MAXIMUM POTENTIAL POTATO YIELDS IN THE COLUMBIA BASIN

by
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INTRODUCTION

The yield of potato tubers obtained from any given field planting is a function of many environmental, biological and cultural variables. Some of these variables are subject to management and control by the grower, and some are determined by nature, and cannot be economically controlled. In both research and production agriculture, it would be helpful to have estimates of production limitations imposed by natural constraints. These could serve to determine how successfully manageable variables were being managed, and would give insight into research areas which are most likely to increase or optimize production. A model for potential production could serve as the basis for a system approach to potato management so that nutrient and water inputs are sufficient for potential production. Van der Zaag (1984) used a simple model based on solar radiation and growing season length to estimate potential potato tuber yield at various locations throughout the world, including the Columbia Basin. He estimated Washington's potential yield at 62 tons/acre, 40% higher than any other location listed. One purpose of this study was to determine whether such high yields can be obtained in the Columbia Basin.

The potato research at Washington State University provides data which could be used to estimate potential yield. Each year from 1959 through 1973 field experiments were set out and tuber yields measured. Several hundred plots were harvested each year, representing a range of tillage, irrigation and cultural practices.

Mechanistic models, which accurately simulate the plant environment and the response of the plant to the environment, can also be used to determine potential production. If model parameters are independently derived, and represent values for crops which are adequately nourished and watered, then the predicted production should be the potential production. The Van der Zaag (1984) model is one example, though it contains rather arbitrary assumptions about plant emergence, growing season length, and canopy development. A more complete model, based on the same approach, is that of MacKerron and Waister (1985). A number of other models are available, ranging in complexity from the simple empirical model of Sands et al. (1979) to the complex substrate partitioning models of Ingram and McCloud (1984) and Ng and Loomis (1985). However, the yield predicted by the model of MacKerron and Waister, for a given environment, relies almost entirely on a single parameter: the amount of solar energy required to produce a gram of dry matter. While this parameter is empirical, it has been observed in a large number of experiments under many conditions, and it is therefore likely that values representing potential production are available.

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We will present yield data for 134 different plots of Russet Burbank potatoes, obtained over a 15 year period. These data will be used to derive a simple empirical model of yield, based on the length of the growing season. Some data for other varieties are also presented. Results of simulations using the computer model for all data sets will also be shown and compared to the measured values.

EXPERIMENTAL DATA

Yield data for the Russet Burbank experiments were obtained for individual plot yields from a variety of treatments. All plots were located in the Columbia Basin, on or near the WSU experiment farm near Othello, Wa. Plots were furrow irrigated, with a typical irrigation interval being 2.5 days for alternate rows. Pest management was according to accepted practices. Each year, for the years 1959 through 1973, hundreds of experimental plots were established as part of the WSU potato research program. From the individual plot records we selected the yields for the highest yielding Russet Burbank plots. The number selected each year varied from 2 to 22. In all, 134 plots were selected.

The data for high yields of cultivars other than Russet Burbank were taken from variety trials at Othello, as well as trials at other location in the Columbia Basin. Forty three plot yields from the years 1964 - 1980 were selected.

MODEL

The model of MacKerron and Waister (1985) is based on the assumption that the total dry matter accumulation of a crop is proportional to the quantity of solar energy intercepted by the canopy. They divided crop growth into three phases: planting to emergence, emergence to canopy closure, and canopy closure to haulm destruction. The lengths of the first two phases is determined by temperature. The total dry matter production is therefore determined by temperature, incident solar radiation, planting data, and date of haulm destruction. Dry matter is converted to fresh weight using an average tuber dry matter of 21%. Of the total dry matter fixed by the plant, the MW model assumes 75% is used for tuber production.

As input data, the model requires solar radiation, maximum and minimum air temperature, and soil temperature. Solar radiation and soil temperature measurements were not available for the time and location of the experiments, so these were simulated. The model was run on a standard IBM microcomputer using Turbo Pascal as the programming language. A program listing is given in the appendix.

RESULTS AND DISCUSSION

Yields of the 134 Russet Burbank plots are shown as a function of time after planting in Fig. 1. We see a roughly linear relationship between yield and time after planting, with highest yields reaching about 60 tons/acre, approximately the value given for potential yield by Van der Zaag.

The relationship between yield and time is statistically highly significant, but to analyze the data in this way is clearly inappropriate for our purposes. The upper limit of the data points forms a fairly distinct boundary, indicating a maximum yield atainable for any given time from planting. The Boundary Line method of Webb (1972) can be used to estimate the highest yields which can be obtained at any time from planting. The Boundary Line shown in Fig. 1 was drawn by inspection. The equation of the line is $Y = 0.45\ (D - 36)$, where Y is in tons/acre, and D is the days from planting. The maximum bulking rate predicted by this equation is therefore 0.45 tons per acre per day.

While we have chosen a straight line to represent the Boundary Line, it is obvious from Fig. 1 that yields late in the season do not reach the boundary. This is to be expected, since days are cooler and shorter then, and growth is likely to be slower than at mid-season.

Predicted and measured yields are compared in Fig. 2 for the MacKerron and Waister model. A Boundary Line is apparent at about the 1:1 line. Data values which fall well below this line likely resulted from yield limitations due to some factor other than climate. Both predicted and measured maximum potential yields are around 60 tons/acre. Figure 2 indicates that the MacKerron and Waister model provides reasonable estimate of potential production of Russet Burbank potatoes in the Columbia Basin.

In the MacKerron-Waister model, we used an efficiency of conversion of solar radiation to dry matter of 1.35 grams of dry matter produced per megajoule of radiation intercepted by the crop. This is somewhat lower than the values of 1.43 to 1.84 g/MJ reported by MacKerron and Waister forScottish conditions and varieties. We were not sure whether this lower conversion efficiency was the result of the warmer temperatures and higher solar radiation in the Columbia Basin, or was a characteristic of the Russet Burbank cultivar.

To determine whether other cultivars had the same conversion efficiencies as Russet Burbank, we compared modeled and measured yields for a number of high-yielding cultivars and clones selected from our own data as well as unpublished data from W. G. Hoyman and Mark Martin. Figure 3 shows a comparison of these yields. About half of the plots had measured yields above those predicted using a conversion efficiency of 1.35 g/MJ, while, in Fig. 2, virtually none of the Russet Burbank samples had conversion efficiencies above this value. The range of conversion efficiencies for the top ten plots, calculated from the measured and simulated yields, is 1.5 to 2 g/MJ, which is comparable to the Scottish values. It appears, therefore, that the low conversion efficiency is related to cultivar, and not to the Columbia Basin climate. Potential yields even higher than 60 tons/acre therefore appear possible for cultivars other than Russet Burbank.

CONCLUSIONS

We conclude that the model of MacKerron and Waister (1985) adequately predicts maximum potential yield of Russet Burbank potatoes for the Columbia Basin of Washington.

A solar radiation conversion efficiency of 1.35 g/MJ appears appropriate for this variety and climate. Even higher conversion efficiencies apparently are possible using other cultivars.

Van der Zaag's (1984) estimate of potential yield for Washington, of 62 tons/acre was confirmed by the model, and actual yields of Russet Burbank close to this value were shown. Measured plot yields as high as 70 tons/acre were observed with other cultivars.

Two avenues for improved potato yields are suggested by this work. First, actual yields could be brought closer to potential yield, and second, varieties with improved conversion efficiencies could be sought. The first is probably the most significant. The models of Van der Zaag (1984) and MacKerron and Waister (1985) are both based on the assumption that dry matter production is linearly related to intercepted solar radiation. We can therefore assume that those yields in Figs. 2 and 3 which are below the potential yield line have absorbed less than the maximum possible amount of radiation. As Scott and Wilcockson (1978) point out, maintenance of a healthy, green canopy throughout the growing season, by proper nutrient water and pest management, is probably the most important factor in determining the final yield of the potato crop. The quantity of nutrients removed from an acre with 60 tons of potatoes is easily calculated, since the concentration of nutrients in potatoes remains relatively constant (Kunkel et al., 1973). The percentages of the major elements, N, P, and K, in potato tubers are 0.30, 0.07, and 0.44 respectively. Sixty tons of potatoes would therefore contain about 360 lbs. of N, 84 lbs. of P, and 528 lbs. of K. While the soil is able to supply some of these nutrients from storage, on a temporary basis, sustained high production requires that the nutrients which are removed with the crop be replaced. Efficient production is achieved only when all inputs to production are managed and balanced. When one input is limiting, then others are wasted.

REFERENCES

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Figure 1. Measured yield for 134 experimental plots of Russet Burbank potatoes as a function of time from planting. A possible Boundary line is shown (fit by inspection) which has a slope of 0.46 tons per acre per day and an intercept of 36 days.

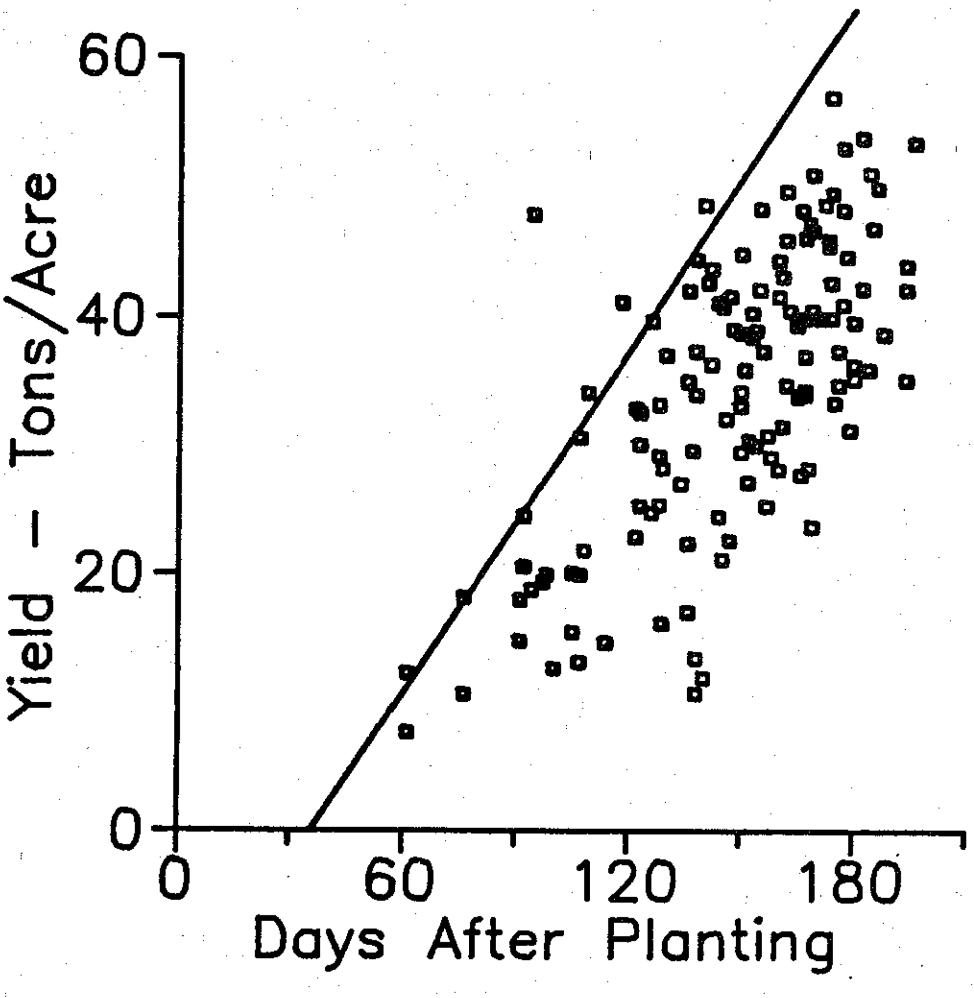


Figure 2. Measured tuber yield for 134 experimental plots of Russet Burbank potatoes as a function of predicted yield using the model of MacKerron and Waister (1985). Points falling on the line show perfect agreement between measured and model values.

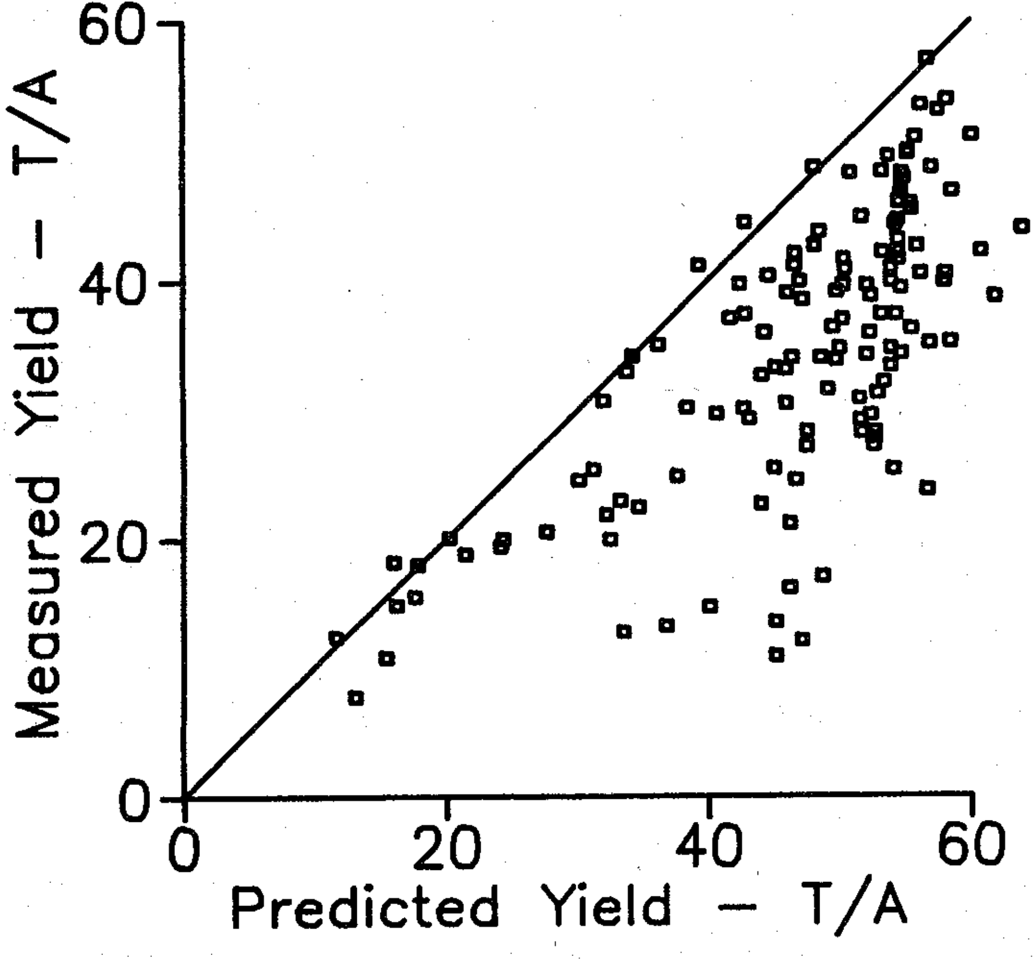
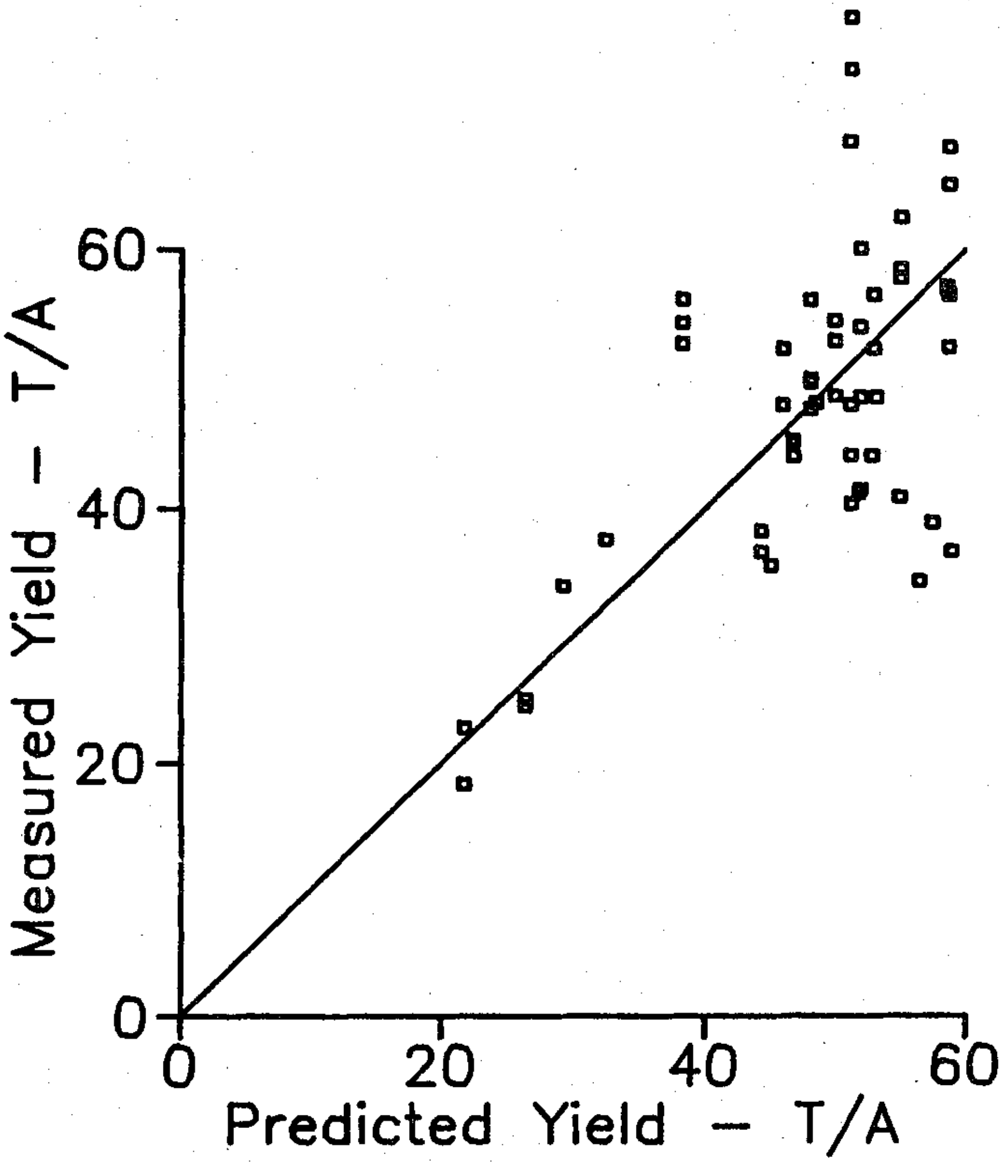


Figure 3. Measured tuber yield for 53 experimental plots of cultivars other than Russet Burbank as a function of predicted yield using the model of MacKerron and Waister (1985). The line is for a conversion efficiency of 1.35 g/MJ. Points falling above the line have conversion efficiencies greater than this value.



APPENDIX

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PROGRAM POTATO; {THE MODEL OF MACKERRON AND WAISTER, AG. FOR. METEOR 34:241}
TYPE ARYINDEX = 0..215;
VAR TMAX,TMIN:ARRAY[ARYINDEX] OF REAL;
FUNCTION ARCCOS(X:REAL):REAL;
  BEGIN
    IF (X>=1.0) OR (X<=-1.0) THEN ARCCOS:=0.0
    ELSE ARCCOS:=PI/2.0-ARCTAN(X/SQRT(1-X*X));
  END;
FUNCTION TAN(X:REAL):REAL;
  BEGIN
    TAN:=SIN(X)/COS(X);
  END;
FUNCTION POW(X,Y:REAL):REAL;
  BEGIN
    IF X<=0 THEN POW:=0 ELSE POW:=EXP(Y*LN(X));
  END;
FUNCTION FNDEC(DA:INTEGER):REAL; {SOLAR DECLINATION FOR DAY, DA}
  BEGIN
    FNDEC:=0.39785*SIN(4.869+0.0172*DA+0.03345*SIN(6.224+0.0172*DA));
  END;
FUNCTION POTENTIALSOLAR(DAY:INTEGER;LATITUDE:REAL):REAL;
  VAR DEC,HOURANGLE:REAL;
  BEGIN
    DEC:=FNDEC(DAY);
      HOURANGLE:=ARCCOS(-TAN(LATITUDE)*TAN(DEC));
      POTENTIALSOLAR:=117.5*(HOURANGLE*SIN(LATITUDE)*SIN(DEC)+COS(LATITUDE)
                          *COS(DEC)*SIN(HOURANGLE))/PI;
  END;
FUNCTION TRANSMITTANCE(DAY:INTEGER):REAL;    {CALCULATION OF ATMOSPHERIC      }
  VAR A,B,C,DELTAT:REAL;                     {TRANSMITTANCE FROM TMAX AND TMIN}
      I:INTEGER;                             {BRISTOW & CAMPBELL (1984), AG.  }
  BEGIN                                      {FOR. METEOROL. 31:159-166       }
    I:=DAY-90;                               {DATA STARTS ON DAY 91, APR 1    }
    A:= 0.7   ;   B:= 0.0026   ;   C:= 2.4;
    DELTAT:=TMAX[I]-(TMIN[I]+TMIN[I+1])/2;
    TRANSMITTANCE:=A*(1-EXP(-B*POW(DELTAT,C)));
  END;
PROCEDURE READDATA;
  VAR I:INTEGER;      FILENAME:STRING[12];     INFILE:TEXT;
  BEGIN
    WRITE('FILENAME FOR WEATHER DATA ');  READLN(FILENAME);
    {THE WEATHER DATA FILE CONTAINS MAXIMUM AND MINIMUM TEMPERATURES,}
    {DEGREES F, FOR THE MONTHS APR, MAY, JUN, JUL, AUG, SEP, AND OCT.}
    ASSIGN(INFILE,FILENAME);
    RESET(INFILE);
    FOR I:=1 TO 214 DO BEGIN
      IF EOF(INFILE) THEN WRITELN('OUT OF DATA IN INPUT FILE');
      READ(INFILE,TMAX[I]);READ(INFILE,TMIN[I]);READLN(INFILE);
      TMAX[I]:=5*(TMAX[I]-32)/9 ; TMIN[I]:=5*(TMIN[I]-32)/9;
      TMIN[215]:=TMIN[214];
    END;
  END;
```

```
VAR DAY,STARTDAY,ENDDAY,I,K:INTEGER;               {MAIN PROGRAM}
    LATITUDE,DRYMATTER,CONVEFF,LAI,PLANTDENSITY:REAL;
    TDIF,TTIME,S,R,AREA,SPROUTTIME,SPROUTLENGTH:REAL;
BEGIN
  LATITUDE:=PI*48/180;
  STARTDAY:=91;    PLANTDENSITY:=6.2;  {32 IN. ROW SP, 8 IN SEEDPIECE SP}
  CONVEFF:=1.35;   {SOLAR RADIATION CONVERSION EFFICIENCY, G/MJ}
  TDIF:=0;
  READDATA;
  DAY:=STARTDAY-1;
  SPROUTTIME:=0;
  WHILE SPROUTTIME<125 DO BEGIN   {TIME TO SPROUT TUBER}
    DAY:=DAY+1; I:=DAY-90;
    TTIME:=TDIF+(TMAX[I]+TMIN[I])/2 - 5;  IF TTIME<0 THEN TTIME:=0;
    SPROUTTIME:=SPROUTTIME+TTIME;
  END;                              WRITELN('SPROUTED ',DAY);
  SPROUTLENGTH:=0;
  WHILE SPROUTLENGTH<100 DO BEGIN  {TIME TO EMERGE}
    DAY:=DAY+1; I:=DAY-90;
    TTIME:=TDIF + (TMAX[I]+TMIN[I])/2 - 2; IF TTIME < 0 THEN TTIME:=0;
    SPROUTLENGTH:=SPROUTLENGTH + TTIME;
  END;                  WRITELN('EMERGED ',DAY);
  AREA:=2.5E-3; LAI:=PLANTDENSITY*AREA;    {TIME TO CANOPY CLOSURE}
  DRYMATTER:=0;
  WHILE LAI<=3 DO BEGIN
    DAY:=DAY+1; I:=DAY-90;
    TTIME:=(TMAX[I]+TMIN[I])/2-2.4; IF TTIME<0 THEN TTIME:=0;
    AREA:=AREA*EXP(0.01333*TTIME);
    LAI:=PLANTDENSITY*AREA;
    S:=TRANSMITTANCE(DAY)*POTENTIALSOLAR(DAY,LATITUDE);
    DRYMATTER:=DRYMATTER+CONVEFF*S*LAI/3;
  END;                  WRITELN('CANOPY CLOSED ',DAY);
  REPEAT                                    {TIME TO END OF SEASON}
    DAY:=DAY+1; I:=DAY-90;
    S:=TRANSMITTANCE(DAY)*POTENTIALSOLAR(DAY,LATITUDE);
    DRYMATTER:=DRYMATTER+CONVEFF*S;
  UNTIL (TMIN[I] < -2) OR (I>215);
  WRITELN('FINISHED ',DAY);
  WRITELN('TUBER DRY MATTER - G/M2 ',DRYMATTER*0.75:8:2);
END.
```