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Influence of fertilisation on potato growth functions

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Abstract. Aimed at elaboration of a soil fertility module for the potato production model POMOD, the determination of growth functions was carried out for the late potato variety 'Anti' at different fertilisation levels. These functions characterise the distribution of growth between plant organs and redistribution of the biomass of vegetative organs at their late growth stage. Results of the field experiments in 2002–2003 revealed that fertilisation decreased the maximum of root growth function and shifted the maximum of leaf growth function forward. The bigger amount of fertiliser slows down the decrease of leaf and stem growth functions and the increase of tuber growth function. Moreover, it leads to a break in the tuber growth function occurring with secondary maximums in leaf and stem growth functions. Variability of growth functions induced by fertilisation is dominant during the second half of growing period. At an early growing stage, variations between years exceed variability between fertilisation plots.

Key words: growth functions, fertilisation, potato, crop modelling

INTRODUCTION

Mathematical models of production process obtain more and more considerable part in agricultural forecast, evaluation and management systems. 50 years had passed until the first paper on mathematical modelling of photosynthesis and productivity was published in Japan (Monsi & Saeki, 1953). This is a research area into which Estonian scientists have made a quite significant contribution. Its development in Estonia, as well as in the former Soviet Union, was initiated 40 years ago by the publication of a paper from Budagovsky et al. (1964). The following work in the area is marked by a series of monographs: Bichele et al. (1980), Ross (1981), and Tooming (1977, 1984). Based on the principle of maximum plant productivity and the method of reference yields, published in the last monographs, a potato production process model named POMOD was elaborated (Kadaja, 2001; Sepp & Tooming, 1991). It is quite a simple dynamic model designed for solving practical problems on agroecosystem level. Of environmental conditions, this model allows, at present, scientists to take into consideration the influence of solar radiation, air temperature and soil water, and calculate potential and meteorologically possible yields (Sepp & Tooming, 1991).

At the current stage, the development of the POMOD model is directed to introducing the influence of soil fertility into the model. Construction of a soil fertility submodel demands knowledge of the influence of fertilisation on the model parameters. One group of the basic parameters of the model are the growth functions describing the distribution of net photosynthesis product between plant organs and the

redistribution of the biomass of organs at the late stage of growth. The aim of this paper was to estimate the effect of fertilisation levels on the growth functions.

MATERIALS AND METHODS

The distribution of a total increase of biomass between different plant organs is determined by using growth functions (Ross, 1966). These are derived from the growth equation of plant organs:

$$\frac{\Delta m_i}{\Delta t} = A_i \frac{\Delta M}{\Delta t} + B_i m_i \ , \tag{1}$$

where Δm_i is the increase of the organ i (in the case of potato i marks roots, stems, leaves and tubers) during the time increment Δt; ΔM the increase of biomass of the whole plant; m_i the biomass of organ i; A_i is named as vegetative growth function and B_i as reproductive growth function.

Functions of vegetative growth A_i (Ross, 1966), also referred to in literature as distribution ratios (Monsi & Murata, 1970) or partitioning coefficients of growth, characterise the distribution of total growth between plant organs:

$$A_i = \frac{\Delta m_i}{\Delta M}. \tag{2}$$

Vegetative growth functions are calculated by this formula if $\Delta m_i > 0$, in other cases $A_i = 0$.

The reproductive growth functions B_i characterise the part of biomass transported over to seeds or storage organs (in the case of potato to the tubers) from other plant organs after their vegetative growth has stopped, i.e. when $A_i = 0$. Proceeding from this condition, B_i is defined from the equation (9) as:

$$B_i = \frac{\Delta m_i}{\Delta t} \cdot \frac{1}{m_i}. \tag{3}$$

In model calculations we replaced ordinary time with the so-called biological time, using accumulated temperatures for the purpose. The latter describe the progress of plant growth and development processes more correctly than the chronological time scale. Our earlier investigations have shown that, in the case of potato crop, the best coincidence of experimental growth functions data of different years was achieved by using accumulated daily mean temperatures above zero (Sepp, 1983). In this case, the time increment Δt between measurements is replaced by the sum of mean daily temperatures ΣT for the same period, thus calculating the B_i per degree-day.

$$B_i = \frac{\Delta m_i}{\Sigma T} \cdot \frac{1}{m_i}. \tag{4}$$

The values of the growth functions A_i and B_i can be identified from the data of field biometric measurements. The determination of reproductive growth functions assumes that vegetative growth has stopped for the period used in calculations, i.e.

A_i = 0 during it. From the other hand, the best period for it is before the start of withering of plant tops. If the periods satisfying both the conditions exist, the calculation of reproductive growth functions actually consists of finding the lowest values computed by the formula (4), using the living biomass data (Sepp, 1983). If these conditions are not simultaneously met, the dried-out plant parts and litters have to be taken into consideration in the calculations of Δm_i.

The trials for determination of growth functions for the late potato variety 'Anti' were carried out in 2001–2003 in the experimental fields of the Estonian Research Institute of Agriculture. In 2001 there was one and in 2001–2002 there were four different fertilisation levels in the experiment. In the two first years, the trials were located at 59°17' N and 24°37' E on a sod–calcareous soil, in 2001 on silty loam and in 2002 on sandy loam. In 2003 the location was two kilometres to SE on a leached sod–calcareous sandy loam soil on clay (all the soils in the trials were haplic luvisols by the FAO–UNESCO classification).

Potato was planted in furrows of 0.7 m width and density of 4 plants per metre (57,000 per ha). In 2001, 2002 and 2003, the nutrient status of the soil before planting was, respectively: P – 127. 90 and 71 mg/kg, K – 87.165 and 75 mg/kg, humus 2.3, 2.5 and 4.6%. The soil chemical analysis was ordered from the Control Centre of Plant Production (CCPP). In 2001–2002, K and P were determined by the double–lactate method, in 2003 by the Mehlich III method. All the presented data were converted into correspondence with the results obtained for the Mehlich III method using the coefficients obtained from the CCPP. The humus content was determined by the Tjurin method. The fertiliser used before planting was Kemira–Cropcare 10–10–20. In the case of different fertilisation levels, the amounts 0, 500, 1000 and 1500 kg per ha were used, the elements being, respectively, $N_0P_0K_0$, $N_{50}P_{20}K_{85}$, $N_{100}P_{40}K_{170}$ and $N_{150}P_{60}K_{255}$. In 2001 only the version $N_{100}P_{40}K_{170}$ was under investigation. Chemical protection against weeds was applied once and against late blight three times during the vegetation.

Dry periods prevailed during the summers of 2002 and 2003. In 2002 potato plants suffered from draught from mid-August, whereas in 2003, depending on the soil type and groundwater status, the wilting of tops was not observed. Vegetation was stopped by night frosts on 21 September in 2002 and during the nights from 1 September to 3 September in 2003. To some extent, damage of leaves by early blight occurred in 2002 and by late blight from the mid-August of 2003. In 2002 seed tubers were weakly germinated, in 2001 and 2003 well germinated, but in the last year sprouting was delayed by damping-off caused by low temperatures over the shooting period.

Determination of growth functions was based on samples taken from each plot 8–9 times during the vegetation period. Every sample consisted of 10–20 plants chosen by the distribution of their simple biometrical indicators. The height of plants and the number of shoots were observed as indicators at the early growth stage. Later, when shoots were lodged, the distribution of shoots by their strength (divided into four grades) and the sum of shoot length was used. An observation of these parameters was carried out before every sampling on 20 or 40 fixed plants. The height of plants was measured over the plots.

The sampled plants were washed, their organs were separated and weighed. Calculation of dry mass was based on the transition coefficients from wet to dry mass,

determined by drying out four random samples of each organ. Growth increments of plant organs, necessary for calculation of growth functions by the formulas (2) and (4), were calculated as an increase or decrease of dry mass between subsequent measurements.

RESULTS AND DISCUSSION

The vegetative growth functions of the potato variety 'Anti' at the fertilisation level $N_{100}P_{40}K_{170}$ as the functions of accumulated temperature, presented in Fig. 1, are the average results from 2001 to 2003. For calculation of mean curves, the growth functions of separate years were interpolated and then averaged after every 10 degree-days of accumulated temperature. It is also the frequency these functions are used in the model as tabulated values.

The vegetative growth functions for different fertilisation levels are compared in Fig. 2. These results of averaging over the years 2002 and 2003 have been presented separately, by the plant organ. From these results the following conclusions can be made.

The maximum of root growth function is lower if the fertilisation level is higher. However, this trend was not discovered in 2002 when root growth function was almost not influenced by the fertilisation level. Differences in the initial soil nutrient status between these years refer to a lack of potassium as the reason of accelerated root growth at the early growth stage.

The fertilisation level does not influence the maximum value of leaf growth function but its arrival is shifted further if nutrition is better. After passing its maximum, the leaf growth function maintains higher value longer, to some extent, in the case of higher fertilisation. The secondary maximum of leaf growth function appears if nutrition level is high.

Although more unsteady, the tendency of the curves of stem growth functions is similar to the case observed with leaves: the growth functions of less fertilised versions decrease more rapidly. Similarly to leaves, the secondary maximum of stems growth function appears at high fertilisation levels.

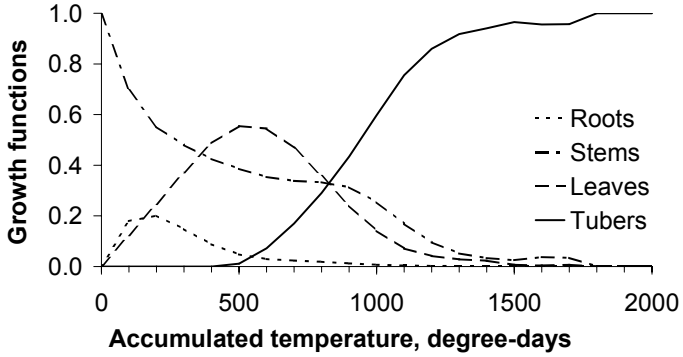

Fig. 1. Growth functions of the late potato variety 'Anti'. Mean values from three-year experiment at the fertilisation level $N_{100}P_{40}K_{170}$.

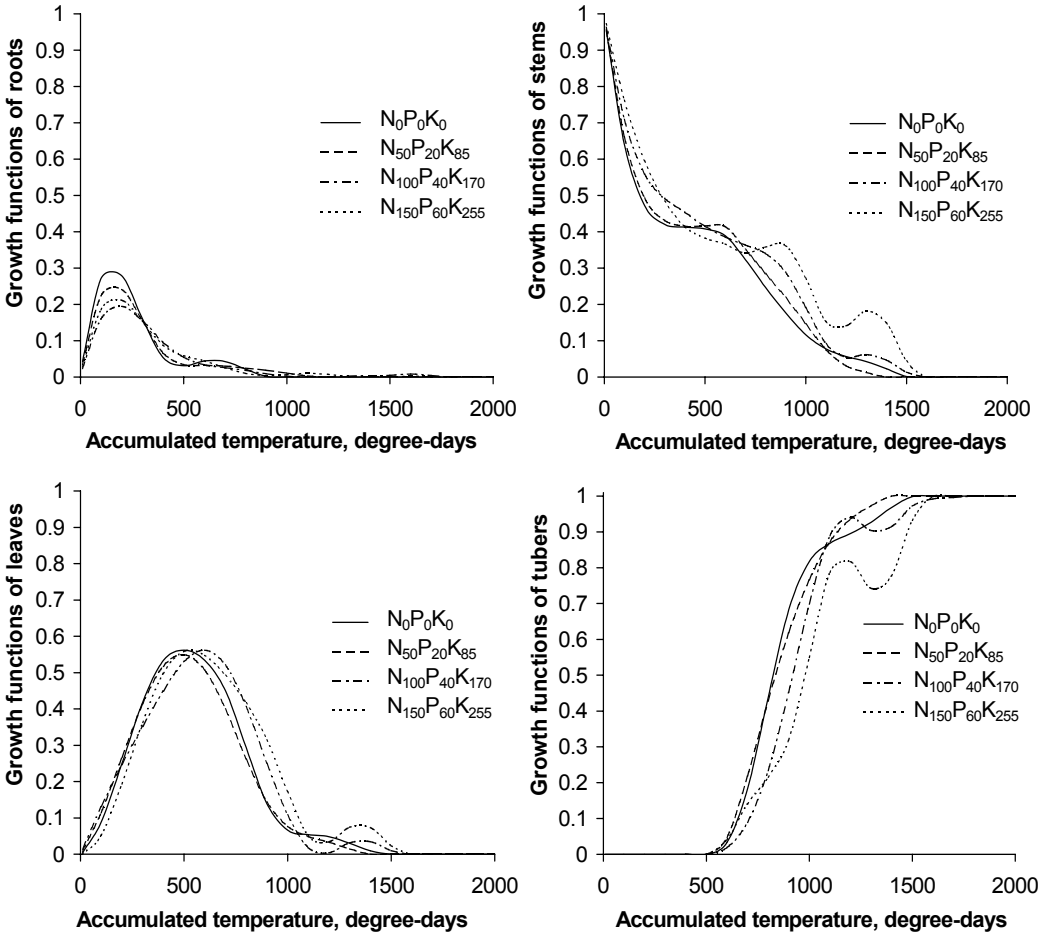

Fig. 2. Vegetative growth functions of potato organs at different fertilisation levels (the variety 'Anti'). Mean values in 2002–2003.

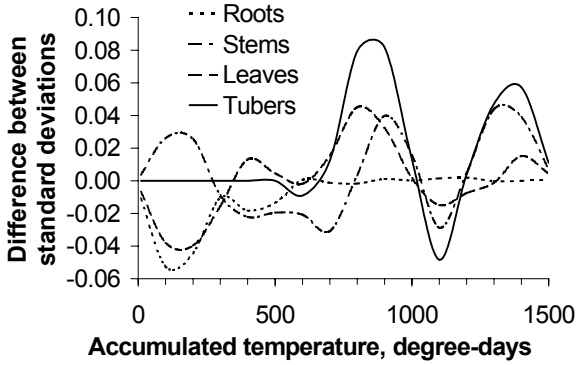

Fig. 3. Differences between standard deviations of growth functions calculated over different years and different fertilisation versions. Values above zero indicate the predominance of fertilisation in the variability of growth functions.

Table 1. Values of reproductive growth functions *B* of the potato variety 'Anti' calculated jointly for all vegetative organs.

Fertilisation version	Values of reproductive growth functions, K^{-1}		
	2002	2003	Mean value
$N_0P_0K_0$	-0.00106	-0.00073	-0.00090
$N_{50}P_{20}K_{85}$	-0.00063	-0.00175	-0.00119
$N_{100}P_{40}K_{170}$	-0.00103	-0.00110	-0.00107
$N_{150}P_{60}K_{255}$	-0.00080	-0.00114	-0.00097

The increase of tuber growth function is the more rapid, the lower the fertilisation level is. Typical of the tuber growth functions is the deceleration of their increase rate when these functions have gained about 70–80% of the entire growth. This deceleration is at minimum in the case of a nutrition deficit. Higher levels of fertilisation lead to a break in the increase or even to a temporary decrease in the value of tuber growth function. This decrease coincides with the period of secondary growth of leaves and tubers.

For evaluation of the reliability of the presented results, the differences in growth functions of the fertilised versions were compared with the variations between different years. In Fig. 3 the differences between standard deviations of growth functions from different years and standard deviations of mean growth functions from different fertilisation versions have been presented. In this figure, the standard deviation between different years has been calculated as the mean value of standard deviations computed separately for all fertilisation versions. The value of difference (Fig. 3) above zero indicates the prevailing influence of fertilisation; if this value is below zero, the variations between years, most probably induced by weather conditions, suppress the influence of fertilisation. Predominantly, differences induced by fertilisation appear at the intervals of accumulated temperatures from 700 to 1,050 degree-days and from 1,200 to 1,500 degree-days (Fig. 3). However, it was not valid for root growth functions having already very low values for this period. Analyses of these differences in couples showed that the near versions, e.g. $N_0P_0K_0$ and $N_{50}P_{20}K_{85}$, express higher variations between different years throughout the growing period. The differences in growing functions due to fertilisation level are the most reliable in the case of the pairs $N_0P_0K_0$–$N_{150}P_{60}K_{255}$ and $N_{50}P_{20}K_{85}$–$N_{150}P_{60}K_{255}$.

Both the years with different fertilisation versions were poor for the identification of reproductive growth functions. Immediately after, or even before the achievement of the biomass maximum of plant tops, the damages caused by drought and early blight in 2002 and by late blight in 2003 followed. Therefore, there was not other possibility for calculating these functions, except to take into consideration dried-out leaf stems and litter. Since their determination cannot be very accurate due to deflation and other losses, the results received for reproductive growth functions are quite rough and maybe elevated. However, their relative importance in forming yield is considerably low compared with vegetative growth functions.

Since the dead material was not differentiated between leaves and stems, the reproductive growth functions were calculated jointly for all vegetative organs. The data for the whole period from the maximum weight of plant tops to the last sampling before night-frost were used. The results (Table 1) do not display a one-directional

relationship of reproductive growth functions from fertilisation level. Also, these values are higher than the values 0.00051 K^{-1} for roots, 0.00056 K^{-1} for leaves and 0.00064 K^{-1} for stems established in the field experiment in 2001. In this year damages to foliage by the diseases were absent for a long time and had minimum values up to the late stage.

CONCLUSIONS

The necessity for taking into consideration the influence of fertilisation on the potato vegetative growth functions becomes obvious in the second part of a growing period. At earlier growth stages, differences between fertilisation levels are lesser than variations between different years.

The dependence of reproductive growth functions on fertilisation was not clearly expressed on the basis of the 2002–2003 trials, and the lower value from 2001 was suggested for use.

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