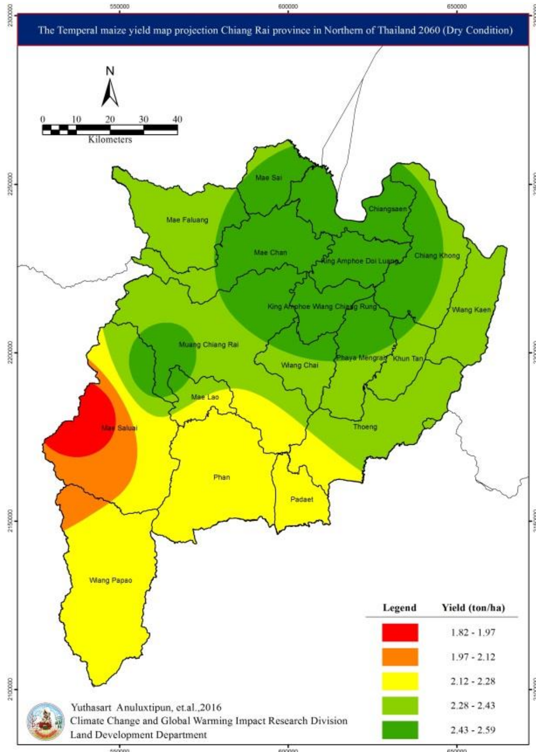


C. Temporal yield in 2060(Extreme)

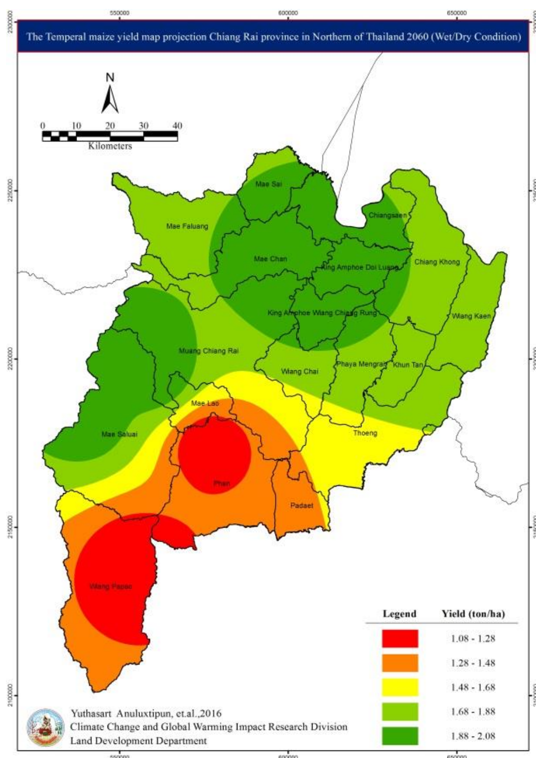
Figure 5c. The actual and temporal rice yield map Chiang rai in Northern Of Thailand.



A. Temporal yield in2060(Wet)



B. Temporal yield in2060(Dry)



C. Temporal yield in 2060(Extreme)

Figure 5d. The actual and temporal maize yield map Chiang rai in Northern of Thailand .

This paper is the same direction of Keith et. al. (2010). They summarize CO2 enrichment is likely to increase yields of most crops by approximately 13 percent but leave yields of C4 crops unchanged. It will tend to reduce water consumption by all crops, but this effect will be approximately canceled out by the effect of the increased temperature on evaporation rates. In many places increased temperature will provide opportunities to manipulate agronomy to improve crop performance. Ozone concentration increases will decrease yields by 5 percent or more.

6. Conclusion and Recommendation

The conclusion that Rice and Maize production in the Northern and Northeastern of Thailand may have increased yielding more decreased yielding level if they are not lost the production from drought, flood, landslide, seasonal shifting, and land use change. Detailed modeling is the study of the effects of climate change (especially precipitation) on yield in the presence of extra CO_2 and its effect on water consumption. Current models can do this, but the researchers will need access to large quantities of daily weather data from many crop-production locations around LMB. Rice and Maize are the good representatives of crop type but cash crops are necessary. However, a limiting of time for the national consultant is a limiting factor for precision and accuracy as well.

These changes are so small in comparison to the comparison to increases in crop productivity achieved in 2030 and 2060. To increase yield by the required amounts farmers will need improved soil, irrigation and varieties of crop plants with larger potential yields, better tolerance or resistance to pests, diseases, drought, flood, seasonal shifting and more efficient extraction and use of water and nutrients. The assumptions about future possibilities are based on past performance and they are therefore rather uncertain, but no more so than the output of some of the large climate change impact studies that rely almost entirely on the climate simulations model.

References

Bernacchi, C.J.; Kimball, B.A.; Quarles, D.R.; Long, S.P. & Ort, D.R. (2007). Decreases in Stomatal conductance of soybean under open-air elevation of CO2 is closely coupled with decreases in ecosystem evapotranspiration, Plant Physiology Vol. 143:134–144.

Ciais, P.H. ; Reichstein, M. ; Viovy, N. ; Granier, A. ; Ogee, J. ; Allard, V. et al. (2005). Europe wide reduction in primary productivity caused by the heat and drought in 2003.Nature Vol. 437: 529–533. http://www.fao.org/nr/water/docs/aquacropv31pluschapter1.pdf

Dirk RAES, Pasquale STEDUTO, Theodore C. HSIAO, and Elias FERERES. (2011, January). *AquaCrop Reference Manual.* Retrieved June 2016, from Food and Agriculture Organization of the United Nations: http://www.fao.org/nr/water/docs/aquacropv31pluschapter1.pdf

FAO. (2016, June). *IntroducingAquaCrop.* Retrieved June 2016, from Food and Agriculture Organization of the United Nations: http://www.fao.org/nr/water/docs/IntroducingAquaCrop.pdf

Ghannoum, O.; Evans, J.R. & von Caemmerer, S (2011). Nitrogen and water use efficiency of C4 plants. In: Raghavendra, A.S. & Sage, R.S. (Eds.) C4 Photosynthesis and Related CO2 Concentrating Mechanisms, Springer Science Business Media B.V., Dordrecht, The Netherlands, pp.129-146.

Intergovernmental Panel on Climate Change, IPCC (2001). Climate change 2001: the Scientific basis. In: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change Summary for Policymakers. Houghton, J.T.; Ding, Y.; Griggs, D.J.; Noguer, M.; van der Linden, P.J.; Dai, X.; Maskell, K. & Johnson, C.A., (Eds.) Cambridge University Press, Cambridge, United Kingdom, pp. 881.

Intergovernmental Panel on Climate Change, IPCC (2007). Climate change 2007: Synthesis report. In: Pachauri, R.K. & Reisinger, A. (Eds.) Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva. pp.104.

Jacovides, C. P., and Kontoyiannis, H. (1995). Statistical procedures for the evaluation of evapotranspiration computing models. Agricultural Water Management 27, 365–371.

Jamieson, P.D., Porter, J.R.,Wilson, D.R. (1191). A test of the computer simulation Model ARCWHEAT1 on wheat crops grown in New Zealand. Field Crops Research 27, 337–350.

Keith W. Jaggard,* Aiming Qi, and Eric S. Ober, 2010. Possible changes to arable crop yields by 2050. Philos Trans R Soc Lond B Biol Sci. 2010 Sep 27;

Krause, P., Boyle, D. P., and Bäse, F. (2005). Advances in Geosciences Comparison of differentefficiency criteria for hydrological model assessment. Advances In Geosciences, 89–97.

Legates, D. R., and McCabe, G. J. (1999). Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. Water Resources Research 35, 233–241.

Loague, K., and Green, R. E. (1991). Statistical and graphical methods for evaluating solute transport models: Overview and application. Journal of Contaminant Hydrology 7, 51–73.

Moriasi, D. N., Arnold, J. G., Liew, M. W. V., Bingner, R. L., Harmel, R. D., and Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions Of The ASABE 50, 885–900.

Raes D, Steduto P, Hsiao TC, Fereres E. 2012.Reference manual AquaCrop, FAO, Land and Water Division, Rome, Italy.Schiermeier, Q. (2008). Water: A long dry summer. Nature Vol. 452: 270–273.

Thomas, C.D.; Cameron, A.; Green, R.E.; Bakkenes, M.; Beaumont, L.J.; Collingham, Y.C.; et al. (2004). Extinction risk from climate change. Nature Vol. 427: 145–158.

Willmott, C. J. (1984). On the evaluation of model performance in physical geography. In Spatial Statistics and Models, Gaile GL, Willmott CJ (eds). D. Reidel: Boston. 443–460.

Willmott, C. J. (1982). Some Comments on the Evaluation of Model Performance. Bulletin American Meteorological Society 63, 1309–1313.