MODELLING THE GROWTH AND PRODUCTIVITY OF YAMS (*Dioscorea* spp.) IN THE PROGRAMMING LANGUAGE CSMP

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CONTENTS

SUMMARY

In this report a simulation model is presented for yams (Dioscorea spp.).

The model is kept relatively simple, with few parameters. The development of yams is described day-dependent and not as usual day-degree-dependent. The influence of sett weight planted on the growth and productivity of yams is taken into account in the model.

The model is divided into several sections; 1. emergence, 2. stem density, 3. leaf area growth until full ground cover, 4. leaf area growth until maturity, 5. dry-matter production and 6. tuber dry matter production.

Several parameters were needed to be enabled to run the model. Most of these parameters are based more or less on literature, but some of them (i.e. rate of sprout growth, rate of leaf area growth on daily basis, radiation use efficiency and the radiation data) are arbitrary fixed on certain values. Therefore, not much value is attached to the exact outcome of the simulation run, but more important was the path that lead to that outcome.

In order to validate the model, it is extremely important to have data sets in which all the relevant data have been measured in individual comprehensive experiments. The model is so developed that it leaves room for extention in case of more information.

1 INTRODUCTION

This report describes the progress that has been made in outlining a model for the growth and productivity of yams. Onwueme, I.C. and Haverkort, A.J. (1990) discussed the prospects and problems of modelling the growth and productivity of yams. This article has been the basis on which the present model has been developed.

The objective of their article was '...to outline the requirements for a model of yam growth and productivity and to identify obstacles and information gaps along the path of developing and validating such a model...'.

The model they proposed had to serve several purposes; '...Firstly, it will serve to provide a deeper understanding and physiological explanation of how the harvested yield of yam is brought about. Secondly, it will help to determine areas where gaps exist with respect to knowledge of the crop. And thirdly, the model will make it possible to predict the potential yield of the crop under various ecologies...'.

They expressed the necessity to keep the model relatively simple, with few parameters. This, because '...a more complex model requires the validitation of routines describing complex processes such as respiration, photosynthesis, or water status of the plants. Equipment and facilities for such validitation is often inadequate or lacking in most yam growing parts of the world...'.

2 THE MODEL

2.1 INTRODUCTION

In temperate climates the development of a crop is described day-degree-dependent. In tropical climates fluctuations in temperatures are of minor importance for the development of plants. Therefore, the development of yams is described day-dependent (appendix 1).

Usually the weight of the planted seed or bulb is of minor influence on the growth and productivity of a crop. Yam growth and productivity, on the contrary, greatly depends on the sett weight planted; proportion emergence, vigour of the sprout and the quantity of dry matter of the sett, translocated to the new tuber are directly influenced by the sett weight.

In the model a linear relationship between proportion emergence and sett weight is assumed to be as follows;

proportion emergence = 0.001 * sett weight + 0.6

This relationship is valid for sett weights that vary from 100g till 350g (derived from: Oriuwa, L.O. and Onwueme, I.C., 1980).

The influence of sett weight on vigour of sprout is neglected. The proportion of dry matter translocated from the sett to the new tuber (Onwueme, 1978) is not founded on research, but arbitrary fixed on 0.2.

2.2 DESCRIPTION OF THE MODEL

The simulation model is developed analogue to the relational diagram given in appendix 2. The model itself is written in the programming language CSMP (appendix 3). The model is divided in several sections;

1. emergence,
2. stem density,
3. leaf area growth until full ground cover,
4. leaf area growth until maturity,
5. dry matter production and
6. tuber dry matter production.

Time to plant emergence is dependent on rate of sprout growth on daily basis and planting depth. The sprout growth rate is assumed constant from planting till emergence, and is fixed on 3.5mm per day. The planting depth is fixed on 150mm.

Stem density in the model is dependent on row density, planting distance in row, number of plants per stand, number of stems per plant and proportion emergence. Row density and planting distance in row are both fixed on 1.1 (Oriuwa, L.O. and Onwueme, I.C., 1980). Number of plants per stand and number of stems per plant are both fixed on 1 (Onwueme, I.C and Haverkort, J.C., 1990). Proportion emergence has been explained in section 2.1.

Early leaf growth until full ground cover is dependent on rate of leaf growth on daily basis and initial leaf area per stem at emergence. 100% ground cover is thought to be equal to a leaf area index of 3. Rate of leaf growth is arbitrary fixed on 0.005m2 per day for the first fifty days, and on 0.25m2 per day afterwards. Initial leaf area per stem at emergence is arbitrary fixed on 0.00136m2 per stem.

The proportion ground cover is one until the onset of maturity. The rate of decline in proportion ground cover depends on the length of the decline period (see appendix 1). The day sum halfway the decline period is defined, because it is easy to determine the proportion ground cover = 0.5 value.

The dry matter production is dependent on the intercepted radiation, the radiation use efficiency and the initial weight. The intercepted radiation is dependent on the daily global radiation and the proportion ground cover. The radiation use efficiency is thought to be constant at 45%. This figure is chosen because it is not known if yam is a C3 or a C4 plant; 45% is in between. The initial weight is estimated at 20% of the sett weight (see section 2.1).

Tuber dry matter is dependent on the proportion total dry matter allocated to the tuber and on the initial weight. The proportion of total dry matter allocated to the tuber is derived from Onwueme (1978) (see appendix 4). It is assumed that the total amount of translocated sett to the new plant goes to the tuber.

Tuber dry weight is thought to be a constant percentage of the tuber fresh weight; i.e. 20%.

In appendix 5 the quantification of parameters and radiation data is summarized.

3 RESULTS OF THE MODEL RUN

3.1 INTRODUCTION

In this chapter the results of the simulation run are presented. The parameters RSPRG, RLAGDB, ILAST, FUNCTION DTRT, RUE, XIW and TUBMC, are arbitrary fixed on certain values, to be enabled to run the model. For the parameters DAYPL, PLDEPT, IPEM, XPEM, DSHDEC, DEDEC and FUNCTION PPT, estimations are made, based more or less on literature (see appendix 5). Therefore, not much value should be attached to the exact outcome of the simulation run presented. The path that leads to the outcome is much more important.

3.2 PROPORTION GROUND COVER

The calculated proportion ground cover is presented in figure 1 (page 10).

The graph of figure 1 can be divided into 4 parts. The first part is from 0 till 43 days after planting (D.A.P.). The sprout has not yet emerged, so the PGC = 0.

The second part is from 43 till 79 days after planting, and describes the early leaf growth until full ground cover (i.e. PGC = 1). A linear relationship during part 2 is assumed to be as follows;

PGC = 0.042 * D.A.P. - 2.327

The third part is from 79 till 184 days after planting. During this part the PGC = 1.

At 184 days after planting the decline period begins, which lasts till 214 days after planting. A linear relationship during part 4 is assumed to be as follows;

PGC = -0.033 * D.A.P. + 7.129

3.3 TOTAL DRY MATTER PRODUCTION

The calculated total dry matter production per square meter is presented in figure 2 (page 11).

Full ground cover is reached at 79 days after planting. Before that point the increase of total dry matter is exponential. During the period of full ground cover the increase op total dry matter is more or less linear. At 184 days after planting the ground cover is declining. According to that the total dry matter-increase is declining too.

3.4 TUBER DRY MATTER PRODUCTION

The calculated tuber dry matter production per square meter is presented in figure 3 (page 12).

Until 135 days after planting the allocation of dry matter to the new tuber is nil. After that point the proportion of total production allocated to the tuber is increasing till 83% at 210 days after planting (see appendix 4).

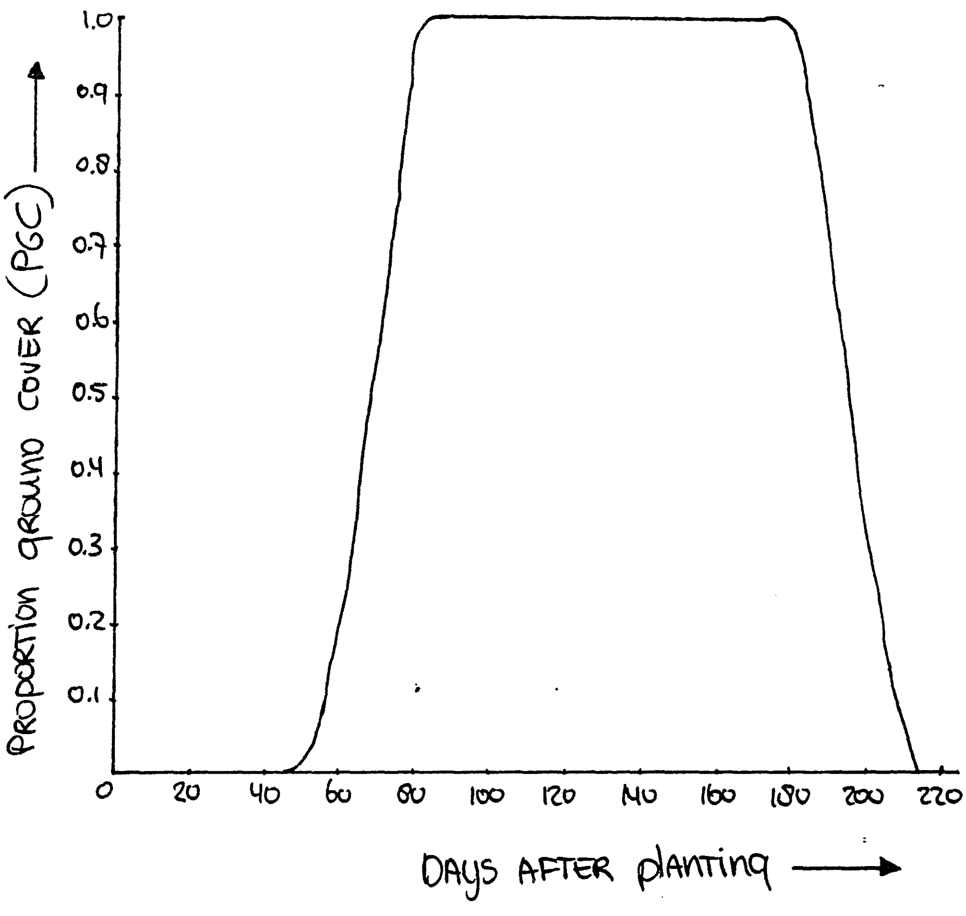


Figure 1: the calculated proportion ground cover (PGC)

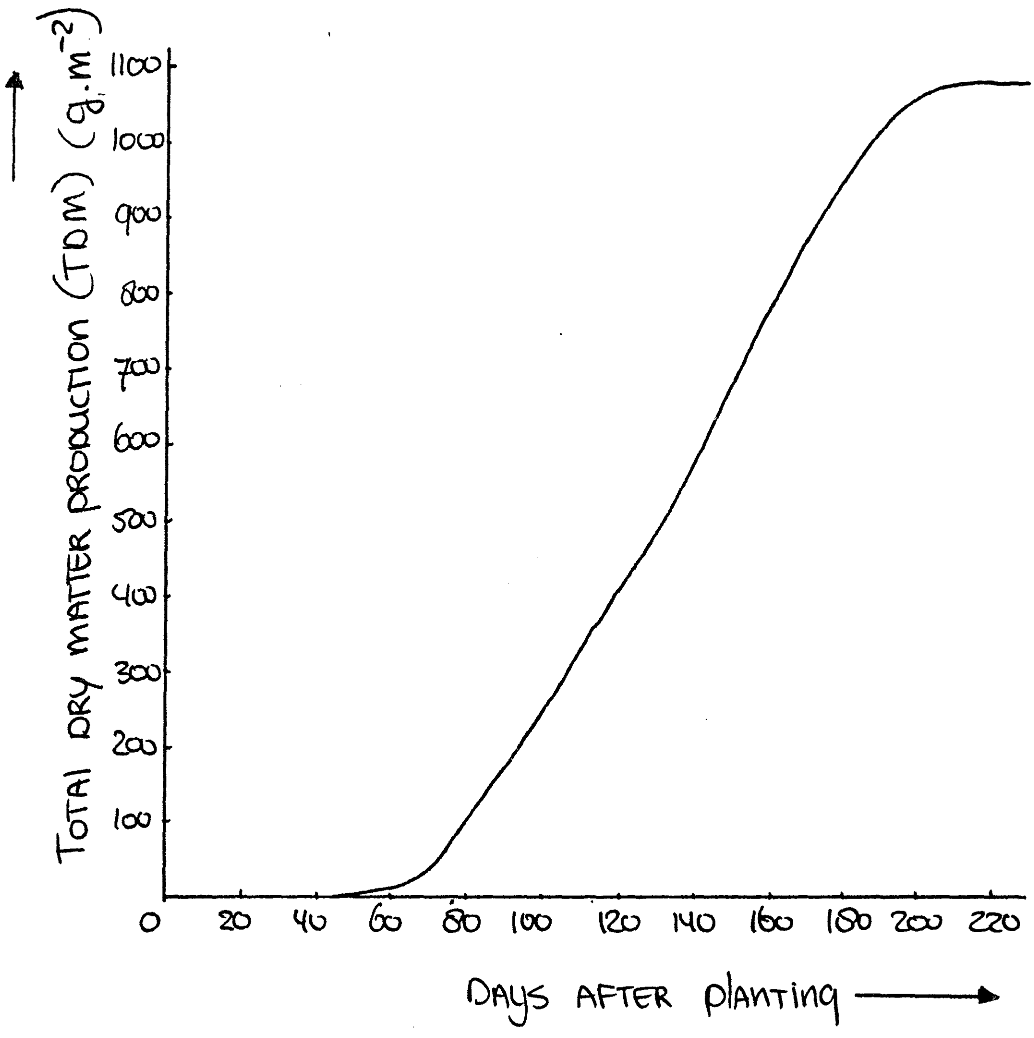


Figure 2: The calculated total dry matter per square meter (TDM)

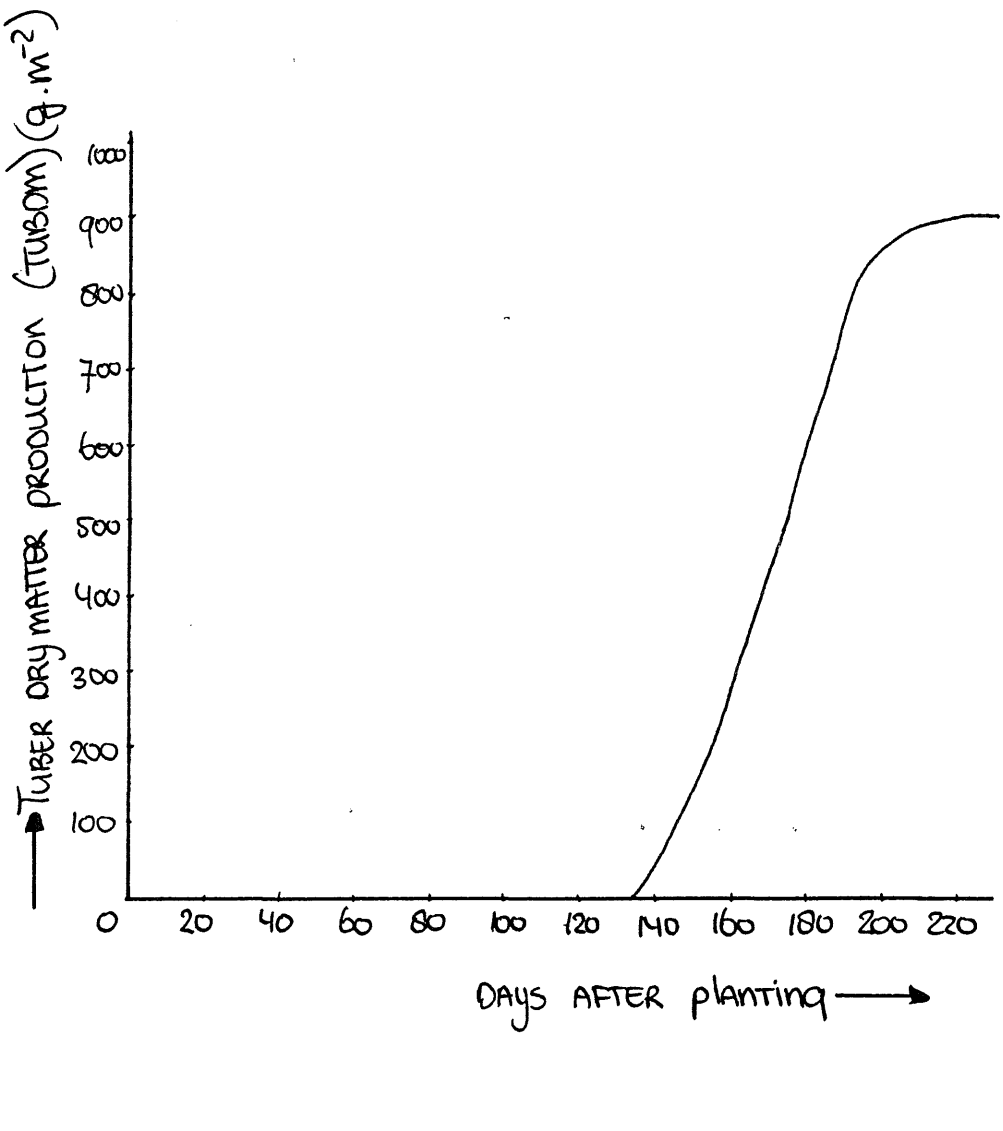


Figure 3: the calculated tuber dry matter production per square meter (TUBDM)

4 DISCUSSION

The proportion ground cover reaches too soon the value 1. Yam, however, is a slow starter; the first one and a half month after emergence the leaf expansion is very low. In the model a rate of leaf area growth per stem per day is fixed on 0.005m2 per day for the first fifty days after emergence. This may even be too high. In the future it will be better to obtain something like growth per gram dry matter.

The model is day dependent. This means that the smallest delt (i.e. simulation step) is automatically 1 (simulating 0.5 day makes no sense). However, according to the time-coefficient (= 0.4) a delt of 0.4 is required. This is as explained not possible. Maybe that a more climate-dependent model (temperature, rainfall, etc.) could take away this problem.

The time-schedule used to run the model is based on estimations.

The function ppt (i.e. proportion production allocated to new tuber) is presented accurate. However, the data on which it is based are not very accurate. Small changes will have large consequences on the outcome of the model.

The function dtrt (i.e. radiation data per ten days) is purely estimated.

The radiation use efficiency is also estimated. Small changes will have large consequences.

5 REFERENCES

Onwueme, I.C., 1978. The Tropical Tuber Crops; Yams, Cassava, Sweet Potatoe, Cocoyams. John Wiley & Sons, New York.

Onwueme, I.C., 1984. The physiology of tropical field crops, chapter 17: Yams. Edited by P.R. Goldsworthy and N.M. Fisher. John Wiley & Sons, New York.

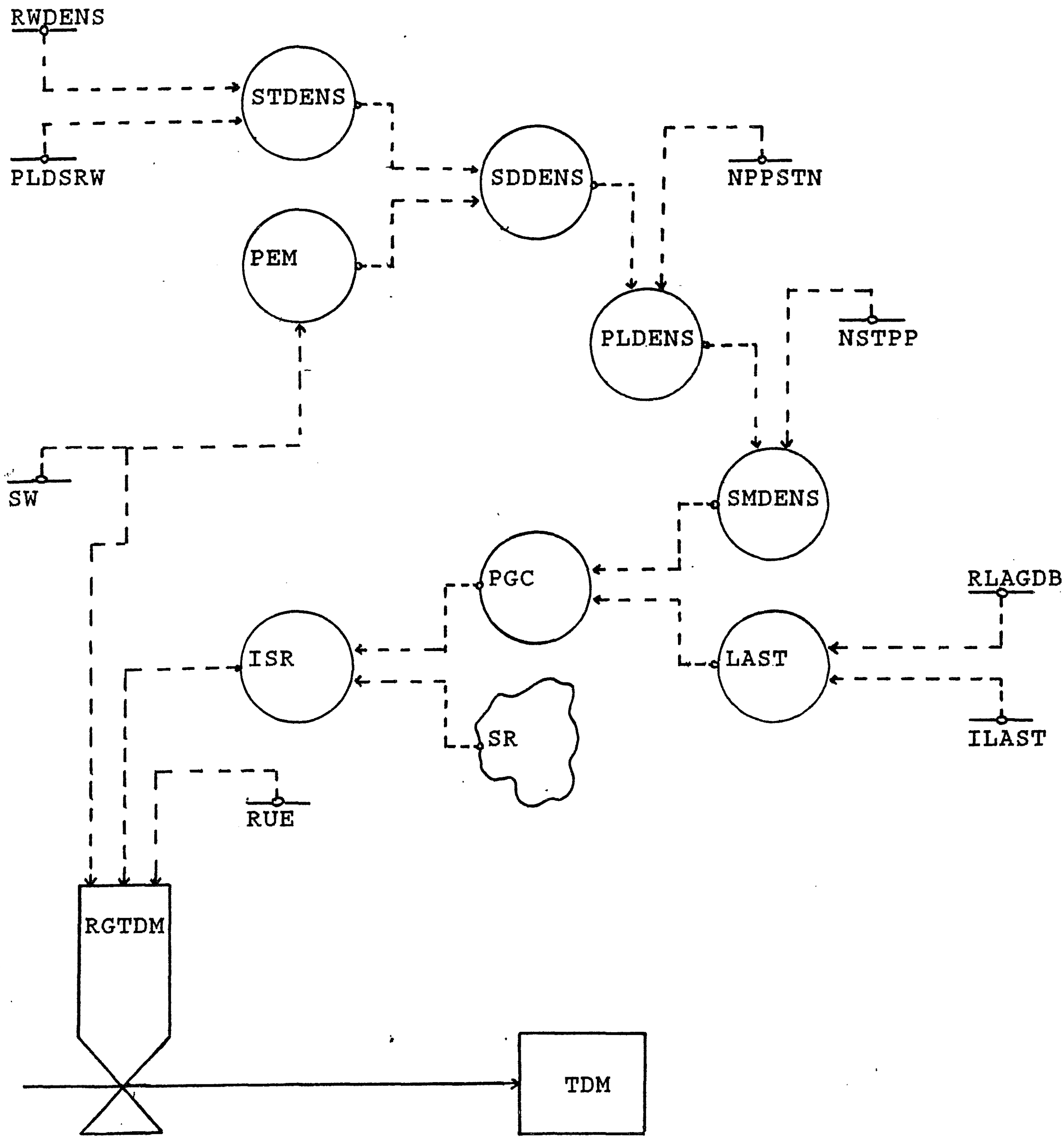
Onwueme, I.C. and Haverkort, A.J., 1990. Modelling Growth And Productivity Of Yams (Dioscorea spp.): Prospects And Problems. Not published (yet).

Oriuwa, L.O. and Onwueme, I.C., 1980. Determining the optimum spacing and sett weight for growing Yam (Dioscorea spp.) without stakes. Journal of International Agriculture -special issue-, p.5-24.

Appendix 1: Time schedule of yam growth in Nigeria

	Julian day	day sum from planting	day sum from emergence
planting	46	0	0
emergence	91	45	0
begin of decline	226	180	135
halway the decline period	241	195	150
senescence	256	210	165

Appendix 2: Relational diagram of yam tuber production



Appendix 3: CSMP model

```
*************************************************************
*************************************************************
*************************************************************
****   SIMULATION OF THE GROWTH OF YAM (Dioscorea spp.) ****
****                                                    ****
*************************************************************
*************************************************************
*************************************************************


DYNAMIC
*************************************************************
****   EMERGENCE                                        ****
****                                                    ****
*************************************************************
****   ACRONYMS USED IN THIS SECTION:                   ****
****   DSPLEM = day sum from planting till emergence    ****
****   DSEM   = day sum from emergence                  ****
****   PLDEPT = plantingdepth (mm)                      ****
****   RSPRG  = rate of sprout growth (mm.day-1)        ****
****   LSPR   = length of sprout (mm)                   ****
****   DSPL   = day sum from planting                   ****
****   PUSHPL = push planting                           ****
****   DAYPL  = julian day number of planting           ****
*************************************************************

*001*
PUSHPL = INSW (DAY - DAYPL, 0., 1.)
*002*
DSPL = DAY - DAYPL
*003*
DSEM = DSPL - DSPLEM
*004*
DSPLEM = PLDEPT/RSPRG
*005*
LSPR = INSW(DSPL - DSPLEM, RSPRG * DSPL * PUSHPL, PLDEPT)
*006*
PARAMETER DAYPL = 46
*007*
PARAMETER PLDEPT = 150
*008*
PARAMETER RSPRG = 3.5


*************************************************************
****   STEM DENSITY                                     ****
****                                                    ****
*************************************************************
****   ACRONYMS USED IN THIS SECTION:                   ****
****   SMDENS = stem density (st.m-2)                   ****
****   PLDENS = plant density (pl.m-2)                  ****
****   NSTPP  = number of stems per plant (st.pl-1)     ****
```

```
****   SDDENS = stand density (sd.m-2)                       ****
****   NPPSTN = number of plants per stand (pl.st-1)         ****
****   STDENS = sett density (s.m-2)                         ****
****   PEM    = proportion emergence                         ****
****   PUSHEM = push emergence                               ****
****   RWDENS = row density (r.m-1)                          ****
****   PLDSRW = planting distance in row (s.m-1.r-1)         ****
****   SW     = sett weight (g.s-1)                          ****
****   XPEM   = increment in PEM per SW (g-1)                ****
****   IPEM   = initial proportion emergence                 ****
*************************************************************

*009*
SMDENS = PLDENS * NSTPP
*010*
PLDENS = SDDENS * NPPSTN
*011*
SDDENS = STDENS * PEM * PUSHEM
*012*
STDENS = RWDENS * PLDSRW
*013*
PEM = XPEM * SW + IPEM
*014*
PUSHEM = INSW(DSPL - DSPLEM, 0., 1.)
*015*
PARAMETER IPEM = 0.6
*016*
PARAMETER XPEM = 0.001
*017*
PARAMETER SW = 200
*018*
PARAMETER PLDSRW = 1.1
*019*
PARAMETER RWDENS = 1.1
*020*
PARAMETER NPPSTN = 1
*021*
PARAMETER NSTPP = 1


*************************************************************
****   LEAF AREA GROWTH UNTILL FULL GROUND COVER            ****
****   PGC1 = LAI/3                                         ****
*************************************************************
****   ACRONYMS USED IN THIS SECTION:                       ****
****   PGC    = proportion ground cover (m2.m-2)            ****
****   LAI    = leaf area index (m2.m-2)                    ****
****   LAST   = leaf area per stem (m2.st-1)                ****
****   ILAST  = initial LA at emergence per stem (m2.st-1)**
****   RLAGDB = rate of LA growth/stem/day (m2.day-1)       ****
****   LAG    = leaf area growth/stem/day                   ****
*************************************************************

*022*
PGC = INSW(LAI - 3., (LAI/3) * PUSHEM, PGC2)
```

```
*023*
LAI = SMDENS * LAST
*024*
LAST = INTGRL(ILAST, RLAGDB * PUSHEM)
*025*
RLAGDB = AFGEN (LAG, DSEM)
*025b*
FUNCTION LAG = 0,0.005, 50,0.25
*026*
PARAMETER ILAST = 0.00136


***********************************************************
****  LEAF AREA DEVELOPMENT UNTIL MATURITY             ****
****                                                   ****
***********************************************************
****  ACRONYMS USED IN THIS SECTION:                   ****
****  DSBDEC = day sum at the beginning of the decline ****
****  PGCDEC = PGC in decline period (m2.m-2)          ****
****  DSEDEC = day sum at the end of the decline       ****
****  DSHDEC = day sum halfway the decline period      ****
****  DSDEC  = day sum of the decline period           ****
***********************************************************

*027*
PGC2 = INSW(DSEM - DSBDEC, 1., PGCDEC)
*028*
PGCDEC = INSW(DSEM - DSEDEC,...
         0.5 + (DSHDEC - DSEM)/DSDEC, 0.)
*029*
DSBDEC = DSHDEC - 0.5 * DSDEC
*030*
DSEDEC = DSHDEC + 0.5 * DSDEC
*031*
PARAMETER DSHDEC = 150
*032*
PARAMETER DSDEC = 30


***********************************************************
****  DRY MATTER PRODUCTION                            ****
****                                                   ****
***********************************************************
****  ACRONYMS USED IN THIS SECTION:                   ****
****  TDM     = total dry matter (g.m-2)               ****
****  IW      = initial weight (g.m-2)                 ****
****  ISR     = intercepted solar radiation (MJ.m-2)   ****
****  RUE     = radiation use efficiency (g.MJ-1)      ****
****  SR      = solar radiation (MJ.m-2)               ****
****  XIW     = proportion sett in new tuber (g.g-1)   ****
****  SWDM    = sett weight dry matter (g.s-1)         ****
****  SWDMM   = sett weight dry matter per m2 (g.m-2)  ****
****  TUBMC   = tuber dry matter content (g.g-1)       ****
****  PUSHTUB = push tuber                             ****
***********************************************************
```

```
*033*
TDM = IW * PUSHTUB + INTGRL(0., ISR * RUE)
*034*
PUSHTUB = INSW(DSEM - 110, 0., 1.)
*035*
IW = XIW * SWDMM
*036*
SWDMM = SWDM * STDENS
*037*
SWDM = SW * TUBMC
*038*
ISR = SR * PGC
*039*
SR = AFGEN (DTRT, DAY)
*040*
FUNCTION DTRT = 0,18, 10,17, 20,19, 30,18, 40,19, 50,17,...
                60,15, 70,16, 80,18, 90,18, 100,19,...
                110,17, 120,15, 130,16, 140,16, 150,18,...
                160,19, 170,20, 180,21, 190,21, 200,19,...
                210,18, 220,19, 230,20, 240,21, 250,20,...
                260,22, 270,21, 280,20, 230,21, 240,21,...
                250,20, 260,21, 270,21, 280,21, 290,22,...
                300,20, 310,21, 320,22, 330,21, 340,20,...
                350,21, 360,20
*041*
PARAMETER RUE = 0.45
*042*
PARAMETER XIW = 0.2
*043*
PARAMETER TUBMC = 0.2


************************************************************
****  TUBER PRODUCTION                                  ****
****                                                    ****
************************************************************
****  ACRONYMS USED IN THIS SECTION:                    ****
****  TUBDM = tuber dry matter (g.m-2)                  ****
****  PPT   = proportion production to tuber            ****
****  TUBFW = tuber fresh weight (g.m-2)                ****
************************************************************

*044*
TUBDM = IW * PUSHTUB + TDM * DEVTUB
*045*
DEVTUB = AFGEN(PPT, DSEM)
*046*
FUNCTION PPT = 0,0., 10,0., 20,0., 30,0., 40,0., 50,0.,...
               60,0., 70,0., 80,0., 90,0., 100,0.13,...
               110,0.27, 120,0.40, 130,0.53, 140,0.66,...
               150,0.80, 160,0.82, 170,0.83, 180.0.83,...
               190,0.83, 200,0.83, 210,0.83
*047*
TUBFW = TUBDM/TUBMC
```

```
***********************************************************
****  SIMULATION RUN SPECIFICATIONS                     ****
****  The program starts running at Julian day 40 and   ****
****  stops at Julian day 270. The time step is 5 days ****
****  and the output is given every 5th day.            ****
****  The rectangular integration method is used in the ***
****  model. Values may be printed (tables) or plotted ****
****  (graphs) with the print, resp. plot command.      ****
***********************************************************

DAY = AMOD(TIME, 365.)
TIMER TIME = 40., FINTIM = 270., DELT = 1., PRDEL = 5.,...
             OUTDEL = 5
METHOD RECT
PRINT PGC, TDM, TUBDM, TUBFW
*PRTPLOT PGC, TDM, TUBDM, TUBFW


***********************************************************
***********************************************************
***********************************************************
END
STOP
ENDJOB
***********************************************************
********************** END OF PROGRAM *********************
***********************************************************
```

Appendix 5: (Sources of) Input figures for the CSMP model

```
PARAMETER DAYPL  = 46     (estimation)
PARAMETER PLDEPT = 150    (estimation)
PARAMETER RSPRG  = 3.5    (4.5 weeks till emergence)
PARAMETER IPEM   = 0.6    (derived from Oriuwa and Onwueme, 1980)
PARAMETER XPEM   = 0.0001 (derived from Oriuwa and Onwueme, 1980)
PARAMETER SW     = 200    (estimation)
PARAMETER PLDSRW = 1.1    (Onwueme and Haverkort, 1990)
PARAMETER RWDENS = 1.1    (Onwueme and Haverkort, 1990)
PARAMETER NPPSTN = 1      (Onwueme and Haverkort, 1990)
PARAMETER NSTPP  = 1      (Onwueme and Haverkort, 1990)
PARAMETER RLAGDB = 0.25 (Biemond, 1990; potatoe)
PARAMETER ILAST  = 0.00136  (Biemond, 1990; potatoe)
PARAMETER DSHDEC = 150    (derived from Onwueme, 1978)
PARAMETER DSDEC  = 30     (derived from Onwueme, 1978)
PARAMETER RUE    = 0.45 (estimation)
PARAMETER XIW    = 0.2    (estimation)
PARAMETER TUBMC  = 0.2    (estimation)
FUNCTION DTRT    = line 040 of appendix 3 (estimation)
FUNCTION PPT     = line 046 of appendix 3 (derived from Onwueme,
                   1978)
FUNCTION LAG     = line 025b of appendix 3 (estimation)
```