Land Use Systems Analysis:
Parameterization of a Sunflower crop in a Mediterranean climate

Jorge BARROS
Department of Soil Science and Geology, Wageningen Agricultural University, P.O. Box 37, 6700 AA Wageningen (The Netherlands)

Abstract
Dynamic simulation of land qualities and corresponding land use requirements for calculation of the biophysical production potential relies entirely on environment data and the crop characteristics. Parameterization of a sunflower crop produces the data needed for analyses. The field experimentation was carried out in Andalusia. Model calibration and sensitivity testing address the main variables considered in the simulation. The best single parameter to evaluate the model output is the LAD (leaf area duration, m^2.d).
Keywords: land evaluation, sunflower, yield, model, Andalusia.

Introduction

Quantified analysis of land-use systems deals with the functioning of a defined land utilization type on a defined land unit over a defined period of time. The land unit is described by its weather and its soil/terrain specifications. It is considered internally uniform. The land utilization type is described by its 'key attributes of land use', e.g. by the crop selection and all aspects of land-use that are relevant to the functioning of the land utilization type (DRIESSEN and KONIJN 1992).

At the highest hierarchical level, crop production refers to a system where only the availability of solar radiation and the photosynthetic energy requirement at the prevailing temperature, determine the production potential of the land use system: water and fertilizers, the main growth limiting factors, are adequately available and growth reducing factors are controlled. The calculations of biophysical production potentials (PS1) require only crop and weather data.

Materials and methods

Field experimentation was carried out in 1993 and 1994 in the experimental farm of the Institute for Natural Resources and Agrobiology of Seville (IRNAS) in Coria del Rio, Spain, (latitude 37.3 °N; longitude 6.1 °W; altitude 39 m).

The study area is situated in the Guadalquivir basin of west Andalusia; the agroclimate is of the mediterranean type and the soils of the experimental farm are Calcaric Cambisols (F.A.O.-UNESCO 1988). Crop characteristics of sunflower (*Helianthus annuus* L.) vary greatly between varieties and also with the use of the plant (CARTER 1978). The commercial specifications of variety 'Florasol' are 'medium cycle, medium height, with uniform flowering and maturation, with high yields and oil percentage'.

Sunflower was grown according to the locally used crop calendar. Dry matter production and distribution were monitored through successive partial harvests, measuring fresh and dry matter weights per plant organ: roots, stems, leaves and storage organs. The leaf area was measured at each partial harvest with a portable area meter. Radiation measurements were done with a Kipp solarimeter. Progress of phenology was monitored regularly through field observations. Plant and seed samples were taken for laboratory analysis. Weather data were available by the meteorological station of the experimental farm.

The model used for land-use systems analysis is a policy support model. It is a comprehensive, deterministic crop production model, developed for dynamic simulation of the sufficiency of land qualities under land use requirements as occur in rigidly defined production situations (DRIESSEN and KONIJN 1992). The processes considered in PS1 calculations are: i) production of assimilates, ii) allocation of these assimilates to the various plant organs; iii) loss of assimilates in respiration to maintain living material, and iv) conversion of the remaining to structural plant matter.

Results, discussion and conclusions

Parameterization produced the following crop data:
C3C4$: sunflower is a C3 plant. This parameter is essential to the determination of the maximum rate of assimilation (AMAX).

TLOW:air temperatures of less than 0°C are harmful to sunflower.

r(org): organ-specific relative maintenance respiration rates are set to 0.05, 0.01, 0.0075 and 0.023 for leaf mass, root mass, stem mass and storage organ mass respectively. The values for root, stem and storage organ are quite stable. Room is left to adjust the value of r(leaf) as it depends greatly on the composition (notably the N-content) of the leaf tissue.

TSUM: this parameter represents the heat requirement of the crop for full development, from emergence till physiological maturity. It is defined as the cumulative sum of daily effective temperatures, i.e. of the difference between the daily average temperature (T24h) and the threshold temperature for development (TO). The two seasons data set the TSUM at 1440 °C.d and the base temperature (TO) at 6.5 °C. These values are indicative because the canopy temperature is likely to be somewhat lower than the air temperature.

TO: data from literature suggest that development of sunflower does not take place at temperatures below 6 °C, what seems to agree with the previous calculation.

TLEAF: the heat requirement for full leaf development (°C.d) defines the leaf lifespan. Measurements of leaf area distribution and dead leaf mass over time suggest a nominal value of 900 °C.d.

Ke: the extinction coefficient for visible light was calculated using the equation: I = Ia * EXP (-LAI * Ke); the incoming radiation above the canopy (Ia) and under the canopy (I), and the LAI are measured. The calculated value is 0.9.

fr(org): the partitioning of assimilates to the various plant organs is calculated with data from partial harvests; it is a function of the plant's relative development stage (RDS). The suggested values are shown in Table 1.

SLA: the plant forms thicker leaves as it develops so that the value of the specific leaf area ($m^2.kg^{-1}$) decreases from a maximum value, early in the season, (SLAmax=19), to a minimum value at the end of the season, (SLAmin=12).

EC(org): To convert sugars (synthesized in assimilation) to structural plant matter, efficiencies of conversion must be known. Plant and seed analyses produces the chemical composition of each plant organ. Accounting biosynthesis costs (LÖVENSTEIN et al., 1992), the following indicative conversion efficiency values were found: EC(leaf)=0.68; EC(root)=0.68; EC(stem)=0.66; EC(s.o.)=0.54.

The weather data refer to one geo-referenced site (latitude, longitude, elevation). All data are daily weather data over at least the crop growth period: Tmax, maximum air temperature (°C); Tmin, minimum air temperature (°C); RHA, relative humidity of air (-); SunH, daily sunny hours ($h.d^{-1}$).

The following weather variables are calculated: DL, day length

$(h.d^{-1})$ is calculated as a function of latitude and day of year; EXTRA, extraterrestrial radiation $(MJ.m^{-2}.d^{-1})$ is estimated from the latitude and the day of year; TRANS, atmospheric transmissivity (-), is estimated as a function of latitude, DL, SunH and RHA; PAR, 'photosynthetically active' radiation at canopy height, is calculated from EXTRA and TRANS; Daily course of temperature : daytime (Tday), nighttime (Tnigth) and equivalent daily temperature (T24h) are estimated by fitting of a coupled curve, sinusoidal at daytime and exponential at night.

Evaluating the variables considered in PS1 calculations the following set of variables was analyzed for sensitivity: the photosynthetically active radiation; the average daily temperature; the specific leaf area; the maximum rate of assimilation; different partitioning patterns; and relative maintenance costs. These variables were varied in a number of scenarios, and the generated output of such scenarios evaluated for length of plant growth (LPG), seed production (YIELD), harvest index (HI) and leaf area duration (LAD). The fluctuation of these variables is summarized in Table 2.

The length of plant growth is only dependent on the temperature and the temperature sum. This might be different in scenarios examining the water-limited potential production where drought affects the LPG. The yield reflects (the interaction of) all factors that affect crop growth and development, but results show that different combinations may result in the same yield. The harvest index depends on all factors that influence dry matter accumulation in the storage organ and the dry mass ratio of storage organ and leaf. The leaf area duration is the most sensitive parameter, with large fluctuations. It is the result of processes that influence leaf maintenance at high leaf area. The differences between the two years are not significant.

The results of the sensitivity analysis are used to calibrate the model. This calibration was performed in a number of steps, matching the required crop characteristics with measured field data: i) TSUM with observed crop duration; ii) r(org) with total dry matter; iii) TLeaf with LAI (with maximum LAI, final LAI and LAD); iv) fr(org) with dry matter ratios. The LAD was used as the main parameter to control the correctness of fitting.

The output obtained with the weather data of Coria del Rio for the year 1994 (emergence date is 25 March) is shown in Fig. 1.

The yield (kg seed/ha, with an oil content of 43 %) is 70 % of the storage organ dry matter. For the example shown in Fig 1, the yield is around 4.2 tons seed/ha or 1.8 tons oil/ha. RAEA

(Andalusian Agricultural Experimentation Network) has done extensive field research on sunflower yields. In the season 1991/93 trials with 46 varieties of sunflower at Posadas (Cordoba) gave an average yield of 3.8 ton/ha with an oil content of 51.7 %. For Florasol the figures are 4.1 and 53.4 % respectively (JUNTA DE ANDALUCIA 1992). In the season 1993/94 trials with 40 varieties of sunflower at Palma del Rio (Cordoba) gave an average yield of 2.9 ton/ha with an oil content of 43.7 %. Florasol yielded 3.2 ton/ha and 41.3 % oil (JUNTA DE ANDALUCIA 1994). These experiments were done under full irrigation (3 applications) and without fertilization (benefitting from nutrients carried over from the previous crop). Precipitation in 1991/92 was 501 mm and 342 mm in 1993/94. Despite the differences between sites and sowing dates, which are ultimately due to different weather data, this shows that the biophysical production potential can be reached under experimental conditions. Agricultural statistics of Andalusia show an average actual yield of 2.3 ton/ha under irrigation and 1.0 ton/ha for rain-fed sunflower (M.A.P.A., 1992). This suggests that sunflower yield in this region can still be doubled.

Conventional field experimentation does not explain the variation between varieties, sites and years. Through dynamic modelling differences between sites, years and sowing dates can be evaluated provided that adequate weather data are available. The few climatic variables required make the use of the program practical.

Acknowledgements:

I thank Prof. Paul Driessen (Department of Soil Science and Geology, WAU) for his suggestions and carefully revision of the text and Prof. Diego de la Rosa and Eng. Manolo Fernandez (IRNAS) for the facilities provided during the field experimentation.

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Table 1. Indicative RDS-to-fr(org) relations for sunflower.

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RDS	Root	Stem	Leaf	S.O.
0.00	0.20	0.19	0.61	0.00
0.11	0.18	0.19	0.63	0.00
0.19	0.17	0.21	0.62	0.00
0.35	0.15	0.31	0.53	0.01
0.55	0.12	0.31	0.35	0.23
0.80	0.00	0.00	0.13	0.87
1.00	0.00	0.00	0.00	1.00

Table 2. Evaluation of relative LPG, Yield, HI and LAD variation.

Year	1993				1994			
Stats	LPG	Yield	HI	LAD	LPG	Yield	HI	LAD
maximum:	1.10	1.23	1.10	1.99	1.10	1.24	1.10	2.03
minimum:	0.91	0.85	0.83	0.69	0.91	0.82	0.83	0.67
average:	1.00	0.99	0.97	1.10	1.00	0.99	0.98	1.10
std dev:	0.03	0.09	0.07	0.33	0.03	0.10	0.07	0.35
c.v.(%):	3	9	7	30	3	10	7	31

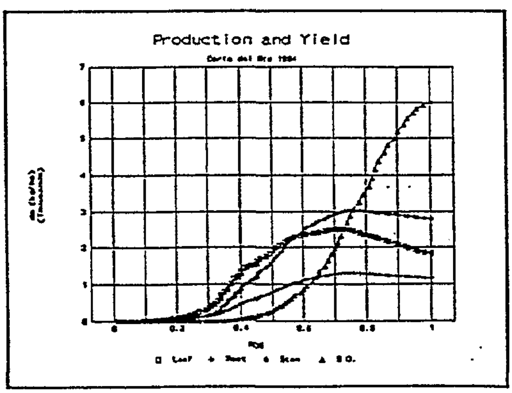

Fig. 1. Biophysical production potential of sunflower.

Leaf, Root, Stem and S.O. dry matter over the crop cycle. RDS= 0 at emergence and RDS= 1 at physiological maturity.