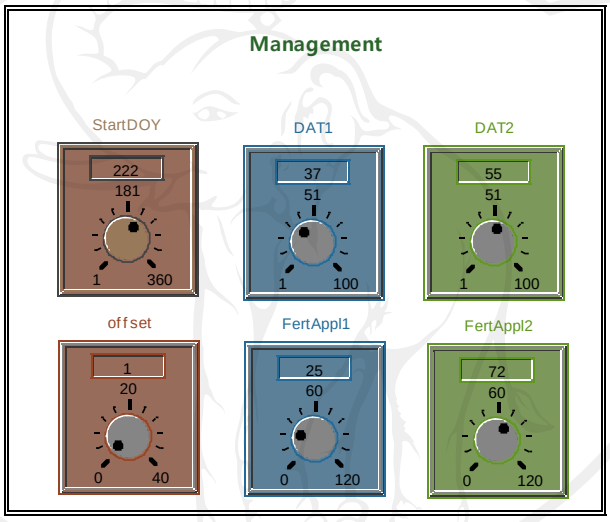
**APPENDICES**

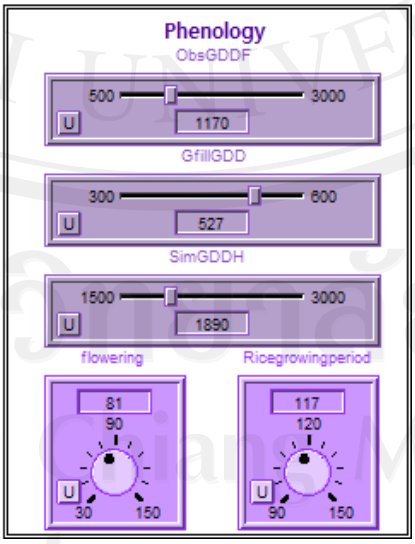
# APPENDIX A

## Model Interface

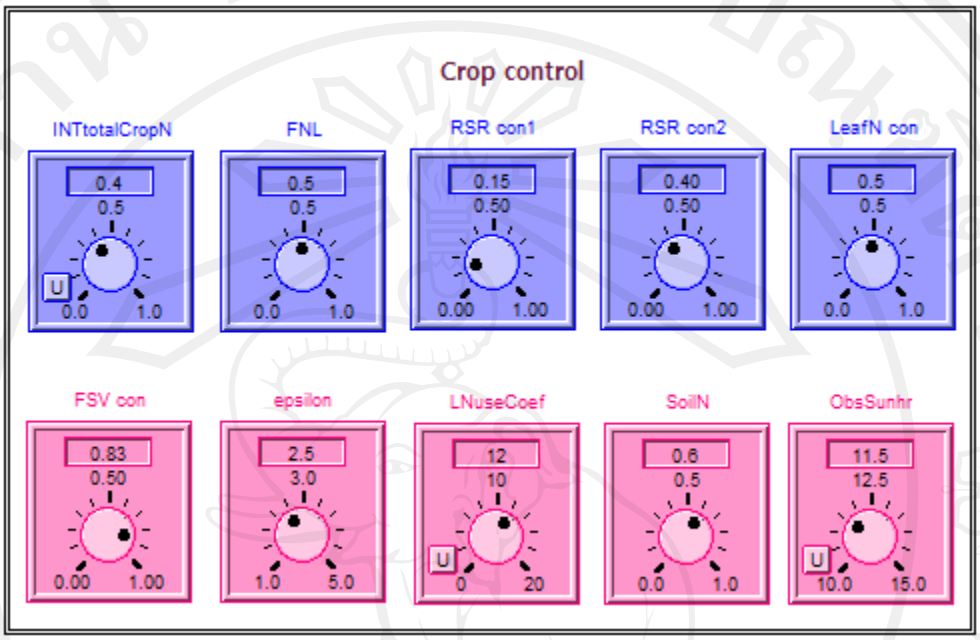
### Management



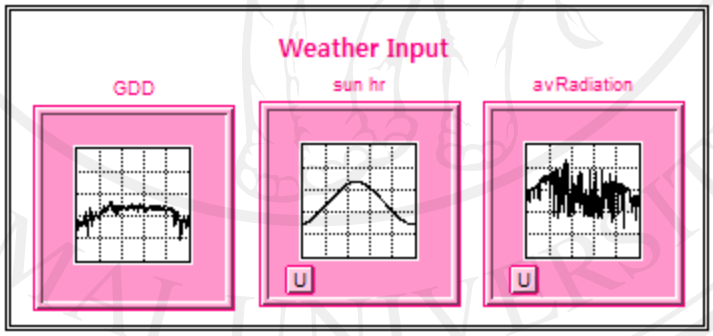

### Phenology



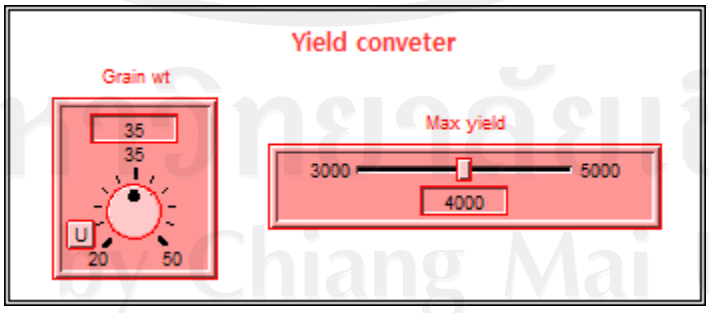
**Crop control**




**Weather input**



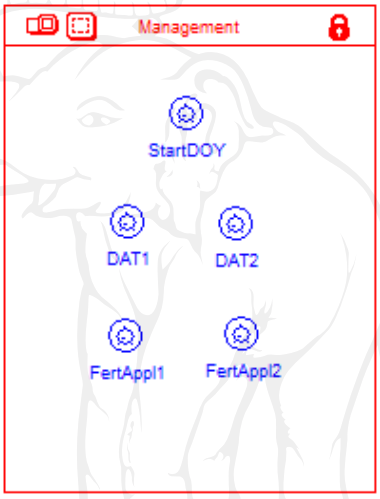

**Yield converter**



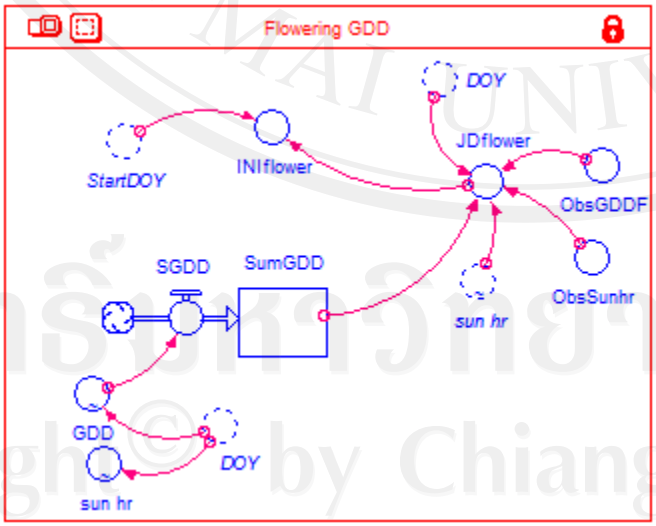
# APPENDIX B

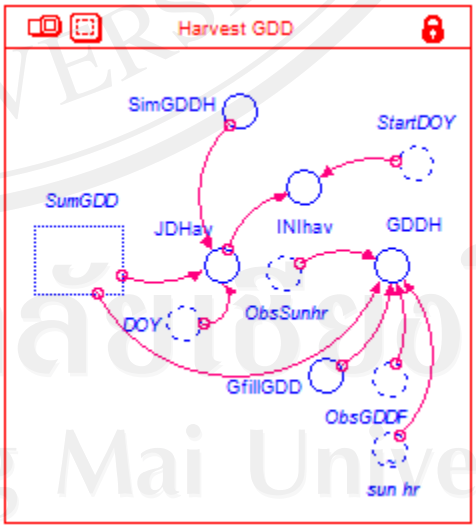
## Model flow diagram

### Management

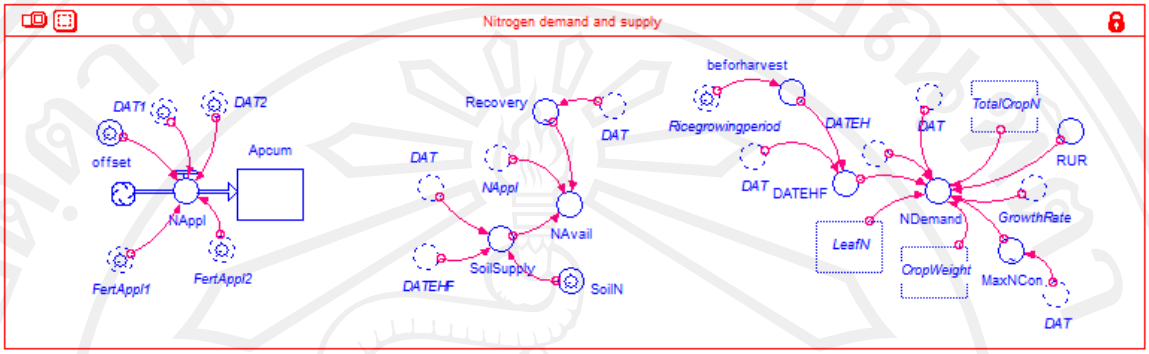



### Phenology

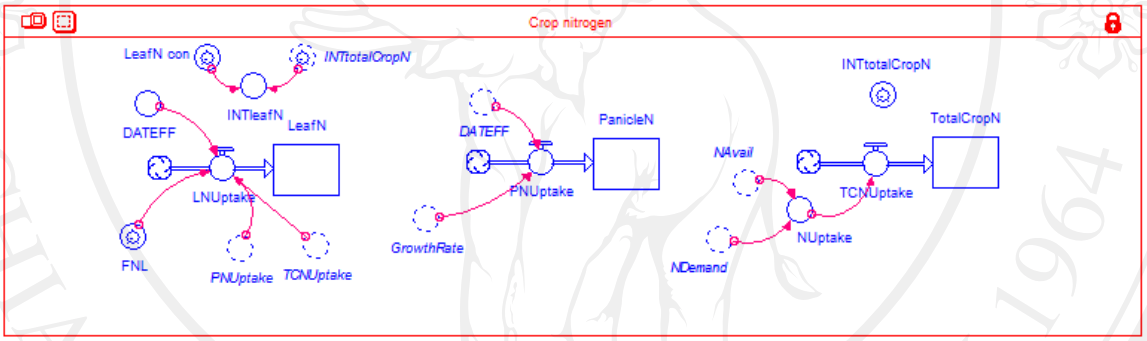


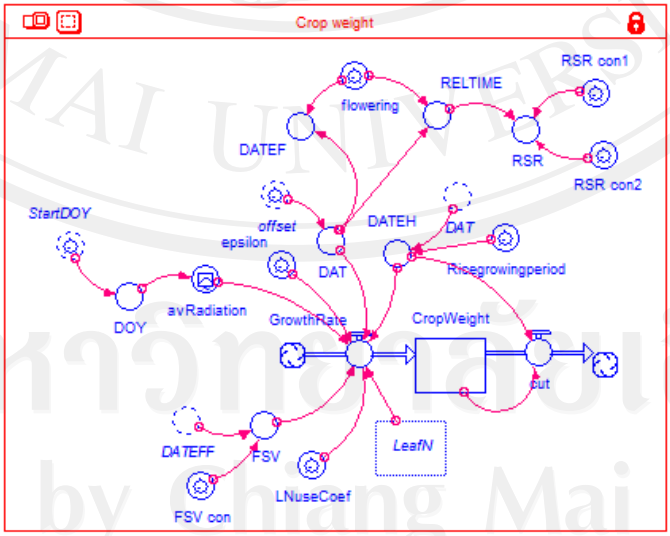
## Nitrogen demand and supply



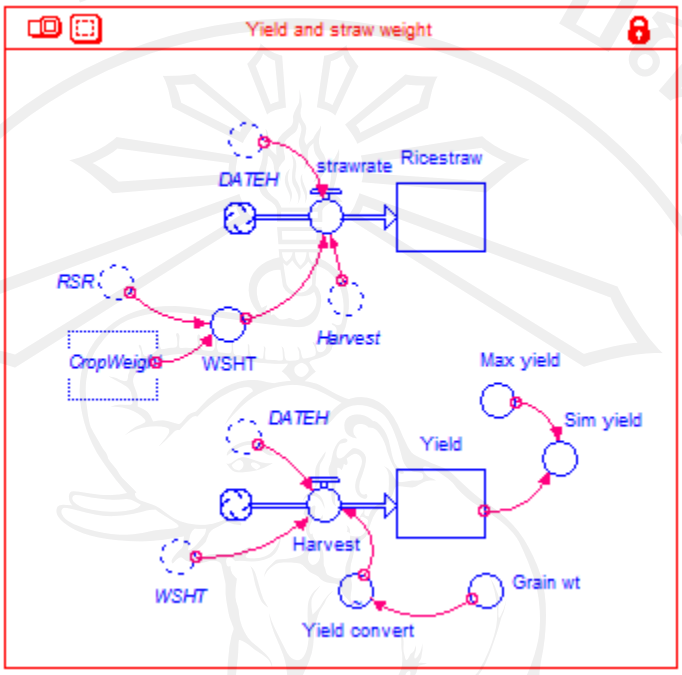

## Crop nitrogen



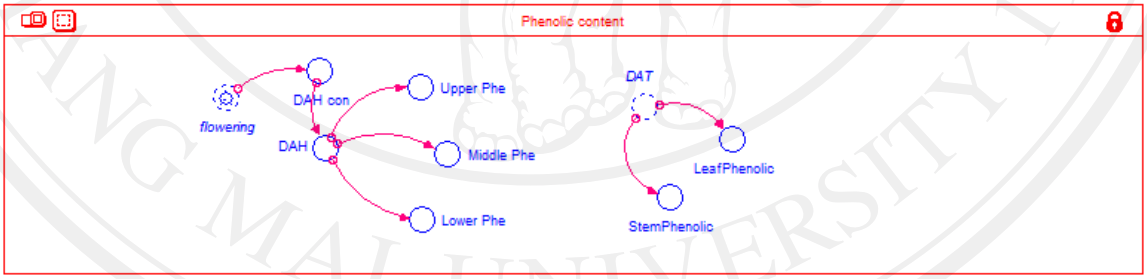

## Crop weight



**Yield and straw weight**




**Phenolic content**



# APPENDIX C

## STELLA: Listing of model equation

**Crop nitrogen**

LeafN(t) = LeafN(t - dt) + (LNUptake) * dt

INIT LeafN = INTleafN

INFLOWS:

LNUptake = IF(DATEFF=0) THEN (TCNUptake*FNL) ELSE (FNL*(TCNUptake-PNUptake))

PanicleN(t) = PanicleN(t - dt) + (PNUptake) * dt

INIT PanicleN = 0.01*0.4

INFLOWS:

PNUptake = IF(DATEFF=1) THEN 0.01*GrowthRate ELSE 0.0

TotalCropN(t) = TotalCropN(t - dt) + (TCNUptake) * dt

INIT TotalCropN = INTtotalCropN

INFLOWS:

TCNUptake = NUptake

DATEFF = 1

FNL = 0.5

INTleafN = LeafN_con*INTtotalCropN

INTtotalCropN = 0.4

LeafN_con = 0.5

NUptake = MAX(0.0,MIN(NAvail,NDemand))

**Crop weight**

CropWeight(t) = CropWeight(t - dt) + (GrowthRate - cut) * dt

INIT CropWeight = 1

INFLOWS:

GrowthRate = IF(DAT<=0)or(DATEH=1) THEN 0 ELSE FSV*LNuseCoef*LeafN*(1-exp(-(epsilon*avRadiation)/(LNuseCoef*LeafN*0.1)))

OUTFLOWS:

cut = IF(DATEH=1) THEN CropWeight ELSE 0

DAT = TIME-offset

DATEF = IF(DAT>=flowering) THEN 1 ELSE 0

DATEH = IF (DAT>=Ricegrowingperiod) THEN 1 ELSE 0

DOY = MOD(StartDOY+TIME,365)

epsilon = 2.5

flowering = 73

FSV = IF(DATEFF=1) THEN FSV_con ELSE 1

FSV_con = 0.83

LNuseCoef = 10.0

RELTIME = IF(DAT<=0) THEN 0 ELSE DAT/flowering

Ricegrowingperiod = 105

RSR = IF(RELTIME<1) THEN RSR_con2-(RSR_con2-RSR_con1)*RELTIME ELSE RSR_con1

RSR_con1 = 0.15

RSR_con2 = 0.4

avRadiation = GRAPH(DOY)

(0.00, 18.1), (0.274, 17.3), (0.548, 18.2), (0.822, 18.1), (1.10, 17.7), (1.37, 18.4), (1.64, 15.9), (1.92, 17.4), (2.19, 15.2), (2.47, 17.9), (2.74, 18.4), (3.01, 18.0), (3.29, 18.3), (3.56, 18.5), (3.84, 18.6), (4.11, 19.0), (4.38, 19.1), (4.66, 18.9), (4.93, 19.1), (5.21, 18.9), (5.48, 19.2), (5.75, 19.3), (6.03, 18.5), (6.30, 16.3), (6.58, 18.5), (6.85, 18.8), (7.12, 18.4), (7.40, 19.3), (7.67, 19.0), (7.95, 19.5), (8.22, 19.1), (8.49, 19.0), (8.77, 19.4), (9.04, 20.0), (9.32, 18.1), (9.59, 17.1), (9.86, 17.5), (10.1, 16.1), (10.4, 16.5), (10.7, 16.2), (11.0, 15.7), (11.2, 18.3), (11.5, 20.4), (11.8, 18.0), (12.1, 20.8), (12.3, 21.2), (12.6, 21.2), (12.9, 21.6), (13.2, 21.6), (13.4, 20.6), (13.7, 21.0), (14.0, 21.8), (14.2, 21.8), (14.5, 21.4), (14.8, 20.6), (15.1, 22.4), (15.3, 21.7), (15.6, 22.1), (15.9, 21.7), (16.2, 20.5), (16.4, 20.4), (16.7, 20.3), (17.0, 21.6), (17.3, 20.8), (17.5, 22.1), (17.8, 19.9), (18.1, 21.9), (18.4, 21.1), (18.6, 21.7), (18.9, 21.0), (19.2, 22.3), (19.5, 21.7), (19.7, 21.4), (20.0, 20.5), (20.3, 22.5), (20.5, 22.9), (20.8, 22.4), (21.1, 16.7), (21.4, 20.8), (21.6, 22.2), (21.9, 22.1), (22.2, 20.2), (22.5, 21.2), (22.7, 22.8), (23.0, 23.4), (23.3, 23.4), (23.6, 21.7), (23.8, 17.1), (24.1, 11.6), (24.4, 14.0), (24.7, 17.9), (24.9, 22.8), (25.2, 23.6), (25.5, 23.6), (25.8, 23.9), (26.0, 24.1), (26.3, 22.6), (26.6, 23.2), (26.8, 11.0), (27.1, 22.0), (27.4, 23.3), (27.7, 23.8), (27.9, 20.7), (28.2, 23.8),

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**Flowering GDD**

SumGDD(t) = SumGDD(t - dt) + (SGDD) * dt

INIT SumGDD = GDD

INFLOWS:

SGDD = sum(GDD)

INIflower = JDflower-StartDOY

JDflower = if SumGDD>ObsGDDF and sun_hr<ObsSunhr then DOY else 0

ObsGDDF = 1173

ObsSunhr = 11.5

GDD = GRAPH(DOY)

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**Harvest GDD**

GDDH = if SumGDD>ObsGDDF and sun_hr<ObsSunhr then SumGDD+GfillGDD else 0

GfillGDD = 570

INIhav = JDHav-StartDOY

JDHav = if SumGDD>SimGDDH then DOY else 0

SimGDDH = 2363

**Management**

DAT1 = 37

DAT2 = 55

FertAppl1 = 25

FertAppl2 = 72

StartDOY = 222

**Nitrogen demand and supply**

Apcum(t) = Apcum(t - dt) + (NAppl) * dt

INIT Apcum = 0

INFLOWS:

NAppl = step(FertAppl1*0.12,DAT1-offset)*(1/0.3)*(exp(-0.2*(time-DAT1-offset))-exp(-0.4*(time-DAT1-offset)))+step(FertAppl2*0.12,DAT2-offset)*(1/0.3)*(exp(-0.2*(time-DAT2-offset))-exp(-0.4*(time-DAT2-offset)))

beforharvest = Ricegrowingperiod-7

DATEHF = IF(DAT>=beforharvest) THEN 1 ELSE 0

NAvail = NAppl*Recovery+SoilSupply

NDemand = IF(DATEH=1) THEN 0 ELSE (IF(DAT<=0) THEN 0 ELSE (IF(TotalCropN<35.0) AND (DAT<20) THEN (RUR*TotalCropN) ELSE MIN(5,0.035*GrowthRate,(MaxNCon*(CropWeight+GrowthRate*DT)-TotalCropN)/DT,IF(LeafN>=100) THEN 0 ELSE 9999.9,IF(DATEHF=1) THEN 0 ELSE 9999.9)))

offset = 1

RUR = 0.2

SoilN = 0.6

SoilSupply = IF(DAT<=0) OR (DATEHF=1) THEN 0 ELSE SoilN

MaxNCon = GRAPH(DAT)

(0.00, 0.04), (20.0, 0.0255), (40.0, 0.0215), (60.0, 0.0195), (80.0, 0.015), (100, 0.0125), (120, 0.0115), (140, 0.01)

Recovery = GRAPH(DAT)

(0.00, 0.015), (5.17, 0.09), (10.3, 0.115), (15.5, 0.155), (20.7, 0.225), (25.9, 0.28), (31.0, 0.325), (36.2, 0.39), (41.4, 0.445), (46.6, 0.5), (51.7, 0.57), (56.9, 0.655), (62.1, 0.805), (67.2, 0.4), (72.4, 0.00), (77.6, 0.00), (82.8, 0.00), (87.9, 0.00), (93.1, 0.00), (98.3, 0.00), (103, 0.00), (109, 0.00), (114, 0.00), (119, 0.00), (124, 0.00), (129, 0.00), (134, 0.00), (140, 0.00), (145, 0.00), (150, 0.00)

**Phenolic content**

DAH = TIME-DAH_con

DAH_con = flowering

LeafPhenolic = -.0108*(DAT^2)+1.1455*DAT+67.801

Lower_Phe = 0.0483*(DAH^3)-1.9148*(DAH^2)+18.291*DAH+13.349

Middle_Phe = 0.0315*(DAH^3)-1.3896*(DAH^2)+15.399*DAH+5.2309

StemPhenolic = 0.0093*(DAT^2)-0.7755*DAT+33.832

Upper_Phe = 0.0068*(DAH^3)-0.7337*(DAH^2)+13.397*DAH+3.3637

**Yield and straw weight**

Ricestraw(t) = Ricestraw(t - dt) + (strawrate) * dt

INIT Ricestraw = 0

INFLOWS:

strawrate = IF(DATEH=1) THEN WSHT-Harvest ELSE 0

Yield(t) = Yield(t - dt) + (Harvest) * dt

INIT Yield = 0

INFLOWS:

Harvest = IF(DATEH=1) THEN WSHT*Yield_convert ELSE 0

Grain_wt = 40

Max_yield = 4000

Sim_yield = MIN(Yield,Max_yield)

WSHT = CropWeight/(1+RSR)

Yield_convert = GRAPH(Grain_wt)

(25.0, 0.25), (27.9, 0.3), (30.7, 0.35), (33.6, 0.4), (36.4, 0.45), (39.3, 0.5), (42.1, 0.55), (45.0, 0.6)

## APPENDIX D

**Appendix table 1** Alphabetical list of all acronyms used in the model.

| Acronym | Explanation | Unit |
|---|---|---|
| Apcum | cumulative fertilizer nitrogen applied to the rice field | [kg N ha-1] |
| avRadiation | daily average radiation | [MJm-2 d-1] |
| beforeharvest | rice growth period minus seven days | [d] |
| CropWeight | total DM produced on rice field (roots and shoots) | [kg DM/ha] |
| cut | total amount of rice DM harvested (roots and shoots | [kg DM/(ha*d)] |
| DAH | day after flowering | [day] |
| DAH_con | day after flowering convertor | [-] |
| DAT | days after rice transplanting | [days] |
| DAT1 | date of first fertilizer application to rice field | [DAT] |
| DAT2 | date of second fertilizer application to rice field | [DAT] |
| DATEF | date of rice flowering | [-] |
| DATEFF | date of rice first flowering | [-] |
| DATEH | date of rice harvest | [-] |
| DATEHF | one week before rice harvest | [-] |
| DOY | day of year (Julian date) | [-] |
| epsilon | initial global radiation use coefficient of rice | [g DM/(MJ*m$^2$)] |

**Appendix table 1** (Continue)

| Acronym | Explanation | Unit |
|---|---|---|
| FertAppl1 | amount of nitrogen applied to rice field on DAT1 | [kg N/ha] |
| FertAppl2 | amount of nitrogen applied to rice field on DAT2 | [kg N/ha] |
| flowering | day of rice flowering | [-] |
| FNL | fraction of total rice nitrogen stored in the canopy | [g/g] |
| FSV | rice growth calibration parameter | [-] |
| FSV_con | rice growth calibration converter | [-] |
| GDD | daily growing degree day | [$^{o}$C] |
| GDDH | growing degree days to maturity | [$^{o}$C] |
| GfillGDD | growing degree days from flowering to maturity | [$^{o}$C] |
| Grain_wt | 1000-grain weight | [g] |
| GrowthRate | rice growth rate | [kg DM/(ha*d)] |
| Harvest | amount of grains and hulls harvested | [kg DM/(ha*d)] |
| INIflower | day after planting to flowering | [-] |
| INIhav | day after planting to harvesting | [-] |
| INTleafN | initial leaf nitrogen | [kg N/ha] |
| INTtotalCropN | initial total crop nitrogen | [kg N/ha] |
| JDflower | day of rice flowering (Julian date) | [-] |
| JDHav | day of rice harvesting (Julian date) | [-] |
| LeafN | amount of nitrogen in the rice canopy | [kg N/ha] |
| LeafN _con | leaf nitrogen converter | |
| LeafPhenolic | phenolic content in leave | [mg/ml GAE] |
| LNUptake | leaf nitrogen uptake | [kg N/(ha*d)] |
| LNuseCoef | initial leaf nitrogen used coefficient | [kg DM/kg leaf N] |

**Appendix table 1** (Continue)

| Acronym | Explanation | Unit |
|---|---|---|
| Lower_Phe | phenolic content in panicle (lower part) | [mg/ml GAE] |
| MaxNCon | maximal nitrogen concentration in the rice plant | [kg N/kg] |
| Max_yield | Maximum yield | [kg/ha] |
| Middle_Phe | phenolic content in panicle (middle part) | [mg/ml GAE] |
| NAppl | rate of nitrogen application to the rice field | [kg N/(ha*d)] |
| NAvail | available soil nitrogen | [kg N/ha] |
| NDemand | nitrogen demand of the rice crop | [kg N/(ha*d)] |
| NUptake | nitrogen uptake of the rice plant | [kg N/(ha*d)] |
| ObsGDDF | observed accumulated growing degree day from planting to flowering | [$^{o}$C] |
| ObsSunhr | observed day length from planting to flowering | [hour] |
| offset | time between start of simulation and rice transplanting | [d] |
| PanicleN | amount of nitrogen stored in the rice panicle | [kg N/ha] |
| PNUptake | panicle nitrogen uptake | [kg N/(ha*d)] |
| Recovery | fraction of applied fertilizer which is available to the plant | [g/g] |
| RELTIME | root-shoot ratio converter | [-] |
| Ricegrowingperiod | rice growth period | [d] |
| Ricestraw | amount of rice straw harvested | [kg/ha] |
| RSR | root - shoot ratio | [-] |
| RSR_con1 | root - shoot ratio converter 1 | [-] |
| RSR_con2 | root - shoot ratio converter 2 | [-] |
| RUR | relative nitrogen uptake coefficient | [1/d] |
| SGDD | accumulate growing degree day rate | [$^{o}$C/d] |

**Appendix table 1** (Continue)

| Acronym | Explanation | Unit |
|---|---|---|
| SimGDDH | simulated growing degree days to maturity | [$^{o}$C] |
| Sim_yield | simulated yield | [kg/ha] |
| SoilN | nitrogen in soil | [kg N/ha] |
| SoilSupply | nitrogen supply by the soil, soil fertility | [kg N/(ha*d)] |
| StartDOY | starting day of the simulation, Julian date | [-] |
| StemPhenolic | phenolic content in stem | [mg/ml GAE] |
| strawrate | amount of rice straw harvested | [kg/(ha*d)] |
| SumGDD | accumulate growing degree day | [$^{o}$C] |
| sun_hr | daily day length | [hour] |
| TCNUptake | total crop nitrogen uptake | [kg N/(ha*d)] |
| TotalCropN | total crop nitrogen | [kg/ha] |
| Upper_Phe | phenolic content in panicle (upper part) | [mg/ml GAE] |
| WSHT | rice shoot weight | [kg DM/ha] |
| Yield | amount of primary products harvested | [kg DM/ha] |
| Yield_convert | yield converter | [-] |

## APPENDIX E

### Weather input

**Appendix table 2** Daily growing degree day, day length and solar radiation.

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 1 | 13.00 | 10.9 | 18.07 |
| 2 | 12.25 | 10.9 | 17.26 |
| 3 | 10.30 | 10.9 | 18.22 |
| 4 | 10.05 | 10.9 | 18.14 |
| 5 | 10.75 | 10.9 | 17.65 |
| 6 | 11.75 | 10.9 | 18.41 |
| 7 | 12.33 | 10.9 | 15.95 |
| 8 | 12.15 | 10.9 | 17.44 |
| 9 | 12.00 | 10.9 | 15.18 |
| 10 | 12.10 | 10.9 | 17.93 |
| 11 | 11.00 | 10.9 | 18.39 |
| 12 | 11.05 | 11.0 | 18.01 |
| 13 | 11.00 | 11.0 | 18.26 |
| 14 | 11.25 | 11.0 | 18.52 |
| 15 | 11.75 | 11.0 | 18.57 |
| 16 | 11.85 | 11.0 | 19.04 |
| 17 | 12.50 | 11.0 | 19.09 |
| 18 | 12.60 | 11.0 | 18.93 |
| 19 | 12.25 | 11.0 | 19.09 |
| 20 | 12.50 | 11.0 | 18.94 |
| 21 | 12.55 | 11.0 | 19.21 |
| 22 | 12.00 | 11.0 | 19.27 |
| 23 | 12.05 | 11.1 | 18.47 |
| 24 | 12.75 | 11.1 | 16.26 |
| 25 | 13.85 | 11.1 | 18.48 |
| 26 | 14.50 | 11.1 | 18.76 |
| 27 | 14.35 | 11.1 | 18.38 |
| 28 | 14.50 | 11.1 | 19.32 |
| 29 | 11.45 | 11.1 | 18.95 |

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 30 | 13.50 | 11.1 | 19.46 |
| 31 | 15.25 | 11.2 | 19.09 |
| 32 | 14.10 | 11.2 | 19.04 |
| 33 | 8.35 | 11.2 | 19.45 |
| 34 | 12.45 | 11.2 | 19.96 |
| 35 | 13.35 | 11.2 | 18.14 |
| 36 | 12.30 | 11.2 | 17.09 |
| 37 | 12.35 | 11.2 | 17.49 |
| 38 | 12.50 | 11.3 | 16.09 |
| 39 | 12.75 | 11.3 | 16.49 |
| 40 | 13.00 | 11.3 | 16.22 |
| 41 | 13.25 | 11.3 | 15.71 |
| 42 | 14.50 | 11.3 | 18.28 |
| 43 | 14.55 | 11.3 | 20.42 |
| 44 | 16.95 | 11.3 | 17.97 |
| 45 | 15.70 | 11.4 | 20.80 |
| 46 | 15.30 | 11.4 | 21.23 |
| 47 | 13.75 | 11.4 | 21.19 |
| 48 | 11.50 | 11.4 | 21.62 |
| 49 | 11.50 | 11.4 | 21.59 |
| 50 | 15.00 | 11.4 | 20.61 |
| 51 | 15.50 | 11.5 | 21.04 |
| 52 | 14.30 | 11.5 | 21.83 |
| 53 | 13.75 | 11.5 | 21.79 |
| 54 | 14.40 | 11.5 | 21.40 |
| 55 | 13.25 | 11.5 | 20.64 |
| 56 | 12.75 | 11.5 | 22.39 |
| 57 | 13.00 | 11.6 | 21.75 |
| 58 | 14.05 | 11.6 | 22.07 |

**Appendix table 2** (Continue)

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 59 | 15.05 | 11.6 | 21.66 |
| 60 | 15.00 | 11.6 | 20.53 |
| 61 | 14.75 | 11.6 | 20.36 |
| 62 | 15.00 | 11.6 | 20.31 |
| 63 | 14.70 | 11.7 | 21.60 |
| 64 | 15.25 | 11.7 | 20.82 |
| 65 | 14.50 | 11.7 | 22.11 |
| 66 | 14.00 | 11.7 | 19.85 |
| 67 | 13.85 | 11.7 | 21.88 |
| 68 | 14.00 | 11.7 | 21.09 |
| 69 | 14.50 | 11.8 | 21.65 |
| 70 | 14.25 | 11.8 | 20.98 |
| 71 | 13.75 | 11.8 | 22.28 |
| 72 | 14.00 | 11.8 | 21.72 |
| 3 | 13.50 | 11.8 | 21.41 |
| 74 | 14.50 | 11.9 | 20.48 |
| 75 | 15.70 | 11.9 | 22.54 |
| 76 | 15.60 | 11.9 | 22.85 |
| 77 | 15.50 | 11.9 | 22.41 |
| 78 | 15.30 | 11.9 | 16.68 |
| 79 | 15.00 | 11.9 | 20.76 |
| 80 | 15.00 | 12.0 | 22.20 |
| 81 | 14.65 | 12.0 | 22.13 |
| 82 | 14.70 | 12.0 | 20.16 |
| 83 | 14.75 | 12.0 | 21.22 |
| 84 | 16.00 | 12.0 | 22.80 |
| 85 | 15.90 | 12.1 | 23.36 |
| 86 | 15.50 | 12.1 | 23.40 |
| 87 | 15.80 | 12.1 | 21.66 |
| 88 | 16.00 | 12.1 | 17.10 |
| 89 | 16.45 | 12.1 | 11.64 |
| 90 | 17.00 | 12.1 | 13.97 |
| 91 | 16.05 | 12.2 | 17.86 |
| 92 | 15.75 | 12.2 | 22.77 |
| 93 | 16.25 | 12.2 | 23.58 |

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 94 | 16.00 | 12.2 | 23.62 |
| 95 | 16.30 | 12.2 | 23.92 |
| 96 | 16.75 | 12.3 | 24.08 |
| 97 | 16.65 | 12.3 | 22.57 |
| 98 | 16.05 | 12.3 | 23.25 |
| 99 | 16.50 | 12.3 | 11.00 |
| 100 | 16.35 | 12.3 | 22.02 |
| 101 | 16.40 | 12.3 | 23.34 |
| 102 | 16.75 | 12.4 | 23.76 |
| 103 | 17.00 | 12.4 | 20.67 |
| 104 | 17.30 | 12.4 | 23.81 |
| 105 | 17.20 | 12.4 | 20.72 |
| 106 | 17.00 | 12.4 | 18.93 |
| 107 | 18.05 | 12.5 | 19.47 |
| 108 | 17.20 | 12.5 | 13.26 |
| 109 | 18.70 | 12.5 | 20.03 |
| 110 | 18.55 | 12.5 | 20.95 |
| 111 | 17.70 | 12.5 | 21.88 |
| 112 | 18.25 | 12.5 | 18.39 |
| 113 | 18.50 | 12.6 | 23.73 |
| 114 | 16.40 | 12.6 | 22.31 |
| 115 | 17.00 | 12.6 | 20.12 |
| 116 | 16.25 | 12.6 | 16.50 |
| 117 | 17.75 | 12.6 | 18.46 |
| 118 | 17.30 | 12.6 | 16.52 |
| 119 | 16.75 | 12.6 | 12.90 |
| 120 | 15.75 | 12.7 | 17.84 |
| 121 | 15.40 | 12.7 | 23.03 |
| 122 | 15.70 | 12.7 | 20.06 |
| 123 | 16.80 | 12.7 | 23.69 |
| 124 | 16.50 | 12.7 | 25.64 |
| 125 | 14.40 | 12.7 | 25.13 |
| 126 | 14.00 | 12.8 | 26.29 |
| 127 | 16.00 | 12.8 | 26.30 |
| 128 | 17.00 | 12.8 | 21.38 |

**Appendix table 2** (Continue)

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 129 | 17.50 | 12.8 | 21.77 |
| 130 | 17.05 | 12.8 | 22.42 |
| 131 | 16.75 | 12.8 | 17.39 |
| 132 | 16.80 | 12.8 | 25.00 |
| 133 | 16.35 | 12.9 | 25.65 |
| 134 | 16.55 | 12.9 | 15.98 |
| 135 | 17.00 | 12.9 | 11.47 |
| 136 | 15.15 | 12.9 | 11.47 |
| 137 | 16.25 | 12.9 | 11.48 |
| 138 | 16.70 | 12.9 | 11.48 |
| 139 | 16.50 | 12.9 | 13.03 |
| 140 | 17.05 | 12.9 | 11.49 |
| 141 | 16.05 | 12.9 | 13.03 |
| 142 | 16.60 | 13.0 | 11.88 |
| 143 | 16.35 | 13.0 | 17.65 |
| 144 | 16.90 | 13.0 | 12.78 |
| 145 | 16.75 | 13.0 | 16.37 |
| 146 | 16.75 | 13.0 | 22.39 |
| 147 | 16.55 | 13.0 | 20.59 |
| 148 | 16.80 | 13.0 | 22.25 |
| 149 | 17.00 | 13.0 | 12.78 |
| 150 | 16.55 | 13.0 | 18.28 |
| 151 | 17.30 | 13.0 | 12.02 |
| 152 | 17.00 | 13.1 | 14.69 |
| 153 | 16.75 | 13.1 | 20.18 |
| 154 | 16.75 | 13.1 | 15.85 |
| 155 | 17.00 | 13.1 | 17.88 |
| 156 | 17.05 | 13.1 | 15.33 |
| 157 | 16.75 | 13.1 | 16.09 |
| 158 | 16.55 | 13.1 | 16.60 |
| 159 | 16.50 | 13.1 | 17.24 |
| 160 | 16.25 | 13.1 | 16.60 |
| 161 | 16.80 | 13.1 | 15.32 |
| 162 | 16.85 | 13.1 | 15.32 |
| 163 | 17.45 | 13.1 | 18.37 |

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 164 | 16.30 | 13.1 | 20.40 |
| 165 | 16.90 | 13.1 | 22.43 |
| 166 | 17.50 | 13.1 | 17.85 |
| 167 | 17.20 | 13.1 | 18.11 |
| 168 | 16.70 | 13.1 | 16.83 |
| 169 | 16.45 | 13.1 | 16.58 |
| 170 | 16.95 | 13.1 | 15.43 |
| 171 | 17.00 | 13.1 | 17.21 |
| 172 | 17.00 | 13.1 | 13.78 |
| 173 | 17.00 | 13.1 | 22.40 |
| 174 | 16.90 | 13.1 | 18.85 |
| 175 | 17.00 | 13.1 | 19.74 |
| 176 | 17.80 | 13.1 | 23.54 |
| 177 | 17.40 | 13.1 | 19.73 |
| 178 | 17.05 | 13.1 | 22.90 |
| 179 | 17.30 | 13.1 | 20.36 |
| 180 | 16.95 | 13.1 | 15.29 |
| 181 | 17.30 | 13.1 | 15.92 |
| 182 | 17.25 | 13.1 | 14.65 |
| 183 | 16.25 | 13.1 | 15.54 |
| 184 | 17.55 | 13.1 | 14.33 |
| 185 | 17.20 | 13.1 | 17.57 |
| 186 | 16.95 | 13.1 | 12.11 |
| 187 | 17.00 | 13.1 | 11.47 |
| 188 | 16.80 | 13.1 | 12.11 |
| 189 | 16.75 | 13.1 | 11.47 |
| 190 | 17.25 | 13.1 | 12.61 |
| 191 | 17.05 | 13.1 | 14.51 |
| 192 | 16.78 | 13.1 | 15.91 |
| 193 | 16.50 | 13.1 | 12.09 |
| 194 | 17.00 | 13.1 | 12.22 |
| 195 | 17.00 | 13.0 | 17.81 |
| 196 | 17.00 | 13.0 | 14.50 |
| 197 | 16.50 | 13.0 | 14.25 |
| 198 | 16.80 | 13.0 | 12.08 |

**Appendix table 2** (Continue)

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 199 | 17.45 | 13.0 | 11.44 |
| 200 | 16.95 | 13.0 | 11.43 |
| 201 | 15.75 | 13.0 | 11.43 |
| 202 | 16.90 | 13.0 | 15.63 |
| 203 | 16.75 | 13.0 | 11.68 |
| 204 | 16.75 | 13.0 | 22.14 |
| 205 | 16.85 | 13.0 | 24.05 |
| 206 | 17.98 | 12.9 | 14.34 |
| 207 | 17.59 | 12.9 | 12.81 |
| 208 | 16.55 | 12.9 | 11.40 |
| 209 | 17.35 | 12.9 | 12.54 |
| 210 | 17.00 | 12.9 | 12.02 |
| 211 | 17.40 | 12.9 | 12.02 |
| 212 | 17.00 | 12.9 | 11.88 |
| 213 | 17.30 | 12.9 | 12.90 |
| 214 | 17.50 | 12.9 | 11.87 |
| 215 | 16.65 | 12.8 | 11.35 |
| 216 | 17.00 | 12.8 | 18.26 |
| 217 | 16.70 | 12.8 | 18.38 |
| 218 | 16.80 | 12.8 | 13.89 |
| 219 | 16.15 | 12.8 | 20.55 |
| 220 | 17.50 | 12.8 | 11.69 |
| 221 | 17.50 | 12.8 | 17.97 |
| 222 | 16.10 | 12.7 | 15.65 |
| 223 | 16.25 | 12.7 | 17.95 |
| 224 | 16.55 | 12.7 | 17.04 |
| 225 | 16.00 | 12.7 | 13.31 |
| 226 | 16.75 | 12.7 | 17.92 |
| 227 | 15.75 | 12.7 | 23.44 |
| 228 | 16.75 | 12.7 | 16.10 |
| 229 | 16.50 | 12.6 | 15.57 |
| 230 | 16.90 | 12.6 | 16.85 |
| 231 | 16.60 | 12.6 | 11.82 |
| 232 | 16.30 | 12.6 | 11.16 |
| 233 | 16.55 | 12.6 | 11.15 |

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 234 | 16.90 | 12.6 | 11.13 |
| 235 | 16.75 | 12.6 | 12.92 |
| 236 | 16.80 | 12.5 | 16.24 |
| 237 | 17.00 | 12.5 | 13.01 |
| 238 | 16.75 | 12.5 | 13.38 |
| 239 | 16.75 | 12.5 | 15.16 |
| 240 | 16.75 | 12.5 | 11.67 |
| 241 | 16.85 | 12.5 | 13.58 |
| 242 | 16.60 | 12.4 | 11.76 |
| 243 | 16.75 | 12.4 | 10.97 |
| 244 | 17.00 | 12.4 | 14.15 |
| 245 | 16.25 | 12.4 | 19.89 |
| 246 | 16.75 | 12.4 | 20.76 |
| 247 | 16.70 | 12.4 | 23.67 |
| 248 | 17.00 | 12.3 | 20.32 |
| 249 | 16.60 | 12.3 | 15.18 |
| 250 | 16.95 | 12.3 | 20.00 |
| 251 | 16.25 | 12.3 | 20.23 |
| 252 | 16.25 | 12.3 | 15.99 |
| 253 | 17.15 | 12.2 | 14.05 |
| 254 | 16.55 | 12.2 | 13.51 |
| 255 | 16.25 | 12.2 | 15.64 |
| 256 | 16.00 | 12.2 | 17.01 |
| 257 | 17.25 | 12.2 | 19.13 |
| 258 | 17.05 | 12.2 | 16.30 |
| 259 | 16.70 | 12.1 | 17.41 |
| 260 | 16.75 | 12.1 | 20.65 |
| 261 | 16.75 | 12.1 | 20.61 |
| 262 | 16.00 | 12.1 | 14.27 |
| 263 | 16.60 | 12.1 | 14.23 |
| 264 | 17.35 | 12.1 | 13.57 |
| 265 | 16.95 | 12.0 | 16.92 |
| 266 | 16.15 | 12.0 | 17.88 |
| 267 | 16.45 | 12.0 | 20.33 |
| 268 | 16.35 | 12.0 | 16.28 |

**Appendix table 2** (Continue)

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 269 | 17.00 | 12.0 | 15.24 |
| 270 | 16.80 | 11.9 | 12.84 |
| 271 | 16.45 | 11.9 | 12.42 |
| 272 | 16.50 | 11.9 | 14.61 |
| 273 | 16.50 | 11.9 | 22.59 |
| 274 | 16.70 | 11.9 | 21.17 |
| 275 | 16.25 | 11.9 | 20.62 |
| 276 | 16.50 | 11.8 | 10.01 |
| 277 | 16.70 | 11.8 | 17.31 |
| 278 | 16.25 | 11.8 | 17.01 |
| 279 | 16.60 | 11.8 | 16.23 |
| 280 | 16.35 | 11.8 | 14.12 |
| 281 | 16.05 | 11.7 | 15.27 |
| 282 | 16.30 | 11.7 | 10.98 |
| 283 | 16.60 | 11.7 | 15.40 |
| 284 | 16.10 | 11.7 | 14.03 |
| 285 | 16.30 | 11.7 | 15.29 |
| 286 | 17.05 | 11.7 | 19.79 |
| 287 | 15.70 | 11.6 | 20.55 |
| 288 | 15.60 | 11.6 | 21.32 |
| 289 | 15.50 | 11.6 | 21.60 |
| 290 | 16.00 | 11.6 | 20.10 |
| 291 | 16.35 | 11.6 | 18.97 |
| 292 | 15.95 | 11.5 | 20.20 |
| 293 | 16.25 | 11.5 | 18.13 |
| 294 | 16.25 | 11.5 | 20.05 |
| 295 | 16.50 | 11.5 | 19.04 |
| 296 | 16.35 | 11.5 | 11.88 |
| 297 | 16.00 | 11.5 | 18.44 |
| 298 | 16.35 | 11.4 | 14.90 |
| 299 | 16.60 | 11.4 | 20.15 |
| 300 | 16.50 | 11.4 | 19.61 |
| 301 | 16.75 | 11.4 | 19.77 |
| 302 | 15.95 | 11.4 | 18.10 |
| 303 | 16.00 | 11.4 | 19.74 |
| 304 | 16.00 | 11.3 | 19.44 |

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 305 | 16.05 | 11.3 | 17.90 |
| 306 | 16.80 | 11.3 | 17.49 |
| 307 | 16.60 | 11.3 | 20.24 |
| 308 | 16.75 | 11.3 | 20.16 |
| 309 | 15.50 | 11.3 | 19.87 |
| 310 | 16.00 | 11.3 | 19.46 |
| 311 | 16.30 | 11.2 | 12.95 |
| 312 | 15.75 | 11.2 | 18.88 |
| 313 | 16.15 | 11.2 | 19.25 |
| 314 | 15.20 | 11.2 | 19.74 |
| 315 | 12.75 | 11.2 | 18.35 |
| 316 | 11.50 | 11.2 | 8.43 |
| 317 | 12.20 | 11.2 | 18.77 |
| 318 | 12.00 | 11.1 | 18.49 |
| 319 | 11.00 | 11.1 | 18.21 |
| 320 | 11.75 | 11.1 | 17.50 |
| 321 | 12.25 | 11.1 | 17.99 |
| 322 | 14.00 | 11.1 | 18.79 |
| 323 | 14.95 | 11.1 | 18.62 |
| 324 | 15.05 | 11.1 | 18.89 |
| 325 | 15.75 | 11.1 | 18.94 |
| 326 | 15.70 | 11.0 | 19.10 |
| 327 | 14.75 | 11.0 | 19.04 |
| 328 | 14.55 | 11.0 | 18.89 |
| 329 | 15.40 | 11.0 | 18.83 |
| 330 | 15.00 | 11.0 | 18.57 |
| 331 | 14.55 | 11.0 | 18.63 |
| 332 | 13.20 | 11.0 | 18.69 |
| 333 | 12.75 | 11.0 | 18.65 |
| 334 | 11.10 | 11.0 | 18.50 |
| 335 | 10.05 | 11.0 | 17.60 |
| 336 | 8.00 | 11.0 | 16.18 |
| 337 | 7.15 | 10.9 | 16.64 |
| 338 | 7.65 | 10.9 | 17.28 |
| 339 | 9.40 | 10.9 | 15.93 |
| 340 | 10.80 | 10.9 | 14.45 |

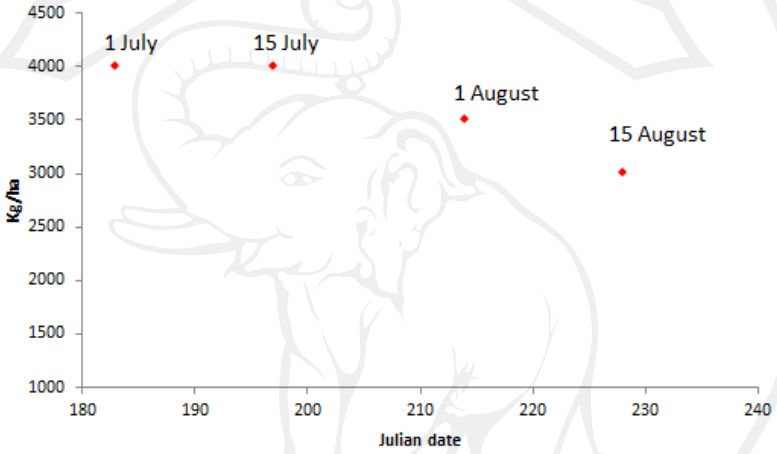
**Appendix table 2** (Continue)

| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 341 | 11.25 | 10.9 | 13.41 |
| 342 | 12.75 | 10.9 | 15.15 |
| 343 | 11.90 | 10.9 | 15.26 |
| 344 | 12.25 | 10.9 | 13.12 |
| 345 | 11.50 | 10.9 | 16.27 |
| 346 | 13.65 | 10.9 | 16.00 |
| 347 | 12.90 | 10.9 | 14.36 |
| 348 | 12.20 | 10.9 | 16.22 |
| 349 | 12.75 | 10.9 | 17.11 |
| 350 | 12.75 | 10.9 | 16.07 |
| 351 | 12.30 | 10.9 | 16.45 |
| 352 | 11.95 | 10.9 | 16.75 |
| 353 | 12.00 | 10.9 | 16.69 |

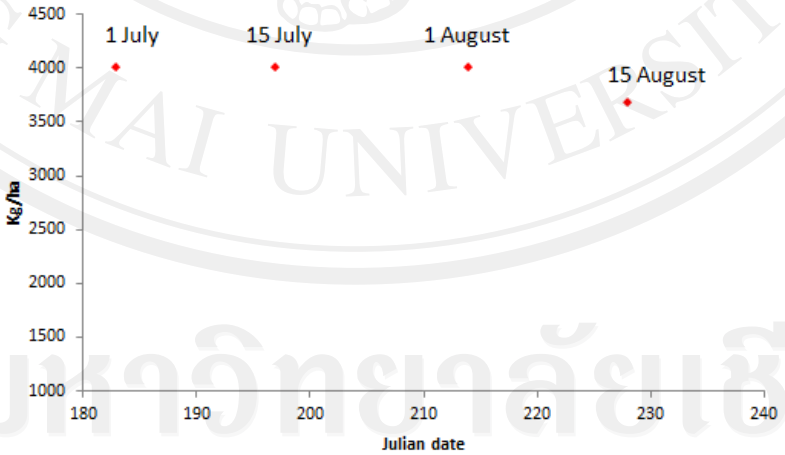
| DOY | GDD | Sun hr | avRadiation |
|---|---|---|---|
| 354 | 12.75 | 10.9 | 16.10 |
| 355 | 10.55 | 10.9 | 15.00 |
| 356 | 10.65 | 10.9 | 14.51 |
| 357 | 11.05 | 10.9 | 14.87 |
| 358 | 12.10 | 10.9 | 10.41 |
| 359 | 12.40 | 10.9 | 14.24 |
| 360 | 12.55 | 10.9 | 14.27 |
| 361 | 14.30 | 10.9 | 15.98 |
| 362 | 11.00 | 10.9 | 15.71 |
| 363 | 12.00 | 10.9 | 15.13 |
| 364 | 11.85 | 10.9 | 16.79 |
| 365 | 12.70 | 10.9 | 16.78 |
| 366 | 12.15 | 10.9 | 16.57 |

## APPENDIX F

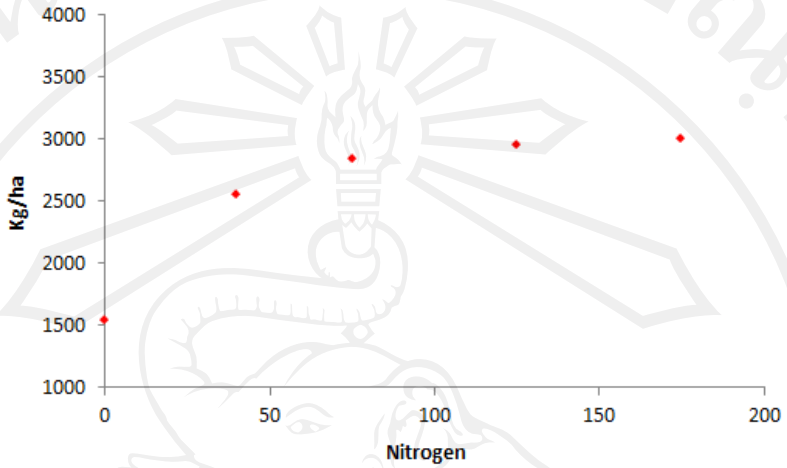
### Scenario simulation



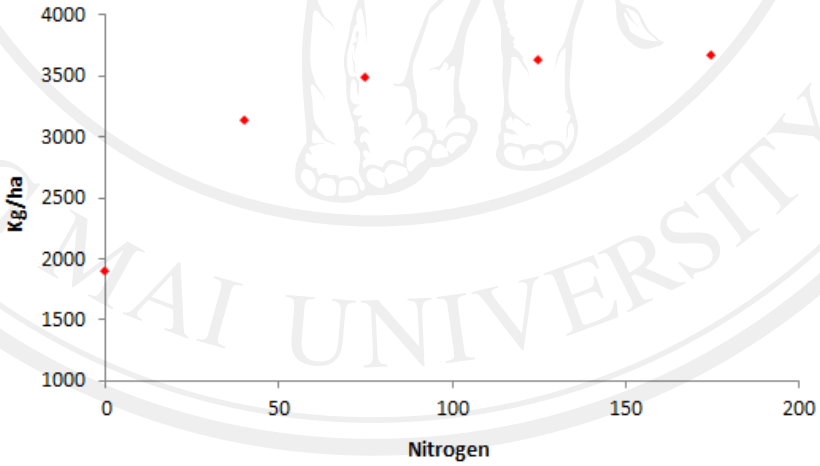

**Appendix figure 1** Simulated yield of MHS1 planted at 1 July, 15 July, 1 August and 15 August.



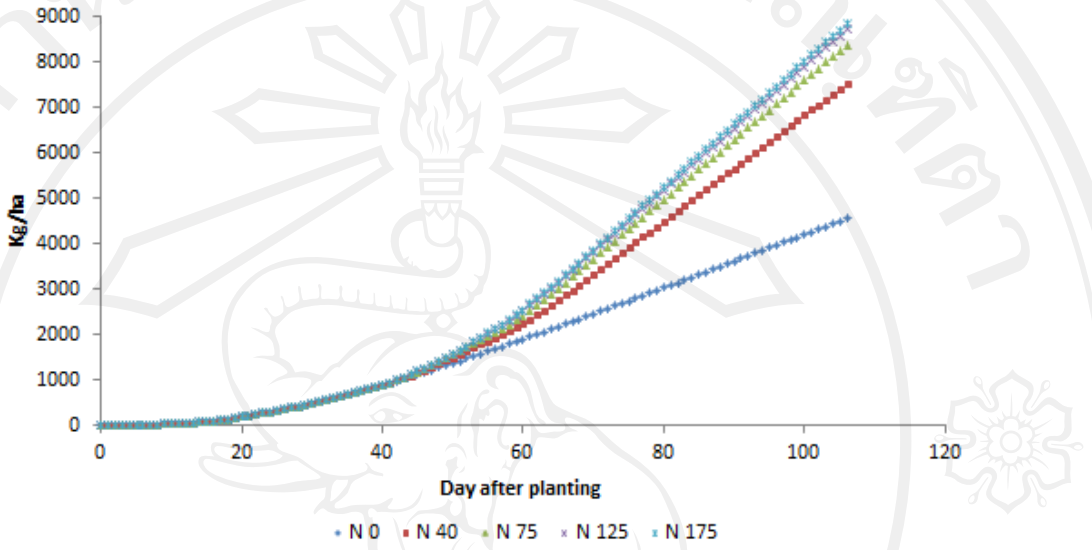

**Appendix figure 2** Simulated yield of PGMHS17 planted at 1 July, 15 July, 1 August and 15 August.




**Appendix figure 3** Simulated yield of MHS1 when applied with 0, 40, 75, 125 and 175 kgN/ha.




**Appendix figure 4** Simulated yield of PGMHS 17 when applied with 0, 40, 75, 125 and 175 kgN/ha.




**Appendix figure 5** Simulated biomass accumulation of MHS1 and PGMHS 17 applied with 0, 40, 75, 125 and 175 kgN/ha.

## CURRICULUM VITAE

**Name** Ms. Saibua Khempet

**Date of birth** 20 February 1981

**Education**

| | | |
|---|---|---|
| M.S. (Postharvest Technology) | 2005 | Chiang Mai University, Thailand |
| B.Sc. (Agronomy) | 2002 | Chiang Mai University, Thailand |