CATCHCROP: modeling crop yield and water demand for integrated catchment assessment in Northern Thailand

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Abstract

As part of an Integrated Water Resource Assessment and Management project (IWRAM) in Northern Thailand, a Decision Support System is being constructed in order to provide guidelines for crop diversification and water allocation. The IWRAM software integrates a crop model with hydrological and economic models. Presented here is the integrated crop model, called CATCHCROP, which is capable of simulating yield response to water deficit and fertility depletion. External and internal constraints have largely influenced the model construction. Paucity of observed data and its reliability required the use of conceptual and recognized algorithms. Linkages with the economic and hydrological models led to the choice of a 10-days time step. The stand-alone version of the model has been tested against available data sets coming from two small catchments. First results are fairly satisfactory but it is acknowledged that this kind of integrated model should not be used at the farm plot level to assess cropping practices. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: CATCHCROP; Crop modeling; Integrated catchment assessment; Thailand; Water balance

1. Introduction

Difficulties in environmental modeling can be characterized as problems of natural complexity, spatial heterogeneity and the lack of available data (Jakeman et al., 1999). Thus, crop models embed in Integrated Assessment Tools often show a poor level of prediction due to the inconsistency of scale between measured parameters and the way they are used in the model (van Diepen et al., 1991). Williams and Probert (1983) identified the importance in restricting the number of parameters in mechanistic crop models without significantly sacrificing their theoretical principles or predictive capacity for larger scale use. Besides, several studies have proved that conceptual models were efficient enough to simulate actual processes provided that time steps and input parameters were correctly defined (Maraux and Lafolie, 1998; Wegehenkel, 2000). However, simplifying mechanistic crop models may result in limited feedback and limited applicability to a wide range of management practices (Penning de Vries, 1990). Indeed, as stated by Montieth (1996) “crop modeling suffers from the obscure mixing of its inductive and cognitive sources of knowledge”. Thus, most crop models, described as conceptual, represent a compromise between rigor and utility.

An Integrated Water Resource Assessment and Management (IWRAM) commenced in irrigated small catchments of Northern Thailand in 1997. The multi-disciplinary project aims at identifying and integrating hydrological, economic and agricultural information into a Decision Support System. The latter provides guidelines in terms of agricultural diversification and its consequences on water management (Scoccimarro et al., 1999).

The integrated crop model has been conceived according to external and internal constraints. The data availability is the main external constraint to take into account. Kuneepong et al. (1990) already noted that the

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major problem in using WOFOST (van Diepen et al., 1989) in Northern Thailand was that the required input data could only be collected from experimental sites but were generally not collected during extensive surveys at the catchment scale. A second external constraint derives from the requirement that the DSS deals with agricultural diversification; hence, the crop model had to be generic enough to allow the addition of new crops to the existing list.

Internal constraints derive from the exchange of information with the other components of the DSS. The economic model simulates how agricultural households seasonally allocate natural and human resources between farming activities. Twice a year, the decision making process is simulated through a linear programming approach which optimizes income according to water, cash and labor resources (Walker and Scoccimarro, 1999). Hence, the economic model needs seasonal figures of yields and water consumption. Conversely, it provides information about irrigation, fertilization and terracing to the crop model. Detailed information about the farming calendar is not available.

The hydrological model encapsulated in the DSS calculates the streamflow discharge at successive nodes of the network, corresponding to specific land use patterns (Schreider et al., 1999). It provides daily values of discharge even if it has been calibrated against aggregated monthly data, due to the poor reliability of observed data sets. The model requires, at each node, the volume of water diverted for irrigation.

The last constraint comes from the number of simulations to perform at each time step: each catchment is constituted with 2 or 3 nodes; each node includes between 5 to 10 types of households, 5 to 10 different land units and 5 to 10 types of crops. Thus, the choice of the relevant time step is crucial in terms of computer resources allocation. A 10-day time step has proven to be a fairly good compromise in the case of conceptual, mono-dimensional and non-layered crop models (Allen et al., 1998).

Among previous crop modeling attempts in Northern Thailand, CROPWAT (Smith, 1992) constitutes one of the most achieved use of a conceptual and generic model at the regional scale (Kuneepong et al., 1990). Unfortunately, CROPWAT aims at providing irrigation time schedules rather than yield response to water. Moreover, some essential aspects for the IWRAM Decision Support System are poorly handled in CROPWAT (runoff losses, influence of fertility variations). Thus, we have kept its conceptual framework and used an internal clock based on a 10-days time step. A runoff module adapted from Chow (1964) has been added along with a fertility trigger elaborated by the Department of Land Development of Thailand (DLD) and a root growth algorithm proposed by Baron et al. (1995).

We first describe the different components of the model; then, we describe the data set and information used to test CATCHCROP. Finally we give the results and comment on the predictive limits of such an integrated tool.

2. Model description

In order to calculate the different components of the crop water balance, CATCHCROP includes eight successive sub-routines (Fig. 1). An external file provides Rainfall ($RR$) and Potential Evapotranspiration ($ETO$) values. At each time step, the water balance can be expressed as a mass conservation equation (all units in mm):

$$RR_i + IR_i + (SR_i - SR_{i-1}) - RO_i - DD_i - ETA_i = 0$$  \hspace{1cm} (1)

with: $RR_i$=rainfall during the 10-day period ($i$); $IR_i$=irrigation during the 10-day period ($i$); $SR_i$=actual soil water storage during the 10-days period ($i$); $RO_i$=runoff during the 10-day period ($i$); $DD_i$=deep drainage during the 10-day period ($i$); and $ETA_i$=actual evapotranspiration during the 10-days period ($i$).

![Fig. 1. CATCHCROP flowchart.](image-url)
2.1. Step 1: Calculating runoff losses

According to the methodology proposed in Chow (1964), runoff losses depend on rainfall (RR) and two parameters (Tables 1 and 2):

- Daily infiltration rate for a given type of soil (IS, in mm).
- Correction factor due to crop management (CC).

Many catchments in Northern Thailand present very steep and often cropped slopes. Thus, a slope correction factor (CS) has been added, reflecting the reduction in surface retention with increasing steepness. As this equation needs a daily calculation, runoff is estimated on a pseudo-daily time step calculated according to the actual number of rainy days during a 10-day period (NRD):

\[
rr_i = RR/NRD_i
\]

If \( rr_i \approx (IS-CS-CC) \), then:

\[
ro_i = [rr_i-0.2(IS-CS-CC)]^2/[rr_i+0.8(IS-CS-CC)]
\]

\[
RO_i = NRD_i \cdot ro_i
\]

with: \( RR \)=rainfall during the 10-day period \( i \); \( rr_i \)=pseudo-daily average rainfall; \( RO_i \)=runoff during the 10-day period \( i \); \( ro_i \)=pseudo-daily average runoff.

2.2. Step 2: Calculating soil water storage

According to Baron et al. (1995) and Allen et al. (1998) the soil water storage is represented by two reservoirs in parallel. The Maximum Soil Available Water (SAW, in mm) and the Maximum Crop Available Water (CAW, in mm) are defined as following:

\[
SAW = TAW \cdot SD
\]

\[
CAW = TAW \cdot RD_i
\]

with: \( TAW \)=total available amount of water (in mm/m); \( SD \)=soil depth (in m); \( RD_i \)=root depth during the 10-days period \( i \) (in m).

\( TAW \) is defined as the amount of water available in the soil between the field capacity and the wilting point water contents. Soil specific values of \( TAW \) are given in Table 2. At each time step, the root depth is updated according to the initial \( RD_{ini} \) and the final \( RD_{end} \) root depth values given in Table 1. Rainfall and irrigation values given, using Eq. (1) and Eq. (2) lead to the following developments (all units in mm):

\[
DD_i = \text{Max}[0:(SR_i+RR_i+IR_i-RO_i-SAW)]
\]

\[
SR_i = \text{Min}[SAW_i:(SR_i+RR_i+IR_i-RO_i)]
\]

\[
CR_i = \text{Min}[CAW_i:(CR_i+RR_i+IR_i-RO_i)]
\]

with: \( DD_i \)=actual deep drainage during the 10-days period \( i \); \( SR_i \)=actual soil water storage during the 10-days period \( i \); \( CR_i \)=actual root zone water storage during the 10-days period \( i \).

2.3. Step 3: Calculating maximum evapotranspiration

According to Doorenboos and Pruitt (1977) and Allen et al. (1998), each crop is characterized by a set of parameters (Table 1):

- Four vegetative period durations \( (L_{ini}, L_{dev}, L_{mid}, L_{end}) \).
- Three crop coefficients \( (KC_{ini}, KC_{mid}, KC_{end}) \).

The intermediate values of the coefficients are estimated by time-dependent linear regressions. One can find the description of these algorithms in Baron et al. (1995) and Allen et al. (1998). The maximum evapotranspiration \( (ETM) \), corresponding to a well-developed cover, is calculated along with its cumulative value \( (SUMETM) \):

\[
ETM_i = KC_i \cdot ETO_i
\]

and:

\[
SUMETM_i = SUMETM_{i-1} + ETM_i
\]

with: \( ETO_i \)=potential evapotranspiration during the 10-days period \( i \); \( KC_i \)=Crop coefficient during the 10-days period \( i \).

2.4. Step 4: Soil evaporation correction

During the initial growth stage of the crop \( (L_{ini}) \), topsoil evaporation is usually the dominant source of water losses. To account for it, Allen et al. (1998) proposed creating a virtual and soil specific tank characterized by (Table 2):

- Total amount of water available for evaporation \( (TEW, \text{in mm}) \).
- Amount of water readily available for evaporation \( (REW, \text{in mm}) \).

Again, this correction needs a daily calculation; thus, soil evaporation is estimated on a pseudo-daily time step calculated according to the actual number of rainy days during a 10-day period \( (NRD) \) and the potential evapotranspiration \( (ETO) \):

\[
TD_i = \text{INT}[10-(NDR_i)/NDR_i]
\]

\[
TL_i = Rew/0.115 \cdot ETO_i
\]

If \( TL_i < TD_i \), then:

\[
KE_i = [TEW−{(TEW−REW) \cdot \text{EXP}(X)}]/TD_i \cdot ETO_i/10
\]

And:

\[
X = [(TD_i−TL_i)(0.115 \cdot ETO_i)−(REW/TEW)(TD_i−TL_i)]
\]
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Rice paddy</th>
<th>Rice upland</th>
<th>Soybean</th>
<th>Groundnut</th>
<th>Maize grain</th>
<th>Maize forage</th>
<th>Cabbage</th>
<th>Potato</th>
<th>Onion</th>
<th>Fruit tree tropical</th>
<th>Forest</th>
<th>Other crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{ini}$</td>
<td>day</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>25</td>
<td>15</td>
<td>60</td>
<td>60</td>
<td>user</td>
</tr>
<tr>
<td>$L_{dev}$</td>
<td>day</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>35</td>
<td>35</td>
<td>20</td>
<td>60</td>
<td>30</td>
<td>25</td>
<td>90</td>
<td>90</td>
<td>user</td>
</tr>
<tr>
<td>$L_{mid}$</td>
<td>day</td>
<td>60</td>
<td>40</td>
<td>60</td>
<td>45</td>
<td>40</td>
<td>30</td>
<td>50</td>
<td>45</td>
<td>70</td>
<td>120</td>
<td>120</td>
<td>user</td>
</tr>
<tr>
<td>$L_{end}$</td>
<td>day</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>30</td>
<td>40</td>
<td>95</td>
<td>95</td>
<td>user</td>
</tr>
<tr>
<td>$KC_{ini}$</td>
<td></td>
<td>1.05</td>
<td>0.30</td>
<td>0.40</td>
<td>0.40</td>
<td>0.30</td>
<td>0.30</td>
<td>0.70</td>
<td>0.50</td>
<td>0.70</td>
<td>0.95</td>
<td>0.95</td>
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</tr>
<tr>
<td>$KC_{mid}$</td>
<td></td>
<td>1.20</td>
<td>1.10</td>
<td>1.15</td>
<td>1.15</td>
<td>1.20</td>
<td>1.15</td>
<td>1.05</td>
<td>1.15</td>
<td>1.05</td>
<td>0.90</td>
<td>0.90</td>
<td>user</td>
</tr>
<tr>
<td>$KC_{end}$</td>
<td></td>
<td>0.90</td>
<td>0.55</td>
<td>0.50</td>
<td>0.60</td>
<td>0.50</td>
<td>1.05</td>
<td>0.95</td>
<td>0.75</td>
<td>0.75</td>
<td>0.95</td>
<td>0.95</td>
<td>user</td>
</tr>
<tr>
<td>$RD_{ini}$</td>
<td>mm</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>1800</td>
<td>1800</td>
<td>user</td>
</tr>
<tr>
<td>$RD_{end}$</td>
<td>mm</td>
<td>500</td>
<td>600</td>
<td>1200</td>
<td>1000</td>
<td>1200</td>
<td>1000</td>
<td>700</td>
<td>800</td>
<td>600</td>
<td>2000</td>
<td>2000</td>
<td>user</td>
</tr>
<tr>
<td>$P$ factor</td>
<td></td>
<td>0.20</td>
<td>0.55</td>
<td>0.50</td>
<td>0.50</td>
<td>0.55</td>
<td>0.50</td>
<td>0.45</td>
<td>0.35</td>
<td>0.30</td>
<td>0.50</td>
<td>0.50</td>
<td>user</td>
</tr>
<tr>
<td>$CC$</td>
<td></td>
<td>2.0</td>
<td>2.0</td>
<td>2.5</td>
<td>2.5</td>
<td>2.0</td>
<td>2.0</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>3.0</td>
<td>3.0</td>
<td>user</td>
</tr>
<tr>
<td>$KY$</td>
<td></td>
<td>1.20</td>
<td>0.90</td>
<td>0.85</td>
<td>0.70</td>
<td>1.20</td>
<td>1.00</td>
<td>0.95</td>
<td>1.10</td>
<td>1.10</td>
<td>0.80</td>
<td>0.80</td>
<td>user</td>
</tr>
<tr>
<td>$YM$</td>
<td>t/ha</td>
<td>5.0</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
<td>5.0</td>
<td>15.0</td>
<td>25.0</td>
<td>25.0</td>
<td>30.0</td>
<td>user</td>
<td>user</td>
<td>user</td>
</tr>
</tbody>
</table>
Table 2
Values of soil parameters used in CATCHCROP (source: SCS, 1973; Kuneepong et al., 1990)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Parameter</th>
<th>Unit</th>
<th>Gravel</th>
<th>Sandy</th>
<th>Loamy</th>
<th>Silty</th>
<th>Clayey</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TAW</td>
<td>mm/m</td>
<td>80</td>
<td>80</td>
<td>150</td>
<td>170</td>
<td>150</td>
<td>user</td>
</tr>
<tr>
<td></td>
<td>TEW</td>
<td>mm</td>
<td>16</td>
<td>16</td>
<td>30</td>
<td>35</td>
<td>30</td>
<td>user</td>
</tr>
<tr>
<td></td>
<td>REW</td>
<td>mm</td>
<td>6</td>
<td>6</td>
<td>10</td>
<td>11</td>
<td>10</td>
<td>user</td>
</tr>
<tr>
<td></td>
<td>IS</td>
<td>mm</td>
<td>10</td>
<td>20</td>
<td>13</td>
<td>10</td>
<td>5</td>
<td>user</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Parameter</th>
<th>Unit</th>
<th>Shallow</th>
<th>Moderate</th>
<th>Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SD</td>
<td>mm</td>
<td>500</td>
<td>1000</td>
<td>1500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land slope</th>
<th>Parameter</th>
<th>Unit</th>
<th>0 to 16%</th>
<th>16 to 35%</th>
<th>Over 35%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
<td>1</td>
<td>0.7</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>

\[ -REW)/TEW] \]

Then:

\[ ETM_i = \max(K_{E_i} \cdot KC_i, ETO_i) \]

with: \( TD_i = \) average duration of drought spell during the 10-days period \( i \); \( TL_i = \) number of days for emptying \( REW \) during the 10-days period \( i \); \( KE_i = \) soil evaporation correction coefficient during the 10-days period \( i \).

2.5. Step 5: Soil fertility correction

At this stage, the crop coefficients are corrected according to the estimated level of fertility of the plot \( (LF) \) and the level of fertilizer supplied \( (FI) \). The values of the coefficient of depletion \( (K_F) \) are given in Table 3. Then, the value of the corrected evapotranspiration \( (ETC) \) is calculated as:

\[ ETC_i = K_F \cdot ETM_i \] (7)

2.6. Step 6: Calculating actual evapotranspiration:

According to Doorenboos and Pruitt (1977) and Allen et al. (1998), when the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. The fraction of water content that a crop can extract without suffering moisture stress is defined by a crop specific parameter, called the \( P \)-factor (Table 1). The fraction \( P \) is a function of the evaporation power of the atmosphere (Eq. (8)). Thus, the actual evapotranspiration \( (ETA) \) and its cumulative value \( (SUMETA) \), corresponding to a water stressed cover, are calculated as:

\[ P_i = P_{ref} + 0.04(5 - (ETC_i/10)) \] (8)

Considering \( CR_i \) from Eq. (4):

If \( Cr_i/CAW_i \leq (1 - P_i) \);

then: \( KS_i = CR_i/(1 - P_i) \cdot CAW_i \);

else: \( KS_i = 1 \)

\[ ETA_i = KS_i \cdot ETC_i \]

and: \( SUMETA_i = SUMETA_{i-1} + ETA_i \), with:

\( KS_i \) stress coefficient during the 10-days period \( i \)

Then, water storage in the soil \( (SR_i, Eq. (3)) \) and root \( (Cr_i, Eq. (4)) \) reservoirs are updated by subtracting the newly calculated \( ETA_i \) value.

2.7. Step 7: Calculating water demand

Usually, water demand \( (DEM) \) is defined as the difference between \( ETC \) and \( ETA \) (Smith, 1992). Thus, it corresponds to the quantity of water needed by the crop to evaporate at its maximum rate. In our case, the 10-days time step constraint forced us to modify this approach as the irrigation requirement is calculated at time step \( i \) but only provided at time step \( (i+1) \). We have stated that soil water storage should be maintained above or, at least, equal to the readily available fraction \( (RAF) \), defined as:

Table 3
Values of the fertility coefficient of correction \( (KF) \), given a level of fertility of the land unit \( (LF) \) and a fertilizer index of the farmer’s plot \( (FI) \) (source: DLD, personal communication)

<table>
<thead>
<tr>
<th>Values of KF</th>
<th>LF</th>
<th>0</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>L</td>
<td>0.5</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.5</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>0.75</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>


\[ RAF_i = (1 - P_i) \cdot CAW_i \]

\[ DEM_i = \text{Max}(0; (RAF_i - CR_i)) \] (10)

Then, water demand (Eq. (10)) is used to calculate the irrigation that has to be supplied during the next time step \( IR \). The procedure of water allocation depends on the version of CATCHCROP:

- Stand-alone version: \( IR = DEM \);
- DSS version: \( IR \) is calculated through a water diversion sub-routine. Where a water allocation table aggregates, at each time step, the demand from the different crops and compare with the streamflow available at the river node.

2.8. Step 8: Calculating the adjusted yield

The final yield is estimated with the methodology proposed by Doorenbos and Kassam (1979) requiring two parameters (Table 1):

- Potential or maximal yield of the crop \( YM \).
- Water stress coefficient, reducing the potential yield \( KY \).

The linear relation links the actual yield to the evapotranspiration deficit. The latter is expressed as the ratio between the cumulative values of \( ETA \) and \( ETM \) during the growing period:

\[ YA = YM \cdot [1 - KY \cdot (1 - \text{SUMETA}_i / \text{SUMETM}_i)] \] (11)

With \( \text{SUMETA}_i = \text{cumulative value of } ETA \) during the growing period; \( \text{SUMETM}_i = \text{cumulative value of } ETM \) during the growing period.

3. Materials and methods

A large part of CATCHCROP’s parameters are identical with those of CROPWAT, previously validated or adapted by Kuneepong et al. (1990). The authors have kindly shared their database with us. Concerning the other parameters, standard and largely recognized figures have been used (Chow, 1964; Allen et al., 1998). The Department of Land Development has provided the figures concerning the fertility trigger (Table 3) and the land units definition (Table 4). Hydrological and climate files have been collected by different Thai agencies and should be considered as secondary data.

3.1. Water balance testing

In order to validate the different components of the water balance \( (RO, DD, ETA) \) we have used observed discharge values recorded by the Royal Department of Irrigation at the outlet of the Mae Mu catchment (68.5 km\(^2\)) between 1988 and 1992. This upstream catchment is characterized by a nearly 100% forest cover and three major land units (LU45: 15%; LU47: 40%; LU49: 45%). Land units \( (LU) \) have been defined by the Department of Land Development (DLD) of Thailand. Each one is characterized by its soil type, soil depth and slope. Land unit attributes are described in Table 4.

As deep percolation \( (DD) \) is considered to be an instantaneous process within CATCHCROP, the following assumptions have been used to compare with the hydrological values:

- A1: every year, the rainy season starts on April 1 and the dry season on November 1.
- A2: every year, the rainy season cumulative discharge \( (Q_{\text{wet}}) \) corresponds to the cumulative runoff values simulated during the same period \( (RO_{\text{wet}}) \).
- A3: every year, the dry season cumulative discharge \( (Q_{\text{dry}}) \) corresponds to the runoff simulated during the same period \( (RO_{\text{dry}}) \), plus deep percolation from both periods \( (DD_{\text{wet}} \text{ and } DD_{\text{dry}}) \).

A daily rainfall data set of five years duration was used (1988 to 1992). Average regional values of the potential evapotranspiration \( (ETO) \) were used to describe the atmospheric demand on a 10-day time step. Forest water balance was simulated according to the parameters given in Table 1.

3.2. Yield response testing

According to field surveys conducted in the Mae Uam catchment (43.6 km\(^2\)), farm land is mainly divided into irrigated terraces located along the river streams (paddy fields) and cleared plots located on the upstream slopes (upland fields). Paddy fields represent 8% and upland fields 9% of the total catchment area. Paddy fields are cropped on three major LAND units (LU88: 60%; LU25: 30%; LU45: 10%), upland fields are cropped on slightly different land units (LU10: 47%; LU25: 46%; LU47: 7%). The characteristics of these land units are described in Table 4.

During the rainy season (April to October), 73% of the Paddy fields are cropped with irrigated rice and 45% of the upland fields with vegetables, essentially rainfed cabbage. During the dry season (November to March), irrigated soybean becomes the dominant crop on the
Paddy fields (25% of the paddy area) and 11% of the upland fields are still cropped with irrigated vegetables. On average, rice and vegetables are moderately fertilized and soybean is not fertilized. The Department of Land Development of Thailand has locally conducted a five year yield survey. Unfortunately, the monitoring period (1990 to 1995) does not exactly match the rainfall data set. Thus, only mean production figures were used to compare with the calculated ones: rice 3300±300 kg/ha, soybean 1370±250 kg/ha and cabbage 14220±3500 kg/ha, where the deviations from the mean represent one standard error.

As a first step in model testing, it was decided to simulate with CATCHCROP the water balance for the different land units and crops described. Then, it was possible to calculate the global yield response, according to the actual land use pattern. A five years daily rainfall data set was used (1988 to 1992). Average regional values of the potential evapotranspiration (ETO) were used to describe the atmospheric demand on a 10-day time step.

4. Results and discussion

4.1. Water balance

Table 5 gives seasonal values of the cumulative runoff and percolation calculated with CATCHCROP for the Mae Mu catchment. The simulated cumulative discharge was calculated according to assumptions A1, A2, and A3. The observed cumulative discharge values correspond to the breakdown of the hydrological data series into two periods: April–October (wet season) and November–March (dry season).

Without any parameter optimization procedure, results of this first-pass validation test are reasonably good. According to the Wilcoxon test, the fitting between observed and simulated values is statistically significant \((t=8; z=1.988; p=0.0468)\). Except during 1992, the wet season cumulative discharge is close to the simulated cumulative runoff. On average, dry season cumulative discharge is slightly overestimated by the simulated one. Keeping in mind the simplistic assumptions used within CATCHCROP to calculate deep percolation, this overestimation may derive either from the absence of a groundwater release function in the model or from the absence of a permanent vertical sink.

Nevertheless, most of the percolation process occurs at the end of the rainy season. Thus, it is relevant to assume that the major portion of this volume of water will return to the stream during the following dry season. Figure 2 illustrates this assumption. Simulated runoff corresponds to an early release of surface water that progressively feeds the streamflow. During the second part of the rainy season, percolation volume increases and water has to be slowly released during the streamflow recession period.

4.2. Yield response

Table 6 provides the major components of the crop water balance and yield corresponding to the main farming pattern observed in the Mae Uam catchment. Concerning the irrigation figures, it should be noted that the amount of water takes into account crop requirements.
Table 6

<table>
<thead>
<tr>
<th></th>
<th>Paddy field</th>
<th></th>
<th>Upland field</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wet season</td>
<td>Dry season</td>
<td>Wet season</td>
<td>Dry season</td>
</tr>
<tr>
<td></td>
<td>Rice</td>
<td>Soybean</td>
<td>Cabbage</td>
<td>Cabbage</td>
</tr>
<tr>
<td>Irrigation (mm)</td>
<td>150 [25]</td>
<td>233 [14]</td>
<td>0 [0]</td>
<td>339 [55]</td>
</tr>
<tr>
<td>Runoff (mm)</td>
<td>93 [63]</td>
<td>17 [18]</td>
<td>621 [82]</td>
<td>37 [31]</td>
</tr>
<tr>
<td>Yield (kg/ha)</td>
<td>3207 [217]</td>
<td>1419 [56]</td>
<td>15284 [1344]</td>
<td>16484 [1925]</td>
</tr>
</tbody>
</table>

* Bunded and irrigated plot.
* Irrigated plot.

only. Irrigation efficiency is assumed to be 100%. Obviously, this limitation of the stand-alone version of the model will disappear when CATCHCROP is fully integrated with the hydrological model. In the same way, water uptake from an irrigated crop is not limited, i.e. water demand is entirely satisfied, avoiding any drought stress during the growing period.

As the observed and simulated periods do not exactly match, only a simple comparison between global average yields has been studied. Concerning rice, the simulated yield (3207±217 kg/ha) is very close to the average observed value. Indeed, farming practices on paddy fields are very homogeneous and water is largely available during the rainy season. Thus, the modeling assumptions are fairly realistic. In the case of soybean, the average yield is slightly higher than expected (1419±56 kg/ha). Besides, the very narrow value of the standard deviation emphasizes an unrealistic homogeneity of cropping conditions during the dry season. The integrated version of CATCHCROP should provide more accurate results, taking into account the increased scarcity of the water resource during this period.

With respect to the upland fields, the same comments apply to the simulated yields for cabbage. The fact that rainfed production (15284±1344 kg/ha) is nearly the same as the irrigated one (16484±1925 kg/ha) is due to the very shallow water storage in LU10 where cabbage cannot express its full potential under irrigation. Runoff figures confirm the one reported by Ziegler et al. (2000) and Perez et al. (1999) for similar conditions. As shown in Fig. 3, discrimination between land units and crops is highly effective, when using Eq. (2) to calculate runoff losses.

Although field data are not yet available for more comprehensive model testing, the simulated impact of the different crops on the hydrological balance is physically plausible. On the other hand, rice cropping during the rainy season provides a large amount of percolation while runoff is limited by the terraced paddy fields. On the other hand, vegetable cropping on the upstream slopes provides a lot of runoff during the rainy season.

![Fig. 3. Relation between simulated runoff and rainfall values. Runoff has been calculated with Eq. (2) and parameters corresponding to 2 crops (soybean, cabbage) and 3 land units (LU25, LU47, LU88). The plot on LU88 is considered as bunded.](image)

5. Conclusion

CATCHCROP was constructed to accord with the overall objectives and associated modeling constraints specific to the IWRAM Decision Support System. Input data requirements, time step limitations and general portability have influenced the actual selection of the conceptual algorithm. Most of the time, integrated biophysical modules serve as data generators for the downstream economic or hydrological modeling. This paper presents an initial testing of the different components and assumptions of CATCHCROP within a stand-alone version. The testing is necessarily limited by the availability and reliability of field data.

The encouraging results from the Mae Mu catchment simulations confirm that CATCHCROP is able to quantify, on a seasonal basis, the different components of the hydrological balance. Further investigations are necessary in order to incorporate more complex land use patterns from different (and well documented) catchments. The crop growth and production modeling derive directly from the FAO’s handbook recommendations (Doorenboos and Kassam, 1979). The soil fertility trigger seems adequate for simulating a limited crop cover...
development. But, as with any environmental model, the user has to be very cautious with the choice of relevant options and should seek consistent field observations for validation (Boote et al., 1996). Furthermore, it would not be appropriate to use CATCHCROP as a field practice assessment tool.

6. Software availability

CATCHCROP stand-alone version has been written in JAVA with JBuilder4.0 by N. Ardlie and C. Dietrich. A run time version (iwram.jar) and the algorithm flowchart are available at: perez@cres.anu.edu.au

References