ALSIM I (Level I)
Users' Manual

by: GARY W. FICK

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ALSIM 1 (LEVEL 1) – Users' Manual

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ABSTRACT

ALSIM 1 (LEVEL 1) is a dynamic computer simulation model of
alfalfa (*Medicago sativa* L.) growth and management written in CSMP.
Condition of the crop at the start of simulation, dates of cutting,
and solar radiation and average air temperature data are needed as
input. The model predicts yield of hay and growth curves for leaves,
stems, basal buds, and total nonstructural carbohydrates of the tap-
roots (TNC) with time steps of one day. Following a simulated harvest,
the model overestimates top growth and underestimates TNC levels,
apparently because of insufficient understanding of the regrowth proces-
ses. The most significant contribution of the model is the identifica-
tion of the importance of and the need for research in the area of
regrowth physiology. A discussion of model performance, instructions
on how to use the model, and examples of simulation runs are included
in the report.

ALSIM 1 (LEVEL 1) - Users' Manual[1]

by Gary W. Fick[2]

INTRODUCTION

ALSIM 1 (LEVEL 1) is the first of an intended family of dynamic
computer models to simulate alfalfa growth and management. It was
initiated in the context of the multi-institutional and interdisci-
plinary alfalfa subproject of the Integrated Pest Management Program
(see acknowledgements). The primary objective was to formulate an
alfalfa simulator compatible with insect and management models that
were also being developed by other workers in the project. ALSIM 1,
which has computational time steps equal to one simulated day, capa-
bility of simulating various cutting managements, and simplicity of
model structure, meets that objective.

Our intentions in developing and using the LEVEL 1 model were to
(a) determine an appropriate and simple model structure for the alfalfa
growth system, (b) formulate a cutting management subroutine, and
(c) identify specific modelling problems or deficiencies in our under-
standing of alfalfa production that warranted further study. The model
has proven useful as the crop component of an alfalfa weevil simulation
model (W. G. Ruesink, Illinois Natural History Survey, personal com-
munication), and as a basis for detailed studies of alfalfa regrowth
mechanisms (G. W. Fick, unpublished data).

The purposes of this users' manual are to document and describe
ALSIM 1 (LEVEL 1) for potential users and students and to record the
details of the system from which further study will be made.

DESCRIPTION

The name ALSIM is an acronym for ALfalfa SIMulation. ALSIM 1
(LEVEL 1) is written in the application oriented input language CSMP
(IBM, 1972). A dynamic simulation program in that language can be
prepared directly from block diagrams of the system to be modelled
and from the rate equations that describe the dynamic processes of the
system. ALSIM 1 predicts dry matter yields of various parts of an
alfalfa crop as a function of time. The block diagrams identify the
parts of the system (i.e., state variables) for which predictions are
made. They also show pathways of material flow between parts and
identify rates that control the flow of material. The material of
ALSIM 1 is fixed carbon expressed as plant dry matter (DM).

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Existing dynamic crop growth models vary in complexity and in size of the simulated time steps. The sugar beet growth model SUBGRO (Fick, 1971) contains 455 state variables. The alfalfa growth model SIMED (Holt et al., 1975) contains six state variables. Both are designed to operate with time steps of about one hour. For compatibility with alfalfa insect models, ALSIM 1 was given a time step of one day. The effort to find a simple model structure capable of handling regrowth following a simulated harvest resulted in five state variables in the core of the model (Fig. 1).

Material available for top growth and storage (MATS) defines the supply of photosynthetic DM that can be used for the growth of the parts of the alfalfa crop included in the model (Fig. 1). The photosynthetic input was corrected for respiration and for growth of plant parts not included in the model (e.g., taproots and fibrous roots), but it represents a potential which may not be entirely used. Therefore, one of the flows out of MATS is for other uses, a mechanism of removing MATS in excess of use in top growth and storage.

MATS is primarily used to produce leaves (LEAF), stems (STEM), or total nonstructural carbohydrates accumulated in taproots (TNC). When a harvest is made, the leaves and stems are entirely removed and regrowth is initiated by the elongation of basal buds (BUDS) into leaves and stems. The source of material for bud formation is accumulated TNC (Fig. 1). If there are no buds and the TNC supply is exhausted, harvesting the leaves and stems will kill the crop. The model predicts crop death when there is no photosynthesis (no input to MATS) and the supply of TNC is ≤ 5 g m^{-2}. Photosynthesis requires light interception by leaves so the condition of no photosynthesis occurs when the leaves have been removed and there are no buds to replace them.

The removal of leaves and stems can occur by three processes in the present model (Fig. 2). They can die because of old age (senescence), they can be lost by a killing frost, or they can be harvested as hay. Insect defoliation is not included, but a fourth flow out of leaves for that factor would describe the situation. If the leaves and stems are harvested, the yields are retained in two state variables for harvested leaves (HLEAF) and harvested stems (HSTEM) which are summed to give the hay yield since the start of simulation (HAY). The separate treatment of harvested leaves and stems makes it possible to calculate the fraction of leaves in the harvested hay, which may be important in predicting hay quality (Liu and Fick, 1975).
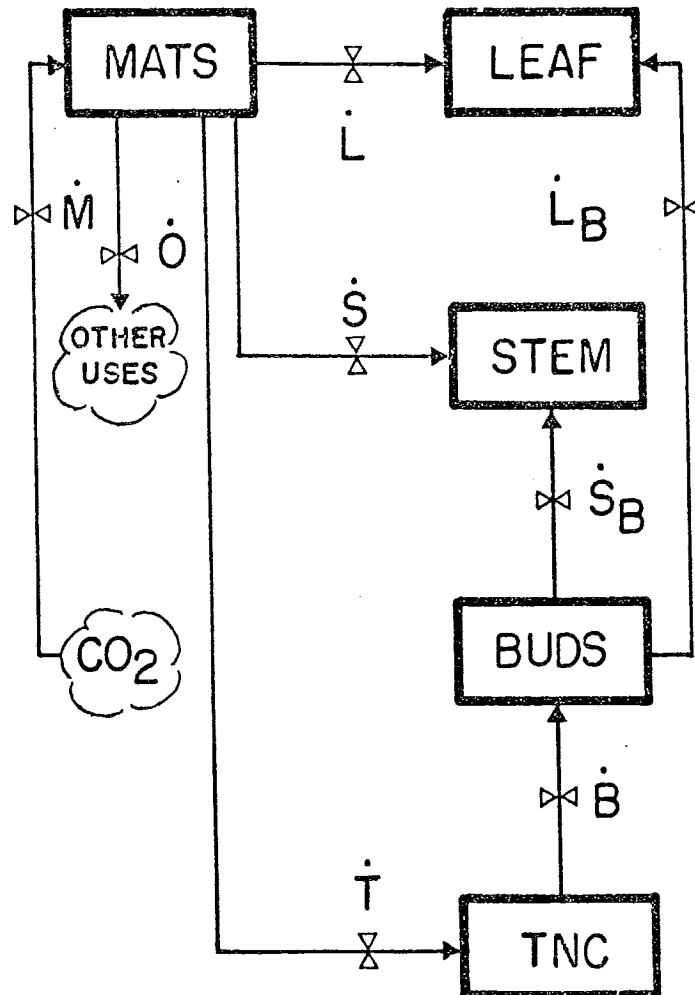
Fig. 1. ALSIM 1 (LEVEL 1) is based on this model of material flow
in the alfalfa crop. Rectangles represent the parts of
the system modelled; arrows, the pathways of material flow;
valve symbols, the rates controlling material flow; cloud
symbols, parts of the system not treated in the model.
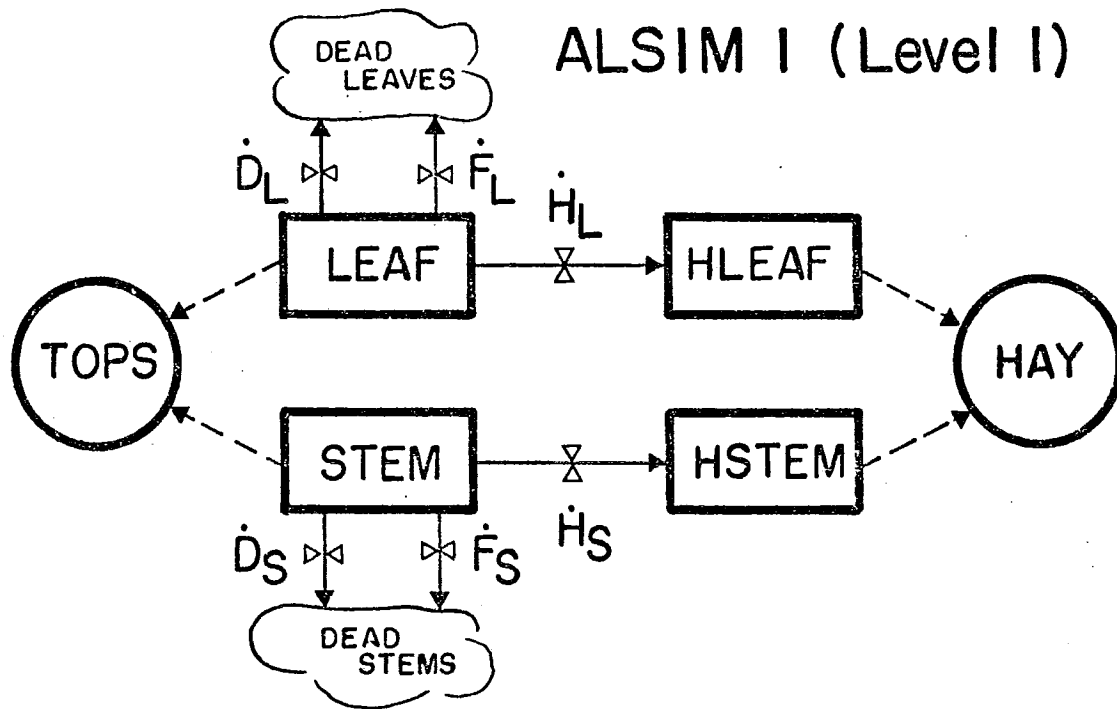Variable names are defined in the description of the model.

Fig. 2. Losses of leaves and stems by freezing, senescence or harvesting in ALSIM 1 (LEVEL 1) are based on this model of material flow. When parts of the system are added together, sums are shown in circles coupled to the addends by dashed arrows. Other symbolism is explained in Fig. 1.

All state variable yields are computed in grams of dry matter per square meter of field surface area ($g\ m^{-2}$). All rates are dimensioned in $g\ m^{-2}\ day^{-1}$. Yields of state variables are updated in the following fashion:

$$V_{t+1} = V_t + \dot{V} \cdot \Delta t$$

where V_{t+1} = yield of state variable V one time step after time t.

V_t = yield of state variable V at time t.

$\dot{V}$ = rate of change in V as computed at time t.

Δt = change in time for one time step.

There are 14 rate equations in ALSIM 1 (LEVEL 1). All are difference equations with a time interval of one day. The following mathematical descriptions also include the computer code for variable names to simplify cross-referencing to the program listing. Definitions of the independent variables in each equation follow, starting on page 7.

[1] Potential rate of top growth and storage, $\dot{M}$; coded GRM.

$$\dot{M} = G_{SR} \cdot T_P \cdot G_{DD} \cdot C$$

[2] Growth rate of leaves, $\dot{L}$; coded GRL.

$$\dot{L} = \text{minimum of } 0.2 \cdot L \cdot L_L \cdot D_L \cdot C$$
$$\text{or } M \cdot F_L \cdot C$$

The constant 0.2 was derived from the corresponding equation of Holt et al. (1975).

[3] Growth rate of stems, $\dot{S}$; coded GRS.

$$\dot{S} = \text{minimum of } 0.499 \cdot S \cdot S_S \cdot D_S \cdot C$$
$$\text{or } M \cdot (1. - F_L) \cdot C$$

The constant 0.499 was derived from the corresponding equation of Holt et al. (1975).

[4] Storage rate of TNC, $\dot{T}$; coded STOR.

$$\dot{T} = \text{minimum of } 1.8 \cdot T_{NC} \cdot C$$
$$\text{or } (M - \dot{L} - \dot{S}) \cdot C$$

The constant 1.8 was derived from Nelson and Smith (1968).

[5] Other uses of MATS, $\dot{O}$; coded OUM.

$$\dot{O} = M - \dot{L} - \dot{S} - \dot{T}$$

[6] Growth rate of buds, $\dot{B}$; coded GRB.

$$\dot{B} \quad = \quad \text{minimum of } (1. - R_C) \cdot T_P \cdot (B_C - B)/(1. - R_C)$$

$$\text{or } (1. - R_C) \cdot T_P \cdot T/T_{ML}$$

$$\text{or } (1. - R_C) \cdot T_P \cdot R_{GR} \cdot (T + B)$$

[7] Growth rate of leaves coming from bud elongation, $\dot{L}_B$; coded GRLB.

$$\dot{L}_B \quad = \quad (B/B_{ML}) \cdot B_D \cdot B_T \text{ if there is no light,}$$

$$\text{or } (B/B_{ML}) \cdot B_D \cdot B_T \cdot B_{SR} \text{ if there is light.}$$

[8] Growth rate of stems coming from bud elongation, $\dot{S}_B$; coded GRSB.

$$\dot{S}_B \quad = \quad 0.1 \cdot \dot{L}_B$$

This relationship is based on the necessity of high leaf fractions in early bud elongation according to the definition of "leaves" by Fick and Holthausen (1975).

[9] Senescence rate of leaves, $\dot{D}_L$; coded SRL.

$$\dot{D}_L \quad = \quad (L - L_M)/L_{ML} \text{ if } L > L_M$$

$$\text{or } 0. \text{ if } L_M \geq L$$

[10] Senescence rate of stems, $\dot{D}_S$; coded SRS.

$$\dot{D}_S \quad = \quad (S - S_M)/S_{ML} \text{ if } S > S_M$$

$$\text{or } 0. \text{ if } S_M \geq S$$

[11] Freezing rate of leaves, $\dot{F}_L$, coded FRL.

$$\dot{F}_L \quad = \quad L \cdot K$$

[12] Freezing rate of stems, $\dot{F}_S$; coded FRS.

$$\dot{F}_S \quad = \quad S \cdot K$$

[13] Harvest rate of leaves, $\dot{H}_L$; coded HRL.

$$\dot{H}_L \quad = \quad L \cdot (1. - C)$$

[14] Harvest rate of stems, $\dot{H}_S$; coded HRS.

$$\dot{H}_S \quad = \quad S \cdot (1. - C)$$

where B   =   yield of buds; coded BUDS.

B_C =   ceiling yield of buds as a function of the amount of TNC stored; no data found; coded BUDC.

B_D =   bud elongation as a function of daylength, no data found; coded BEFD.

B_{ML} =   mean life of bud disappearance when elongation occurs in the light, derived from data of Leach (1968); coded MLBUDS.

B_{SR} =   bud elongation as a function of solar radiation not absorbed by leaves. Solar radiation absorption was based on Hunt, Moore, and Winch (1970), but no data was found for the effect on bud elongation; coded BEFSR.

B_T =   bud elongation as a function of average air temperature; no data found; coded BEFT.

C   =   effect of cutting on growth set equal to 1. when there is no cut and 0. when there is a cut; coded ECG.

D_L =   effect of daylength on potential leaf growth as reported by Holt et al. (1975); coded EDLG.

D_S =   effect of daylength on potential stem growth as reported by Holt et al. (1975); coded EDSG.

F_L =   fraction of top growth in leaves as a function of leaf yield as measured by Fick at Ithaca, N.Y. in 1973 (unpublished data); coded FTGL.

G_{SR} =   growth as a function of absorbed solar radiation, based on growth of sub clover measured by Black (1963); coded GFASR. Solar radiation data must be input. Solar radiation absorption (SRADA) is calculated as a function of leaf area index as measured in alfalfa by Hunt et al. (1970). Leaf area index (LAI) is a function of leaf yield according to relationships used by Holt et al. (1975) with corrections from Fick and Holthausen (1975).

G_{DD} =   effect of growing degree days with a base temperature of 5C on potential alfalfa growth, the maturity factor reported by Holt et al. (1975); coded ESPM.

K   =   killing frost signal set equal to 0. when the average air temperature > the killing frost temperature, and 1. when it is $\leq$ the killing frost temperature (2C); coded KFROST.

L   =   yield of leaves; coded LEAF.

L_M = ceiling non-senescing leaf yield as a function of daylength; no data found; coded CLEAF.

L_L = effect of leaf yield on potential leaf growth as reported by Holt et al. (1975); coded ELLG.

L_{ML} = mean life of the decay time of senescing leaves, no data found; coded DTL.

M = supply of materials available for top growth and storage; coded MATS.

R_C = respiration coefficient, the fraction of TNC lost to respiration when buds are formed as measured by Smith and Marten (1970); coded RCTNC.

R_{GR} = the relative growth rate for plants, reported by de Wit and Goudriaan (1974); coded RGR.

S = yield of stems; coded STEM.

S_C = ceiling non-senescing stem yield based on measurements of the stem fraction of old alfalfa canopies by Fick at Aurora, N.Y. in 1972 (unpublished data); coded CSTEM.

S_{ML} = mean life of the decay time of senescing stems, no data found; coded DTS.

S_S = effect of stem yield on potential stem growth as reported by Holt et al. (1975); coded ESSG.

T = amount of TNC stored, coded TNC.

T_{ML} = mean life of TNC disappearance as measured by Smith and Silva (1969); coded MLTNC.

T_{NC} = effect of TNC level on TNC storage rate derived from Nelson and Smith (1968); coded ETNCS.

T_P = effect of the average air temperature on potential alfalfa growth as measured by Gist and Mott (1957) and Heinrichs and Nielsen (1966); coded ETG. Average air temperature data must be input.

In the coding of losses of leaves and stems, it was necessary to prevent the total losses from exceeding the total amount of leaves and stems present, so we further define the following:

[15] Total leaf losses, $\dot{L}_L$; coded LOSSL.

$$\dot{L}_L = \text{maximum of } \dot{H}_L \text{ or } \dot{F}_L \text{ or } \dot{D}_L$$

[16] Total stem losses, $\dot{L}_S$; coded LOSSS.

$$\dot{L}_S = \text{maximum of } \dot{H}_S \text{ or } \dot{F}_S \text{ or } \dot{D}_S$$

If insect defoliation ($\dot{I}_L$) were added to the model, senescence and defoliation could occur simultaneously, so equation [15] would be changed to

[17] $\dot{L}_L = \text{maximum of } \dot{H}_L \text{ or } \dot{F}_L \text{ or } (\dot{D}_L + \dot{I}_L)$

MODEL PERFORMANCE

Each section of the model was verified at the time it was developed, and after each part was working correctly, the total model was tested by simulating six cutting management systems. Average monthly weather data for Aurora, N.Y. was used (Division of Atmospheric Sciences, 1972), and runs were started on day 90 (March 31). The initial condition of the crop was 10 g m^{-2} of buds and 75 g m^{-2} of TNC. All other state variables were zero. Simulation stopped on day 290 (Oct. 17). One, two, three, four, five, and ten-cut systems were simulated with resulting total seasonal DM yields of 7.3, 12.2, 14.4, 16.1, 14.6, and 6.6 metric tons ha^{-1}, respectively. The patterns of herbage production were in good agreement with those reported by Fuess and Tesar (1968), but TNC yields were lower than those reported by Nelson and Smith (1968) for corresponding treatments. With four or more harvests for the season, the TNC yield on Oct. 17 was less than 0.3 metric tons ha^{-1}, levels too low for winter survival. ALSIM 1 (LEVEL 1) produced tops at the expense of TNC storage. The error occurred in the early stages of regrowth following a cut, and became progressively larger as the number of cuts increased. Thus, the model indicated that maximum yields could be attained with a four-cut management while field data have shown that three-cut systems are usually optimal (Fuess and Tesar, 1968). The model would show the three-cut system to be optimal if several years were simulated and reasonable winter survival mechanisms were included, because survival in the four-cut system would be poor.

ALSIM 1 (LEVEL 1) also gave high estimates of yield. This, however, was expected since the model assumes ideal soil moisture and fertility conditions and thus reflects only air temperature and solar radiation effects on yield. Model predictions represent potential yields for a given climate and thus are most meaningful when compared to highest yields attained with the best management in a given area. The 16 metric tons ha^{-1} maximum yield predicted by the model is about the same as the highest yields reached in central New York State. The three-cut yield of 14.4 metric tons ha^{-1} is also very close to the high three-cut yield of 14.8 metric tons ha^{-1} reported for the area in 1974 (C. C. Lowe, personal communication).

The above general comparisons were based on known patterns of alfalfa herbage and TNC yields, but specific comparisons were not made. As part of other studies at Aurora, N.Y. (Liu and Fick, 1975; Fick and Liu, unpublished data), frequent samples were taken for TNC analysis

(1971 only) or measurement of herbage yield (1972 only), and these data were suitable for model validation. Fig. 3 shows the comparison of 1971 field measurements of TNC in a three-cut management with ALSIM 1 (LEVEL 1) predictions. Simulation was started on day 105 (April 15) and terminated on day 305 (Nov. 1). Initial conditions for the crop were 75 g m^{-2} of TNC and 10 g m^{-2} of buds. Mean monthly weather data for 1971 at Aurora, N.Y. were used (Division of Atmospheric Sciences, 1971). The pattern of underestimation of mid season TNC levels mentioned above showed up clearly (Fig. 3). Autumn TNC accumulation, however, put the crop in a condition to survive the winter, as was the case in the field.

The simulation of top growth curves for the 1972 season (Fig. 4) also showed the overestimation of top production mentioned above. The extent of the difference increased with each harvest. Corresponding TNC data showed a repetition of the pattern of 1971 (Fig. 3) with the higher top yields associated with lower TNC yields. The 1972 simulation was started on day 90 (March 30 in a leap year) and terminated on day 290 (Oct. 16) with the same starting conditions as the 1971 run. Weather data for 1972 at Aurora, N.Y. was used (Division of Atmospheric Sciences, 1972).

In the previous section which describes the model, I noted the absence of data covering bud formation and elongation. Consequently, those parts of the model include a number of relationships based on conjecture. Those same parts of the model control regrowth following a simulated harvest, including the extent and duration of TNC utilization. Our lack of understanding of those processes is the probable cause of the inaccurate predictions made by ALSIM 1 (LEVEL 1). The most significant findings from work with the model are the identification of those deficiencies and of their importance in predicting alfalfa growth. Detailed studies of regrowth physiology in alfalfa are indicated. Simulation studies of alternative regrowth mechanisms would help define the most promising avenues of physiological experimentation.

ASSUMPTIONS AND LIMITATIONS

ALSIM 1 (LEVEL 1) was developed using monthly average air temperature and solar radiation data for just the growing season, and it assumes no limitation on alfalfa production from soil water supply or soil fertility. Thus, model predictions of yield represent the potential rather than the actual yield. The model can handle daily solar radiation and daily average air temperatures, but model performance has not been tested with such input.

The model was also designed for a simulation to begin at the start of the growing season. The computed daylength is given a positive value when daylengths are increasing and a negative value when daylengths are decreasing. However, the first calculated daylength is always positive, so run initiation when daylengths are decreasing results in an incorrect sign for the daylength of the first day. This could result in incorrect predictions of growth rate for that day.

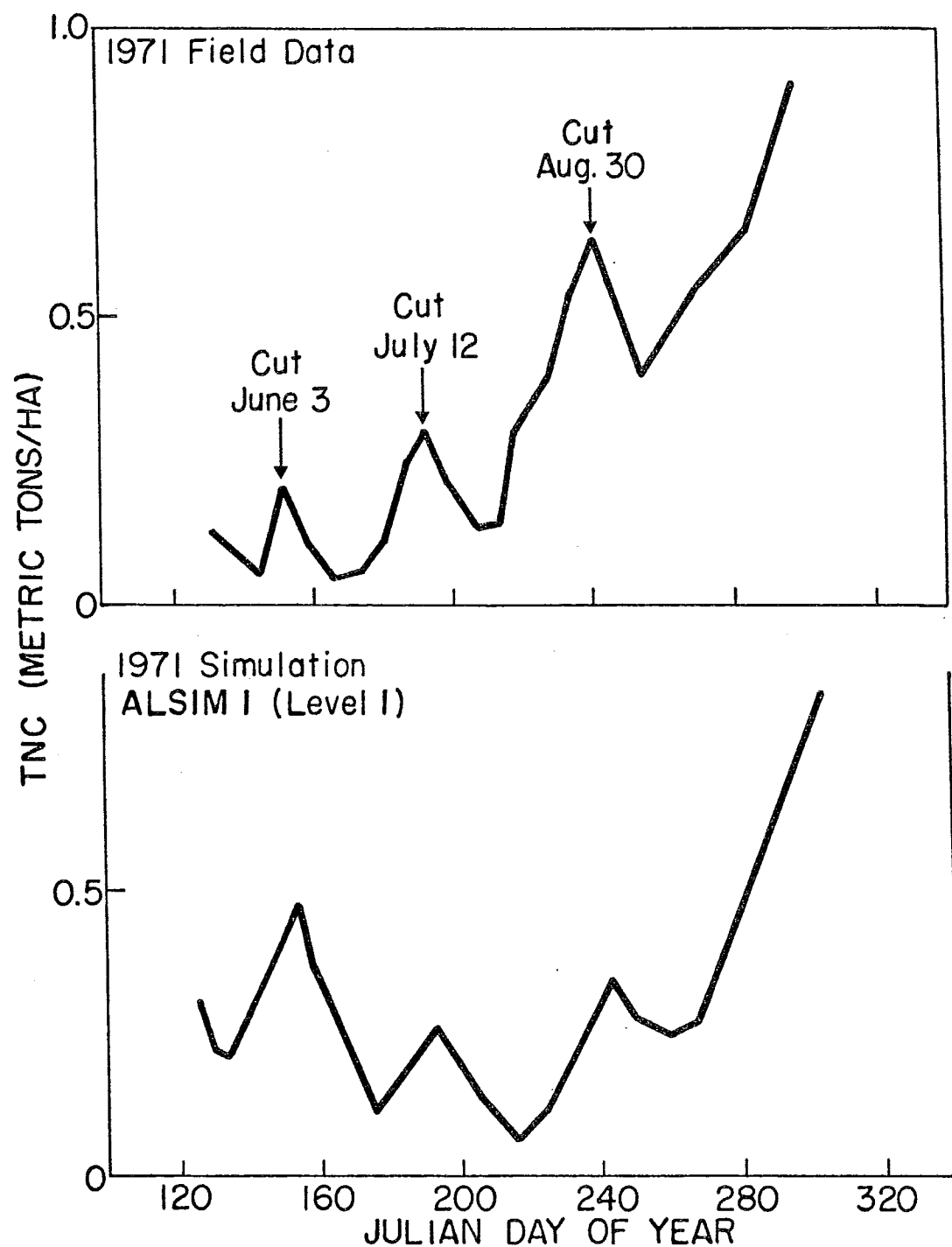Fig. 3. TNC changes through time with a three-cut management as
measured in the field or simulated with ALSIM 1 (LEVEL 1)
for the 1971 growing season at Aurora, N.Y.
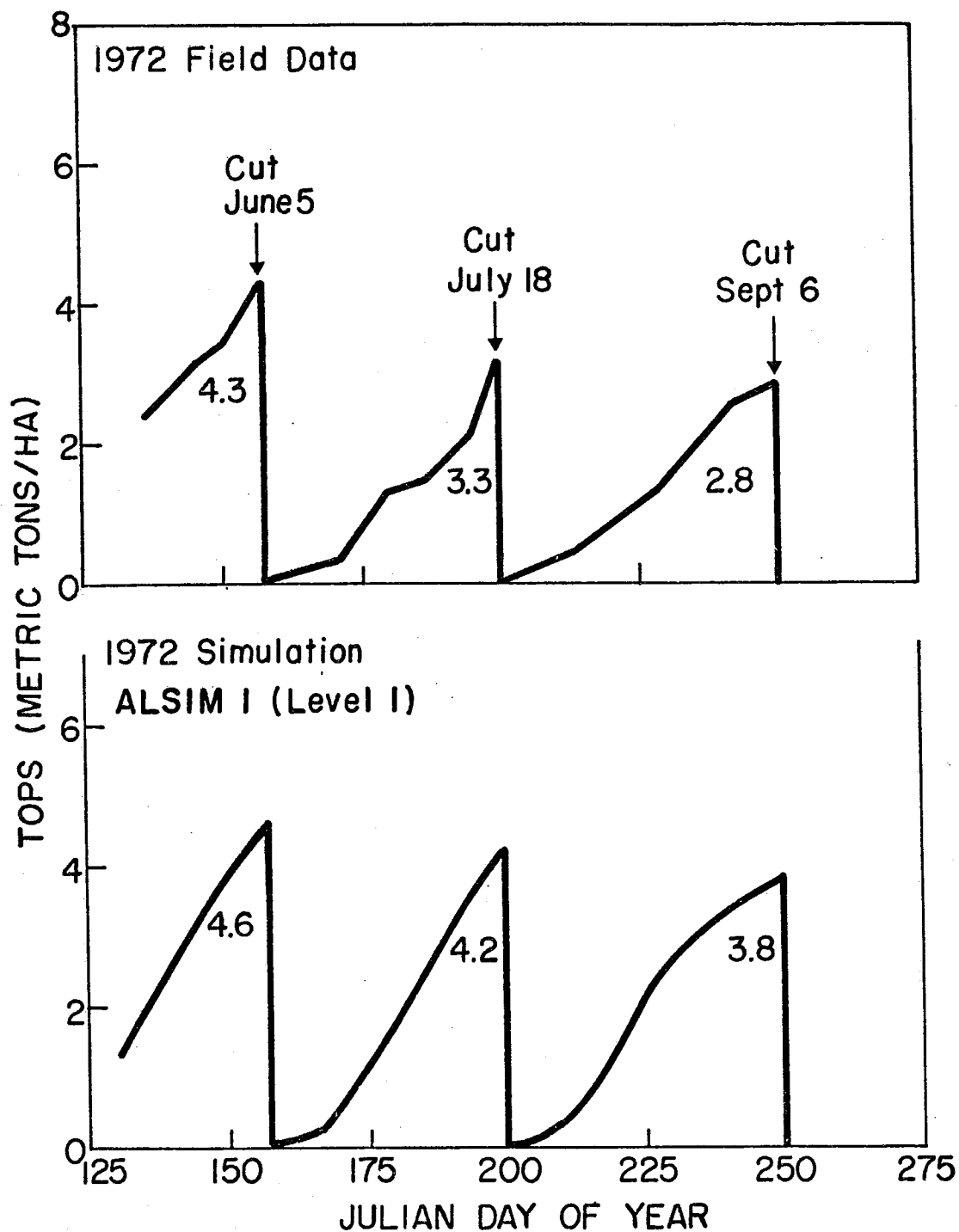
Fig. 4. Growth curves of alfalfa herbage (TOPS) with a three-cut
management as measured in the field or simulated with
ALSIM 1 (LEVEL 1) for the 1972 growing season at Aurora,
N.Y. Numbers under the curves are dry matter yields at
each harvest.

Daylength is also used in conjunction with leaf area index to calculate the fraction of solar radiation absorbed by the leaf canopy. The nature of the functional relationship depends on latitude, i.e., the solar elevation for a particular daylength. The function used was measured in Ontario, Canada at about 43.5° N (Hunt et al., 1970). As the difference between that latitude and the one for simulation increases, errors in predicted light absorption will increase. The effect of this response on the accuracy of model predictions has not been tested.

Though the model was set up primarily for runs lasting only the length of one growing season, it will approximate winter responses of the crop. However, the known overwintering decline in root reserves (TNC) is not simulated (Jung and Smith, 1961). In addition, if simulation continues past the start of a new calendar year, special run control is required to input data for the new year.

When a killing frost occurs (mean air temperature of 2C), all the tops are killed; buds, however, remain alive. A type of alfalfa that goes into or out of winter dormancy at daylengths between 11.0 and 11.5 hours is assumed. Basal bud elongation (transfer from buds to tops) does not begin in the spring until a mean air temperature of 5C is reached. The physiological age of the plant is calculated by heat summation (growing degree days with a 5C base temperature). The sum is reset to zero with every harvest or a killing frost. If simulation is attempted through the winter period and there is no killing frost, physiological age will not be reset when spring growth begins.

The internal physiological functions, constants, and parameters need not be altered for model operation. As mentioned in the section on model performance, some of those relationships are probably incorrect and model predictions constitute only a first approximation of field performance. The source of the physiological data used in the model are given with the definition of terms.

DEFINITION OF TERMS

This section is divided into two parts with the definition of variable names used for data preceding those of the other variables. In CSMP the special labels PARAMETER, INCON, CONSTANT, TABLE, and FUNCTION identify the information that follows as data. Data entered in this way must be given a variable name. This allows the data to be changed between runs without changing the structure of the model. A TABLE contains subscripted data; a FUNCTION contains sets of x, y coordinates.

The dimensions of yield variables in the following definitions are grams of dry matter per square meter of ground surface ($g\ m^{-2}$).

Input Variable Names (data)

AVTAF   Average temperature of the air in degrees Celsius as a function of the Julian day of the year. Input data.

BEFD   Fraction of potential bud elongation rate as a function of daylength in hours. No references found.

BEFSR   Fraction of potential bud elongation rate as a function of solar radiation not absorbed by the leaf canopy in ly day^{-1}. No references found.

BEFT   Fraction of potential bud elongation rate as a function of average air temperature in degrees Celsius. No references found.

BUDCF   Ceiling on yield of buds in g m^{-2} as a function of TNC yield in g m^{-2}. No references found.

BUDI   Yield of buds in g m^{-2} at the start of simulation. Input data.

CDAY   Julian days of the year on which cuts are made. Input data.

CSF   Ceiling on fraction of stems in the TOPS (Fick, 1972 unpublished data).

DECF   Declination of the sun in degrees from the equator as a function of the Julian day of the year (Smithsonian Meteorological Tables, 1951).

DTL   Mean life of the decay time of senescing leaves in days. No references found.

DTS   Mean life of the decay time of senescing stems in days. No references found.

EDLG   Fraction of potential leaf growth rate as a function of daylength in hours (Holt et al., 1975).

EDSG   Fraction of potential stem growth rate as a function of daylength in hours (Holt et al., 1975).

ELLG   Fraction of potential leaf growth rate as a function of leaf yield in g m^{-2} (Holt et al., 1975).

ESPM   Fraction of potential growth rate as a function of maturity in growing degree days (Holt et al., 1975).

ESSG   Fraction of potential stem growth rate as a function of stem yield in g m^{-2} (Holt et al., 1975).

ETG   Fraction of potential growth rate as a function of average air temperature in degrees Celsius (Gist and Mott, 1957; Heinrichs and Nielsen, 1966).

ETNCS   Fraction of potential TNC storage rate as a function of TNC yield in g m^{-2} (Nelson and Smith, 1968).

FTGLF   Fraction of top growth in leaves as a function of leaf yield in g m^{-2} (Fick, 1973 unpublished data).

GDDB5I   Growing degree days with a 5C base for the top growth present at the start of simulation. Input data.

GFASR   Potential growth rate in g m^{-2} day^{-1} as a function of absorbed solar radiation in ly day^{-1} (Black, 1963).

KFROST   The killing frost temperature in degrees Celsius.

LAI   Leaf area index - a function of leaf yield (Holt, et al., 1975 with corrections from Fick and Holthausen, 1975).

LDABT   With long days ($\geq$ 15 hours), the fraction of solar radiation absorbed by leaves in ly day^{-1} as a function of LAI (Hunt et al., 1970).

LDCLAI   The LAI giving 95% absorption of solar radiation on long days, from LDABT.

LEAFI   Yield of leaves in g m^{-2} at the start of simulation. Input data.

MATSI   Yield of MATS in g m^{-2} at the start of simulation. Input data.

Mean Life   With exponential decay, the time to decrease to 1/e or 0.368 of the original amount. Mean life instead of half-life is used in coding because of the simplicity of the form: size change during time interval = present size/mean life.

MLBUDS   Mean life of bud disappearance in days (Leach, 1968).

MLTNC   Mean life of TNC disappearance in days (Smith and Silva, 1969).

NCUTS   The maximum number of cuts in any one year of simulated growth. Input data.

RCTNC   Fraction of TNC lost to respiration when buds are formed (Smith and Marten, 1970).

RGR   Relative growth rate of plant material in g g^{-1} (de Wit and Goudriaan, 1974).

SDABT   With short days ($\leq$ 12 hours), the fraction of solar radiation absorbed by leaves in ly day^{-1} as a function of LAI (Hunt et al., 1970).

SDAY   Julian day of the year when simulation is started. Input data.

SDCLAI   The LAI giving 90% absorption of solar radiation on short days, from SDABT.

SLA   Specific leaf area in m^2 g^{-1} (Holt et al., 1975; Fick and Holthausen, 1975).

SRADF   Solar radiation in ly day^{-1} as a function of Julian day of the year. Input data.

STEMI   Yield of stems in g m^{-2} at the start of simulation. Input data.

TDAY   Total number of days in the calendar years completed since the start of the simulation. Input data.

TNCI   Yield of TNC in g m^{-2} at the start of simulation. Input data.

Output Variable Names

AVTA   Average temperature of the air in degrees Celsius.

BUDC   Ceiling yield of buds in g m^{-2}.

BUDS   Yield of basal buds in g m^{-2}.

CCOND   Crop condition signal: the crop dies and simulation is terminated when CCOND and DEATH have the same value.

CLEAF   Ceiling non-senescing leaf yield in g m^{-2}.

COSUNR   The cosine of the hour of sunrise.

CSTEM   Ceiling non-senescing stem yield in g m^{-2}.

CUT   Signal for simulating a harvest.

DAY   Julian day of the year: Jan. 1 = 1, Dec. 31 = 365 in a non-leap year.

DAYLEN   Daylength in hours with a positive sign when daylengths are increasing and a negative sign when they are decreasing.

DAYLIN   Daylength in hours. This number is always positive, and it is calculated with the method of McKinion et al., 1975.

DD   The daily increment in GDDB5.

DDF   Signal to reset GDDB5 to zero when there is a killing frost.

DDR   Signal to set GDDB5 to zero when there is a cut.

DEATH   Value of CCOND when the crop will die.

DEC   Declination of the sun in degrees from the equator.

DECR   Declination of the sun in radians.

DECY   Declination of the sun for yesterday in radians.

DLFAC   Daylength factor, the fraction of the difference between a short ($\leq$ 12 hours) and a long ($\geq$ 15 hours) day.

DM   Dry matter.

ECG   Signal for the effect of cutting on growth.

FLEAF   Fraction of leaves in tops.

FLHAY   Fraction of leaves in the harvested hay.

FRL   Loss of leaves to freezing in g m^{-2} day^{-1}.

FRS   Loss of stems to freezing in g m^{-2} day^{-1}.

FSRADA   Fraction of solar radiation absorbed.

FTGL   Fraction of top growth in leaves.

GDDB5   Growing-degree days with a base temperature of 5C.

GRB   Growth rate of buds in g m^{-2} day^{-1}.

GRBR   Growth rate of buds, including respiration, in g m^{-2} day^{-1}.

GRL   Growth rate of leaves in g m^{-2} day^{-1}.

GRLB   Growth rate of leaves coming from bud elongation in g m^{-2} day^{-1}.

GRM   Potential rate of top growth and storage in g m^{-2} day^{-1}.

GRS   The growth rate of stems in g m^{-2} day^{-1}.

GRSB   Growth rate of stems coming from bud elongation in g m^{-2} day^{-1}.

HAY   Hay harvested since the start of simulation in g m^{-2}.

HLEAF   Harvested leaves since the start of simulation in g m^{-2}.

HRL   Loss of leaves to harvesting in g m^{-2} day^{-1}.

HRS   Loss of stems to harvesting in g m^{-2} day^{-1}.

HSTEM   Harvested stems since the start of simulation in g m^{-2}.

LAI   Leaf area index in m m^{-2}.

LATR   Latitude of the experimental location in radians.

LDAB   Long-day solar radiation absorption in ly day^{-1}.

LEAF   Yield of leaves in g m^{-2}.

LOSSL   Total leaf losses in g m^{-2} day^{-1}.

LOSSS   Total stem losses in g m^{-2} day^{-1}.

MATS   Materials available for top growth and storage in g m^{-2}.

OUM   Other uses of MATS in g m^{-2} day^{-1}.

PGRL   Potential growth rate of leaves in g m^{-2} day^{-1}.

PGRS   Potential growth rate of stems in g m^{-2} day^{-1}.

PSTOR   Potential rate of TNC storage or accumulation in g m^{-2} day^{-1}.

SDAB   Short-day solar radiation absorption in ly day^{-1}.

SRAD   Solar radiation in langleys (ly) day^{-1}.

SRADA   Solar radiation absorbed in ly day^{-1}.

SRADN   Solar radiation not absorbed by the leaf canopy in ly day^{-1}.

SRL   Loss of leaves to senescence in g m^{-2} day^{-1}.

SRS   Loss of stems to senescence in g m^{-2} day^{-1}.

STEM   Yield of stems in g m^{-2}.

STOR   Rate of TNC storage or accumulation in g m^{-2} day^{-1}.

SUNRIZ   The time in radians from sunrise until noon.

TIME   The intrinsic CSMP variable for time elapsed since the start of simulation. In ALSIM 1, TIME is in days.

TNC   Yield of total nonstructural carbohydrates accumulated in the upper 10 cm of taproots in g m^{-2}.

TNCD   TNC yield when death occurs in g m^{-2}.

TOPS   Yield of the harvestable herbage in g m^{-2}.

YDAYL   Yesterday's daylength in hours.

PROGRAM SETUP AND EXECUTION

ALSIM 1 (LEVEL 1) is written in System/360 Continuous System Modeling Program (CSMP) and has been run on the IBM 360/65 and IBM 370/168 computers at the Cornell University campus in Ithaca. CSMP has a set of application-oriented library functions which are described in the CSMP Users' Manual (IBM, 1972). The standard

FORTRAN IV library is also available to the system. The standard
code is EBCDIC, and the cards were punched on an IBM 029 keypunch.
A FORTRAN IV (LEVEL G) code of the program is a part of the standard
output of a CSMP job.

The card deck has the following arrangement:

1. Job card

2. Initial job control language cards

3. // EXEC CSMP

4. Main program deck

5. ENDJOB

6. Terminal job control language cards

The main program deck is set up in sections in the following
order:

1. Initial section: input data and calculations
    made only once at the start of the run.

2. Cutting management section: input instruc-
    tions for simulated cutting management and
    generation of the CUT signal.

3. Procedure for cutting hay.

4. Crop weather section.

5. MATS section

6. LEAF section.

7. STEM section.

8. TNC section

9. BUD section.

10. Crop death section: terminates the run if
    the crop dies.

11. Run control section: specify TIMER vari-
    ables, output, and format of the output.

Functional relationships and other data follow the program state-
ments of each section, excepting those of the initial section where
they come first.

The program requires a minimum of 102 K bytes of storage and
normally is run in the 124 K region on the IBM 370/168. A simulation
of 200 days with 12 printed output variables at four-day intervals
required about 5.7 seconds of central processor time. A simulation
of 400 days with four graphs of 100 points each required about 8.8
seconds of central processor time.

INPUT, OUTPUT, AND RUN CONTROL

Input

To run a simulation with ALSIM 1 (LEVEL 1), certain information
must be input in the "initial section." These values are treated as
real numbers and must include a decimal point.

LAT   The latitude of the location for which alfalfa growth is
simulated is input on the card reading:

CONSTANT LAT =

The latitude in degrees (using a decimal fraction rather
than minutes and seconds) should follow the equal sign.

SDAY   The Julian day of the year when the simulation run is
started (Jan. 1 = 1., Dec. 31 = 365. in a non-leap year).
It is input with TDAY.

TDAY   The total number of days in the calendar years completed
since the start of simulation follows the SDAY value on the
same card. In the year that simulation starts, it equals
zero. If the starting year is not a leap year, on Jan. 1
of the following year, the value of TDAY should be changed
to 365. If simulation starts on day 100, the card for the
starting year should read as follows:

INCON SDAY = 100., TDAY = 0.

GDDB5I   The growing degree days with a 5C base temperature that have
been received by the growth present at the start of simula-
tion go on a card reading:

INCON GDDB5I =

The GDDB5I follows the equal sign. At the start of the
growing season or following a harvest, it can be set to zero.

The condition of the crop at the start of simulation must also be
specified. The input values are DM yields (g m^{-2}) that would be mea-
sured at the start of the experiment. They are punched on an initial
condition card and are separated by commas. A typical card reads as
follows:

INCON LEAFI = 0., STEMI = 0., TNCI = 75., BUDI = 10., MATSI = 0.

A comma indicates that another variable follows, so the last number should not be followed by a comma.

LEAFI   The initial yield of leaves may range from zero to over 200 g m^{-2}.

STEMI   The initial yield of stems may range from zero to over 300 g m^{-2}.

TNCI   The initial yield of total nonstructural carbohydrates in the taproots may range from zero to 150 g m^{-2}. Below 5 g m^{-2}, the crop will die if there is no photosynthesis.

BUDI   The initial yield of basal buds may range from zero to 20 g m^{-2}.

MATSI   The initial yield (and supply) of materials available for top growth and storage may range from zero to 25 g m^{-2}.

If the start of the growing season or the start of the regrowth period is selected as the starting time of simulation, the values of LEAFI, STEMI, and MATSI should be zero.

Data for the average temperature of the air in degrees Celsius and for the receipt of solar radiation in ly day^{-1} are input as FUNCTION'S or sets of x,y coordinates with x = Julian day of the year, and y = weather condition. The name of the temperature function is AVTAF; the solar radiation function is named SRADF. Actual values for each day can be entered, though we have used monthly averages with the day set equal to the mid-point of each month. Data should run from at least the starting day of simulation up to the time simulation stops. Each number should contain a decimal point and be followed by a comma if more data follows. Three consecutive periods on a card indicate that the data (or the statement) is continued on the next card. If the average air temperature on Jan. 1 (Julian day 1) is -2C and on Feb. 1 (Julian day 32) is -5C, the data is input as follows:

FUNCTION   AVTAF = 1.,-2.,   32.,-5.

A linear change between days is assumed in the program.

The cutting management section must also be set up for each desired simulation. The number of cuts (NCUTS) and the Julian dates when cuts are made (CDAY) must be specified. The comment cards at the front of the "cutting management section" describe how the data should be input. Some of the values are integers and should not include a decimal point. If no cuts are desired, the cutting management section should be removed and replaced with a card reading:

PARAMETER   CUT = 0.

Do not remove the "procedure for cutting hay."

Output

Essentially any variable of the model computed in the process of simulation can be specified as output on PRINT or PRTPLOT (print plot) cards. The values of the specified output variables will be presented as a function of time in a format controlled by the CSMP program and information supplied by the user in the "run control section." A discussion of the "run control section" follows.

The commonly specified output variables are:

TOPS   The yield of harvestable herbage in g m^{-2}.

TNC   The yield of total nonstructural carbohydrates in the taproots in g m^{-2}.

HAY   The total yield of hay harvested since the start of simulation in g m^{-2}.

FLEAF   The fraction of leaves in the TOPS.

FLHAY   The fraction of leaves in the HAY.

Run Control

User options in run control are specified in the "run control section." The CSMP User's Manual (IBM, 1972) describes these options. The user should supply values for the TIMER card, list the variables to be printed as output on the PRINT card, and list the variables to be printed in association with a graph on PRTPLOT cards. He may also designate captions for printed output on TITLE cards and for graphs on LABEL cards.

The TIMER card of ALSIM 1 (LEVEL 1) should specify the values of DELT, FINTIM, PRDEL (if there is printed output), and OUTDEL (if there is printed output in association with a graph). DELT is the size of the time step between calculations of the state of the system and it should always equal 1. FINTIM is the number of days after the start of simulation that the simulation will be stopped. It should not be greater than the days remaining in the year simulation is started. PRDEL and OUTDEL specify the number of days between printed or graphical outputs. PRDEL and OUTDEL should be submultiples of FINTIM. A graph fitting one page of computer output can have no more than 50 lines, so a convenient size for OUTDEL is FINTIM/50. If the user wants a simulation starting on day 90 (March 31), lasting for 200 days (to day 290, Oct. 17), and having graphical output with 4 days between points, the TIMER card should read as follows:

TIMER DELT = 1., FINTIM = 200., OUTDEL = 4.

If the user wants the value of TOPS to be graphed, a PRTPLOT card is used as follows:

PRTPLOT TOPS

The value of TOPS at four-day intervals will be plotted as a function of TIME.

If the user wants non-graphical output for LEAF and STEM in association with the graph of TOPS, the card should read:

PRTPLOT   TOPS (LEAF, STEM)

The values of LEAF and STEM will be printed to the right of the graph of TOPS. Up to three variables (in the parentheses) can be printed in association with a graph and will use the same time scale as the graph. The computer automatically sets the other scale of the graph, though this can be by-passed as explained in the CSMP User's Manual (IBM, 1972).

If two graphs are desired, one for TOPS and one for TNC, the cards should read:

PRTPLOT   TOPS
PRTPLOT   TNC

Only one graph is made for each PRTPLOT card.

If printed output not in association with a graph is desired, the TIMER card should have a value for PRDEL and the variables to be printed should appear on a PRINT card:

PRINT   TOPS, TNC

That card will cause TOPS and TNC to be printed at TIME increments of the value of PRDEL.

If a user wishes a simulation run to last beyond the start of the next calendar year, new TDAY, CDAY (cutting day), weather and FINTIM values must be input at the start of the next year. These values should follow a CONTINUE card. As an example, if simulation starts on day 105 (April 15) and runs through day 305 (Nov. 1) of the following year and both years have 365 days, FINTIM on the first TIMER card should be 250 since 250 days remain in the year simulation was started (365 - 105 = 250). At the end of all the run control cards for the first calendar year of simulation, the user should insert the following cards:

CONTINUE
INCON   TDAY = 365.
TABLE   CDAY(1) = 150.,   CDAY(2) = 195.
FUNCTION   AVTAF = temperature data for new year.
FUNCTION   SRADF = solar radiation data for new year.
TIMER   FINTIM = 555.
END
STOP
ENDJOB

These cards indicate that the run will continue into the new year with new weather and cutting management data (2 cuts, on day 150 and 195), but without resetting TIME or the state of the system. The value on the TIMER card is the sum of the first FINTIM value (250) plus the days simulated in the second year (305). Other TIMER card variables and PRTPLOT and PRINT variables can also be changed following a CONTINUE card. The example run which follows illustrates the use of the CONTINUE option for simulating in more than one calendar year.

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PROGRAM LISTING AND EXAMPLE RUN

The following example simulation run of ALSIM 1 (LEVEL 1) was
set up for Aurora, N.Y. (42.7°N latitude), starting on day 115
(April 25) of 1971. Initial sizes of the parts of the crop were
estimated by a simulation starting before the last killing frost and
running to April 25. Two cuts were simulated in 1971. The first was
on day 180 (June 29), the second on day 240 (Aug. 28). The run was
continued through day 350 (Dec. 15) of 1972, which was a leap year.
The total length of simulation from day 115 of 1971 to day 350 of
1972 was 600 days. The cutting management of 1972 involved four har-
vests; the first on day 147 (May 26), the second on day 184 (July 2),
the third on day 220 (Aug. 7), and the fourth on day 256 (Sept. 12).
Output consisted of two graphs, one for TOPS and one for TNC. The
DAY was printed with both. Accumulated HAY yield was printed with
TOPS. Output for the graphs was at five-day intervals in 1971 and
seven-day intervals in 1972. Weather data was monthly averages (Divi-
sion of Atmospheric Sciences, 1971 and 1972).

```
****CONTINUOUS SYSTEM MODELING PROGRAM****

***PROBLEM INPUT STATEMENTS***

*        EXAMPLE SIMULATION RUN.
*        ALSIM1(LEVEL 1): ALFALFA SIMULATOR WITH DAILY TIMESTEPS
**********      **********      **********      **********      **********
*        INITIAL SECTION
**********      **********      **********      **********      **********
*        THE USER MUST SPECIFY THE VALUES APPROPRIATE FOR EACH RUN ON
*        CONSTANT, INCON, AND FUNCTION CARDS OF THIS SECTION. THEY ARE:
*
*        LAT, LATITUDE OF THE EXPERIMENTATION SITE IN DEGREES.
*        SDAY, THE JULIAN DAY OF THE YEAR WHEN SIMULATION IS STARTED.
*        TDAY, TOTAL NUMBER OF DAYS IN THE CALENDAR YEARS COMPLETED SINCE
*        THE START OF SIMULATION: EQUALS 0. IN THE STARTING YEAR.
*        GDDB5I, GROWING DEGREE DAYS WITH 5C BASE FOR THE GROWTH PRESENT
*        AT THE START OF SIMULATION.
*        LEAFI, YIELD OF LEAVES AT START OF SIMULATION (G/SQUARE METER).
*        STEMI, YIELD OF STEMS AT START OF SIMULATION (G/SQUARE METER).
*        TNCI, YIELD OF TNC AT START OF SIMULATION (G/SQUARE METER).
*        BUDI, YIELD OF BUDS AT START OF SIMULATION (G/SQUARE METER).
*        MATSI, YIELD OF MATS AT START OF SIMULATION (G/SQUARE METER).
*        FUNCTION AVTAF, AVERAGE TEMPERATURE OF THE AIR AS A FUNCTION OF
*        THE JULIAN DAY OF THE YEAR: A SET OF (X,Y) COORDINATES WITH
*        X=DAY, AND Y=DEGREES CELSIUS.
*        FUNCTION SRADF, SOLAR RADIATION AS A FUNCTION OF THE JULIAN DAY
*        OF THE YEAR: A SET OF (X,Y) COORDINATES WITH X=DAY, Y=LY/DAY.
*
**********      **********INITIAL SECTION DATA**********      **********
CONSTANT LAT = 42.7
INCON SDAY = 115., TDAY = 0.
INCON GDDB5I = 0.
INCON LEAFI = 18., STEMI = 2., TNCI = 60., BUDI = .1, MATSI = .4
*        MONTHLY AVERAGE TEMPERATURE OF THE AIR (DEGREES CELSIUS)
*        FOR AURORA, NY DURING 1971.
FUNCTION  AVTAF = 105.,5., 135.,13., 166.,19., 196.,20., 227.,19.,...
                258.,18., 288.,14., 319.,3., 349.,0., 365.,-2.
*        MONTHLY AVERAGE SOLAR RADIATION LEVELS (LY PER DAY) ARE FOR
*        AURORA, NY DURING 1971.
FUNCTION  SRADF = 105.,423., 135.,505., 166.,515., 196.,496.,      ...
                227.,408., 258.,297., 288.,203., 319.,114.,      ...
                349.,85., 365.,110.
**********      **INITIAL SECTION STRUCTURE STATEMENTS**      **********
        LATR = 2.*3.1416*LAT/360.
INITIAL
        DECY = (2.*3.1416/360.)*AFGEN(DECF,SDAY-1.)
        COSUNR = (-SIN(LATR)*SIN(DECY))/(COS(LATR)*COS(DECY))
        SUNRIZ = ARCOS(COSUNR)*12./3.1416
        YDAYL = 2.*SUNRIZ
DYNAMIC
```

```
**********    **********    **********    **********    **********
*        CUTTING MANAGEMENT SECTION
**********    **********    **********    **********    **********
*         THE PURPOSE OF THIS SECTION IS TO GENERATE A SIGNAL (CALLED CUT)
*         THAT WILL RESULT IN A SIMULATED HARVEST.  TWO VARIABLES CONTROL
*         THE SIMULATED CUTTING MANAGEMENT:
*            NCUTS, NUMBER OF CUTS TO BE SIMULATED.
*            CDAY, DAYS WHEN CUTS ARE MADE.
*         IF THREE CUTS ARE TO BE MADE, NCUTS MUST BE SPECIFIED ON TWO
*         CARDS IN THE FOLLOWING MANNER:
*            PARAMETER NCUTS = 3
*            STORAGE  CDAY(3)
*         NOTE THAT THE NUMBERS USED HERE ARE INTEGERS.
*         THE DAYS WHEN THE CUTS ARE MADE ARE INPUT IN A TABLE OF CDAY'S.
*         IF THE FIRST CUT IS TO BE MADE ON JULY 1, WHICH IS THE 182ND DAY
*         OF THE YEAR, THE DATA WILL APPEAR AS FOLLOWS:
*            TABLE  CDAY(1) = 182.
*         NOTE THAT THE NUMBER OF THE DAY IS A REAL NUMBER.
*         THE NUMBER OF CUTS SHOULD  EQUAL THE NUMBER OF CUTTING DAYS
*         IN THE  MANAGEMENT OR YEAR WITH THE MOST CUTS.
*         AN EXAMPLE OF THE TABLE FOLLOWS:
*            TABLE  CDAY(1) = 160.,  CDAY(2) = 202.,  CDAY(3) = 245.
*         IF CUTS ARE NOT WANTED IN A PARTICULAR SIMULATION, THIS SECTION
*         SHOULD BE REMOVED AND REPLACED WITH A CARD :
*            PARAMETER  CUT = 0.
FIXED   NCUTS
PARAMETER NCUTS = 4
STORAGE  CDAY(4)
TABLE  CDAY(1)=180., CDAY(2)=240.
PROCEDURE  CUT = CUTPRO(NCUTS,CDAY,DAY)
        I = 1
   11   IF(CDAY(I)/(DAY+NOT(DAY)).EQ.1.) GO TO 14
        IF(I.LT.NCUTS) GO TO 12
        GO TO 13
   12   I = I + 1
        GO TO 11
   13   CUT = 0.
        GO TO 15
   14   CUT = 1.
   15   CONTINUE
ENDPRO
**********    **********    **********    **********    **********
* PROCEDURE FOR CUTTING HAY.
**********    **********    **********    **********    **********
PROCEDURE  HRL,HRS,ECG,DDR = CUTHAY(CUT,LEAF,STEM,GDDB5)
        IF(CUT) 21,21,22
   21   HRL = 0.
        HRS = 0.
        DDR = 0.
        ECG = 1.
        GO TO 23
   22   HRL = LEAF
        HRS = STEM
        DDR = GDDB5
        ECG = 0.
   23   CONTINUE
ENDPRO
        HLEAF = INTGRL(0.,HRL)
        HSTEM = INTGRL(0.,HRS)
        HAY = HLEAF + HSTEM
        FLHAY = HLEAF/(HAY+NOT(HAY))
```

```
*********    *********    *********    *********    *********
*     CROP WEATHER SECTION
*********    *********    *********    *********    *********
        AVTA = AFGEN(AVTAF,DAY)
        SRAD = AFGEN(SRADF,DAY)
        DAY = SDAY+TIME-TDAY
        GDDB5 = INTGRL(GDDB5I,DD-DDR-DDF)
        DDF = INSW(KFROST-AVTA,0.,GDDB5)
        DD = AMAX1(0.,AVTA - 5.)
        DEC = AFGEN(DECF,DAY)
        DECR = 2.*3.1416*DEC/360.
        COSUNR = (-SIN(LATR)*SIN(DECR))/(COS(LATR)*COS(DECR))
        SUNRIZ = ARCOS(COSUNR)*12./3.1416
        DAYLIN = 2.*SUNRIZ
PROCEDURE  DAYLEN = DLPRO(DAYLIN,YDAYL)
        IF(DAYLIN-YDAYL) 10,20,20
    10  YDAYL = DAYLIN
        DAYLEN = (-1.)*DAYLIN
        GO TO 30
    20  DAYLEN = DAYLIN
        YDAYL = DAYLEN
    30  CONTINUE
ENDPRO
*********    ********* WEATHER SECTION DATA *********    *********
PARAMETER  KFROST = 2.
FUNCTION  DECF = 0.,-23.,  10.,-22.,  20.,-20.,  30.,-18.,        ...
    40.,-15.,    50.,-11.,     60.,-7.,      70.,-3.,      80.,0.,      ...
    90.,4.,      100.,8.,     110.,11.,     120.,14.,    130.,18.,     ...
    140.,20.,    150.,22.,    160.,23.,     170.,24.,    180.,23.,     ...
    190.,22.,    200.,21.,    210.,19.,     220.,16.,    230.,10.,     ...
    240.,6.,     250.,1.,     260.,-2.,     270.,-6.,    280.,-9.,     ...
    290.,-13.,   300.,-17.,   310.,-19.,    320.,-21.,   330.,-22.,    ...
    340.,-23.,   350.,-24.,   360.,-23.,    370.,-23.,   380.,-22.
*********    *********    *********    *********    *********
*     MATS SECTION:  MATERIALS AVAILABLE FOR TOP GROWTH AND STORAGE
*********    *********    *********    *********    *********
        GRM = AFGEN(GFASR,SRADA)*AFGEN(ETG,AVTA)*AFGEN(ESPM,GDDB5)*ECG
        MATS = INTGRL(MATSI,GRM-GRL-GRS-STOR-OUM)
        OUM = MATS-GRL-GRS-STOR
        SRADA = SRAD*FSRADA
        FSRADA = LDAB+(SDAB-LDAB)*DLFAC
        DLFAC = LIMIT(0.,15.-12.,15.-DAYLIN)/(15.-12.)
        SDAB = AFGEN(SDABT,LAI)
        LDAB = AFGEN(LDABT,LAI)
*********    ********* MATS SECTION DATA *********    *********
FUNCTION GFASR = 0.,0.,  100.,5.8,  200.,10.4,  300.,14.2,       ...
        400.,16.9,  500.,19.0,  600.,21.1,  700.,23.1,  800.,25.0
FUNCTION  ETG = -30.,0.,  2.,0.,  5.,.2,  10.,.95,  12.,1.,  15.,1.,...
        21.,.92,  27.,.66,  32.,.36,  40.,.05,  50.,0.
FUNCTION  ESPM = 0.,.95,  125.,1.,  700.,1.,  750.,.95,  875.,.7,   ...
        1000.,.6,  2000.,.35,  4000.,.25
FUNCTION  SDABT = 0.,0.,  .5,.55,  .75,.70,  1.,.80,  1.5,.90,     ...
        2.,.95,  15.,.999
FUNCTION  LDABT = 0.,0.,  .5,.30,  .75,.42,  1.,.50,  1.5,.65,     ...
        2.,.75,  3.,.90,  4.,.95,  15.,.999
```

```
**********    **********    **********    **********    **********
*      LEAF SECTION
**********    **********    **********    **********    **********
        LEAF  = INTGRL(LEAFI,GRL+GRLB-LOSSL)
        GRL = AMIN1(MATS*FTGL,PGRL)*ECG
        FTGL = AFGEN(FTGLF,LEAF)
        PGRL = 0.2*LEAF*AFGEN(ELLG,LEAF)*AFGEN(EDLG,DAYLEN)
        SRL = AMAX1(0.,(LEAF-CLEAF)/DTL)
        CLEAF = (LDCLAI-DLFAC*(LDCLAI-SDCLAI))/SLA
        LOSSL = AMAX1(HRL,SRL,FRL)
        FRL = INSW(KFROSI-AVTA,0.,LEAF)
        LAI = AMAX1(0.,SLA*LEAF)
        FLEAF = LEAF/(LEAF+STEM+NOT(LEAF+STEM))
**********    **********  LEAF SECTION DATA **********    **********
PARAMETER  SLA = .02
PARAMETER  DTL = 7.,    SDCLAI = 1.5,  LDCLAI = 5.
FUNCTION  FTGLF = 0.,,9,  190.,,42,  250.,,4,  350.,,4
FUNCTION  ELLG = 0.,1.,  100.,1.,  110.,.95,  120.,.80,  145.,.40,   ...
        155.,.20,  165.,.10,  200.,.05,  350.,0.
FUNCTION  EDLG = -16.,1.,  -14.,1.,  -13.5,.95,  -10.5,.15,          ...
        -10.,.1,  4.,.1,  4.5,.15,  8.5,.95,  9.,1.,  16.,1.
**********    **********    **********    **********    **********
*      STEM SECTION
**********    **********    **********    **********    **********
        STEM  = INTGRL(STEMI,GRS+GRSB-LOSSS)
        GRS = AMIN1(MATS*(1.-FTGL),PGRS)*ECG
        PGRS = 0.499*STEM*AFGEN(ESSG,STEM)*AFGEN(EDSG,DAYLEN)
        SRS = AMAX1(0.,(STEM-CSTEM)/DTS)
        CSTEM = TOPS*CSF
        TOPS = LEAF+STEM
        LOSSS = AMAX1(HRS,SRS,FRS)
        FRS = INSW(KFROSI-AVTA,0.,STEM)
**********    **********   STEM SECTION DATA **********    **********
PARAMETER  CSF = .75,  DTS = 14.
FUNCTION  ESSG = 0.,1.,  155.,1.,  175.,.95,  205.,.8,  240.,.3,     ...
        265.,.1,  285.,.05,  500.,0.
FUNCTION  EDSG = -16.,1.,  -14.,1.,  -13.5,.9,  -12.5,.25,           ...
        -12.,.15,  -11.5,.1,  -10.5,.05,  9.,.05,  9.5,.1,           ...
        10.5,.4,  12.5,.9,  13.,1.,  16.,1.
**********    **********    **********    **********    **********
*      TNC SECTION
**********    **********    **********    **********    **********
        TNC = INTGRL(TNCI,STOR-GRBR)
        STOR = AMIN1(MATS-GRL-GRS,PSTOR)*ECG
        PSTOR = 1.8*AFGEN(ETNCS,TNC)
**********    **********   TNC SECTION DATA **********    **********
FUNCTION  ETNCS = 0.,1.,  80.,1.,  90.,.9,  100.,.5,  110.,.1,       ...
        140.,.05,  150.,0.
```

```
**********    **********    **********    **********    **********
*       BUD SECTION
**********    **********    **********    **********    **********
        BUDS = INTGRL(BUDI,GRB-GRLB-GRSB)
        GRB = GRBR-GRBR*RCTNC
        GRSB = GRLB*.1
        GRBR = AMIN1((BUDC-BUDS)/(1.-RCTNC),TNC/MLTNC,RGR*(TOPS+BUDS))...
           *AFGEN(ETG,AVTA)
        BUDC = AFGEN(BUDCF,TNC)
        GRLB = (BUDS/MLBUDS)*INSW(MATS*(-1),AFGEN (BEFSR,SRADN),1.)...
          *AFGEN (BEFD,DAYLEN)*AFGEN(BEFT,AVTA)
        SRADN = SRAD-SRADA
**********    **********    BUD SECTION DATA    **********    **********
PARAMETER  RCTNC = .6, RGR = .5, MLTNC = 14., MLBUDS = 2.
FUNCTION  BUDCF = 0.,5.,   50.,8.,   100.,12.,  125.,15.,  150.,20.
FUNCTION  BEFSR = 0.,0.,   30.,0.,   40.,.05,  50.,.15,  80.,.85,       ...
          90.,.95,  100.,1.,  800.,1.
FUNCTION  BEFD = -16.,1., -11.5,1., -11.,0., 11.,0., 11.5,1., 16.,1.
FUNCTION  BEFT = -10.,0., 5.,0., 8.,1., 50.,1.
**********    **********    **********    **********    **********
*       CROP DEATH SECTION
**********    **********    **********    **********    **********
FINISH  DEATH = CCOND
CONSTANT  DEATH = 0.
        CCOND = IOR(TNCD,GRM)
        TNCD = TNC-5.
**********    **********    **********    **********    **********
*       RUN CONTROL SECTION
**********    **********    **********    **********    **********
METHOD  RECT
TIMER DELT = 1., FINTIM = 250.,  OUTDEL = 5.
PRTPLOT  TOPS(DAY,HAY)
PRTPLOT  TNC(DAY)
CONTINUE
INCON   TDAY = 365.
TABLE   CDAY(1)=147., CDAY(2)=182., CDAY(3)=217., CDAY(4)=252.
TIMER   FINTIM = 600., OUTDEL = 7.
*       MONTHLY AVERAGE TEMPERATURE OF THE AIR (DEGREES CELSIUS)
*       FOR AURORA, NY DURING 1972.
FUNCTION  AVTAF = 1.,-2., 15.,-3., 46.,-6., 75.,-2., 106.,4.,       ...
               136.,14., 167.,17., 197.,21., 228.,19., 259.,17.,...
               289.,8., 320.,2., 349.,0., 366.,-1.
*       MONTHLY AVERAGE SOLAR RADIATION LEVELS (LY PER DAY) ARE FOR
*       AURORA, NY DURING 1972.
FUNCTION  SRADF = 1.,110., 15.,138., 46.,193., 75.,282.,       ...
               106.,374., 136.,382., 167.,386., 197.,438.,     ...
               228.,387., 259.,288., 289.,176., 320.,91.,      ...
               349.,56., 366.,90.
END
STOP
ENDJOB
```

The output of a CSMP program includes (a) a listing in CSMP, (b) the output variable sequence, (c) the number of each of the different kinds of variables used, (d) a listing of the simulation data for each segment of computation, (e) a FORTRAN IV listing of the program, and (f) the output specified in the original job. The listing on the previous pages is of the input deck and is identical to (a) above, except in (a) the ENDJOB card is deleted. On the following pages, only part (f) of the output is included.

1971 Herbage Growth Curves

Two Cuts

TOPS   VERSUS   TIME

MINIMUM 0.0   MAXIMUM 6.8899E+02

TIME	TOPS
0.0	2.0000E+01
5.0000E+00	4.5634E+01
1.0000E+01	1.0463E+02
1.5000E+01	1.8501E+02
2.0000E+01	2.6008E+02
2.5000E+01	3.2489E+02
3.0000E+01	3.9050E+02
3.5000E+01	4.5490E+02
4.0000E+01	5.1283E+02
4.5000E+01	5.5647E+02
5.0000E+01	5.9687E+02
5.5000E+01	6.3320E+02
6.0000E+01	6.6492E+02
6.5000E+01	6.8899E+02
7.0000E+01	1.7322E+01
7.5000E+01	5.8709E+01
8.0000E+01	1.2835E+02
8.5000E+01	2.0995E+02
9.0000E+01	2.7581E+02
9.5000E+01	3.3592E+02
1.0000E+02	3.9509E+02
1.0500E+02	4.4987E+02
1.1000E+02	4.9015E+02
1.1500E+02	5.0576E+02
1.2000E+02	5.1195E+02
1.2500E+02	5.1439E+02
1.3000E+02	1.4700E+01
1.3500E+02	3.7459E+01
1.4000E+02	6.9766E+01
1.4500E+02	1.0668E+02
1.5000E+02	1.2574E+02
1.5500E+02	1.3348E+02
1.6000E+02	1.3479E+02
1.6500E+02	1.3407E+02
1.7000E+02	1.3169E+02
1.7500E+02	1.2740E+02
1.8000E+02	1.2443E+02
1.8500E+02	1.2310E+02
1.9000E+02	1.2442E+02
1.9500E+02	1.2753E+02
2.0000E+02	1.2917E+02
2.0500E+02	1.2645E+02
2.1000E+02	1.2367E+02
2.1500E+02	3.6682E-02
2.2000E+02	0.0
2.2500E+02	0.0
2.3000E+02	0.0
2.3500E+02	0.0
2.4000E+02	0.0
2.4500E+02	0.0
2.5000E+02	0.0

DAY	HAY
1.1500E+02	0.0
1.2000E+02	0.0
1.2500E+02	0.0
1.3000E+02	0.0
1.3500E+02	0.0
1.4000E+02	0.0
1.4500E+02	0.0
1.5000E+02	0.0
1.5500E+02	0.0
1.6000E+02	0.0
1.6500E+02	0.0
1.7000E+02	0.0
1.7500E+02	0.0
1.8000E+02	0.0
1.8500E+02	6.8899E+02
1.9000E+02	6.8899E+02
1.9500E+02	6.8899E+02
2.0000E+02	6.8899E+02
2.0500E+02	6.8899E+02
2.1000E+02	6.8899E+02
2.1500E+02	6.8899E+02
2.2000E+02	6.8899E+02
2.2500E+02	6.8899E+02
2.3000E+02	6.8899E+02
2.3500E+02	6.8899E+02
2.4000E+02	1.2034E+03
2.4500E+02	1.2034E+03
2.5000E+02	1.2034E+03
2.5500E+02	1.2034E+03
2.6000E+02	1.2034E+03
2.6500E+02	1.2034E+03
2.7000E+02	1.2034E+03
2.7500E+02	1.2034E+03
2.8000E+02	1.2034E+03
2.8500E+02	1.2034E+03
2.9000E+02	1.2034E+03
2.9500E+02	1.2034E+03
3.0000E+02	1.2034E+03
3.0500E+02	1.2034E+03
3.1000E+02	1.2034E+03
3.1500E+02	1.2034E+03
3.2000E+02	1.2034E+03
3.2500E+02	1.2034E+03
3.3000E+02	1.2034E+03
3.3500E+02	1.2034E+03
3.4000E+02	1.2034E+03
3.4500E+02	1.2034E+03
3.5000E+02	1.2034E+03
3.5500E+02	1.2034E+03
3.6000E+02	1.2034E+03
3.6500E+02	1.2034E+03

1972 Herbage Growth Curves

Four Cuts

TOPS VERSUS TIME

MINIMUM 0.0 MAXIMUM 3.6411E+02

TIME	TOPS
2.5000E+02	0.0
2.5700E+02	0.0
2.6400E+02	0.0
2.7100E+02	0.0
2.7800E+02	0.0
2.8500E+02	0.0
2.9200E+02	0.0
2.9900E+02	0.0
3.0600E+02	0.0
3.1300E+02	0.0
3.2000E+02	0.0
3.2700E+02	0.0
3.3400E+02	0.0
3.4100E+02	0.0
3.4800E+02	0.0
3.5500E+02	0.0
3.6200E+02	2.2273E+00
3.6900E+02	2.7522E+01
3.7600E+02	9.3557E+01
3.8300E+02	1.9431E+02
3.9000E+02	2.8318E+02
3.9700E+02	3.6411E+02
4.0400E+02	1.8676E+01
4.1100E+02	6.8742E+01
4.1800E+02	1.5483E+02
4.2500E+02	2.5171E+02
4.3200E+02	3.3134E+02
4.3900E+02	1.0806E+01
4.4600E+02	4.3055E+01
4.5300E+02	1.1784E+02
4.6000E+02	2.1728E+02
4.6700E+02	3.0108E+02
4.7400E+02	4.6515E+00
4.8100E+02	1.8699E+01
4.8800E+02	6.1665E+01
4.9500E+02	1.4890E+02
5.0200E+02	2.0505E+02
5.0900E+02	7.6348E+00
5.1600E+02	1.6619E+01
5.2300E+02	2.9964E+01
5.3000E+02	4.5203E+01
5.3700E+02	6.0045E+01
5.4400E+02	7.2453E+01
5.5100E+02	8.3181E+01
5.5800E+02	8.6579E+01
5.6500E+02	8.5666E+01
5.7200E+02	6.3330E-08
5.7900E+02	0.0
5.8600E+02	0.0
5.9300E+02	0.0
6.0000E+02	0.0

DAY	HAY
0.0	1.2034E+03
7.0000E+00	1.2034E+03
1.4000E+01	1.2034E+03
2.1000E+01	1.2034E+03
2.8000E+01	1.2034E+03
3.5000E+01	1.2034E+03
4.2000E+01	1.2034E+03
4.9000E+01	1.2034E+03
5.6000E+01	1.2034E+03
6.3000E+01	1.2034E+03
7.0000E+01	1.2034E+03
7.7000E+01	1.2034E+03
8.4000E+01	1.2034E+03
9.1000E+01	1.2034E+03
9.8000E+01	1.2034E+03
1.0500E+02	1.2034E+03
1.1200E+02	1.2034E+03
1.1900E+02	1.2034E+03
1.2600E+02	1.2034E+03
1.3300E+02	1.2034E+03
1.4000E+02	1.2034E+03
1.4700E+02	1.5675E+03
1.5400E+02	1.5675E+03
1.6100E+02	1.5675E+03
1.6800E+02	1.5675E+03
1.7500E+02	1.5675E+03
1.8200E+02	1.8988E+03
1.8900E+02	1.8988E+03
1.9600E+02	1.8988E+03
2.0300E+02	1.8988E+03
2.1000E+02	1.8988E+03
2.1700E+02	2.1999E+03
2.2400E+02	2.1999E+03
2.3100E+02	2.1999E+03
2.3800E+02	2.1999E+03
2.4500E+02	2.1999E+03
2.5200E+02	2.4050E+03
2.5900E+02	2.4050E+03
2.6600E+02	2.4050E+03
2.7300E+02	2.4050E+03
2.8000E+02	2.4050E+03
2.8700E+02	2.4050E+03
2.9400E+02	2.4050E+03
3.0100E+02	2.4050E+03
3.0800E+02	2.4050E+03
3.1500E+02	2.4050E+03
3.2200E+02	2.4050E+03
3.2900E+02	2.4050E+03
3.3600E+02	2.4050E+03
3.4300E+02	2.4050E+03
3.5000E+02	2.4050E+03

1971 TNC Curves

TNC   VERSUS TIME

MINIMUM 2.0374E+01   MAXIMUM 1.0570E+02

TIME	TNC	DAY
0.0	6.0000E+01	1.1500E+02
5.0000E+00	4.6775E+01	1.2000E+02
1.0000E+01	3.3850E+01	1.2500E+02
1.5000E+01	2.3610E+01	1.3000E+02
2.0000E+01	2.1336E+01	1.3500E+02
2.5000E+01	2.4055E+01	1.4000E+02
3.0000E+01	3.1680E+01	1.4500E+02
3.5000E+01	3.9508E+01	1.5000E+02
4.0000E+01	4.7337E+01	1.5500E+02
4.5000E+01	5.5007E+01	1.6000E+02
5.0000E+01	6.2510E+01	1.6500E+02
5.5000E+01	7.0012E+01	1.7000E+02
6.0000E+01	7.7512E+01	1.7500E+02
6.5000E+01	8.4913E+01	1.8000E+02
7.0000E+01	6.9283E+01	1.8500E+02
7.5000E+01	4.9158E+01	1.9000E+02
8.0000E+01	3.4792E+01	1.9500E+02
8.5000E+01	2.4635E+01	2.0000E+02
9.0000E+01	2.3996E+01	2.0500E+02
9.5000E+01	2.8518E+01	2.1000E+02
1.0000E+02	3.6344E+01	2.1500E+02
1.0500E+02	4.4170E+01	2.2000E+02
1.1000E+02	5.1975E+01	2.2500E+02
1.1500E+02	5.9469E+01	2.3000E+02
1.2000E+02	6.6968E+01	2.3500E+02
1.2500E+02	7.4468E+01	2.4000E+02
1.3000E+02	6.2249E+01	2.4500E+02
1.3500E+02	5.1571E+01	2.5000E+02
1.4000E+02	4.4039E+01	2.5500E+02
1.4500E+02	4.4231E+01	2.6000E+02
1.5000E+02	5.2034E+01	2.6500E+02
1.5500E+02	5.9525E+01	2.7000E+02
1.6000E+02	6.7023E+01	2.7500E+02
1.6500E+02	7.4521E+01	2.8000E+02
1.7000E+02	8.2011E+01	2.8500E+02
1.7500E+02	8.9125E+01	2.9000E+02
1.8000E+02	9.5271E+01	2.9500E+02
1.8500E+02	9.9819E+01	3.0000E+02
1.9000E+02	1.0302E+02	3.0500E+02
1.9500E+02	1.0540E+02	3.1000E+02
2.0000E+02	1.0559E+02	3.1500E+02
2.0500E+02	1.0557E+02	3.2000E+02
2.1000E+02	1.0556E+02	3.2500E+02
2.1500E+02	1.0556E+02	3.3000E+02
2.2000E+02	1.0556E+02	3.3500E+02
2.2500E+02	1.0556E+02	3.4000E+02
2.3000E+02	1.0556E+02	3.4500E+02
2.3500E+02	1.0556E+02	3.5000E+02
2.4000E+02	1.0556E+02	3.5500E+02
2.4500E+02	1.0556E+02	3.6000E+02
2.5000E+02	1.0556E+02	3.6500E+02

1972 TNC Curves

TNC VERSUS TIME

MINIMUM 2.3768E+00   MAXIMUM 1.0556E+02

TIME	TNC
2.5000E+02	1.0556E+02
2.5700E+02	1.0556E+02
2.6400E+02	1.0556E+02
2.7100E+02	1.0556E+02
2.7800E+02	1.0556E+02
2.8500E+02	1.0556E+02
2.9200E+02	1.0556E+02
2.9900E+02	1.0556E+02
3.0600E+02	1.0556E+02
3.1300E+02	1.0556E+02
3.2000E+02	1.0556E+02
3.2700E+02	1.0556E+02
3.3400E+02	1.0556E+02
3.4100E+02	1.0556E+02
3.4800E+02	1.0556E+02
3.5500E+02	1.0555E+02
3.6200E+02	1.0497E+02
3.6900E+02	8.2288E+01
3.7600E+02	5.3238E+01
3.8300E+02	3.1874E+01
3.9000E+02	3.4391E+01
3.9700E+02	4.5348E+01
4.0400E+02	3.1241E+01
4.1100E+02	1.8735E+01
4.1800E+02	1.1290E+01
4.2500E+02	1.0320E+01
4.3200E+02	1.6601E+01
4.3900E+02	1.0198E+01
4.6000E+02	6.3072E+00
4.6700E+02	3.9148E+00
4.5000E+02	2.4225E+00
4.6000E+02	1.0720E+01
4.6700E+02	6.7553E+00
4.7400E+02	8.0014E+00
4.8100E+02	1.4855E+01
4.8800E+02	1.1218E+01
4.9500E+02	1.0785E+01
5.0200E+02	9.6530E+00
5.0900E+02	1.5675E+01
5.1600E+02	1.9530E+01
5.2300E+02	2.1904E+01
5.3000E+02	3.0564E+01
5.3700E+02	4.1633E+01
5.4400E+02	5.1229E+01
5.5100E+02	5.3558E+01
5.5800E+02	5.4084E+01
5.6500E+02	5.4048E+01
5.7200E+02	5.4048E+01
5.7900E+02	5.4048E+01
5.8600E+02	5.4048E+01
5.9300E+02	5.4048E+01
6.0000E+02	5.4048E+01

DAY
0.0
7.0000E+00
1.4000E+01
2.1000E+01
2.8000E+01
3.5000E+01
4.2000E+01
4.9000E+01
5.6000E+01
6.3000E+01
7.0000E+01
7.7000E+01
8.4000E+01
9.1000E+01
9.8000E+01
1.0500E+02
1.1200E+02
1.1900E+02
1.2600E+02
1.3300E+02
1.4000E+02
1.4700E+02
1.5400E+02
1.6100E+02
1.6800E+02
1.7500E+02
1.8200E+02
1.8900E+02
1.9600E+02
2.0300E+02
2.1000E+02
2.1700E+02
2.2400E+02
2.3100E+02
2.3800E+02
2.4500E+02
2.5200E+02
2.5900E+02
2.6600E+02
2.7300E+02
2.8000E+02
2.8700E+02
2.9400E+02
3.0100E+02
3.0800E+02
3.1500E+02
3.2200E+02
3.2900E+02
3.3600E+02
3.4300E+02
3.5000E+02

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