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Effects of thermal shock and pre-sprouting on field performance of potato in Estonia

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Abstract. Pre-sprouting (PS), and to a lesser degree, pre-planting thermal shock (TS) had positive effects on tuber yield and other performance indicators. The experiment was carried out during the 2000, 2001 and 2002 growing seasons in the Department of Field Crop Husbandry of the Estonian University of Life Sciences. An untreated control (0) was compared with TS (2 days at 30^{o}C, then 5 days at 12–15^{o}C in a lighted room just prior to planting) and PS (35–38 days before planting in a humid (85–90%) and lighted room at 12–15^{o}C). All treatments were applied to three varieties: 'Agrie Dzeltenie' (early), 'Piret' (medium early) and 'Ants' (medium late). In the present study, the TS accelerated the emergence of plants by 2–5 days and PS by 7–12 days. Averaged over 3 years and 3 varieties, maximum leaf area index (LAI, 3.9 units) was reached 74 days after planting (DAP) and on the 50th day after emergence. Maximum LAI was 3.7 at 72 DAP for PS, 3.8 at 73 DAP for TS, and 4.1 at 76 DAP for the control. TS accelerated the beginning of tuber formation by about 5 days compared to the control, but the tuber yield of the control equalled TS from 65 days onward. Tuber formation began even slightly earlier in the PS treatment, and tuber yield exceeded PS throughout the season. All treatments reached maximum yield by 120 DAP.

Key words: dynamics, growth analysis, haulms, LAI, leaf area index, tuber yield

INTRODUCTION

Potato plant (*Solanum tuberosum* L.) has an indeterminate growth pattern. Quantifying above-and below-ground plant phenology in relation to different environmental factors (Ojala et al., 1990) and cultivars (Van der Zaag et al., 1990) is an important step toward an adequate understanding of potato growth and development. This quantification has been done only in a few environments, especially in relation to pre-planting thermal shock (TS) and pre-sprouting treatments (Lõhmus et al., 1999).

A physiologically young seed tuber has preconditions to develop better and stronger roots as well as all above-ground parts of the plant, and the largest assimilation surface possible, leading to formation of a high tuber yield. The drawback is that the late sprouting and canopy closure decreases the ability of potato plants to compete with weeds. The delayed development of the assimilation surface puts much of the assimilation potential past the time of maximum physiologically active radiation.

Getting a relatively early potato yield is important not only for early varieties but also for late ones. Late varieties are grown for their higher tuber yield potential and easier preservation. Various methods are used to get an earlier potato yield, including the thermal treatment of seed tubers, which adds physiological age to potato tubers and shortens the chronological time that is necessary for the tuber yield to become harvest-ripe (Allen et al., 1992). This method boosts enzyme activity in tubers, stimulates faster development of sprouts from the eyes, reduces the sprouting period and accelerates plant development and tuber yield formation. The physiological age is defined as the physiological status of a tuber that influences its productivity. It could also be defined as the developmental level which has been modified by varying the chronological age (Caldiz et al., 2001). The physiological age of a tuber is its chronological age that has been affected by storage conditions (Struik & Wiersema 1999).

The physiological age of the seed tubers could be divided into the following stages: (1) single sprout stage; (2) multiple sprout stage; (3) branching stage; and (4) small tuber formation stage (Wurr 1982). If seed tubers are kept at a higher temperature for some time in spring, they will produce physiologically older tubers. This can be applied to the growing of both early and late potatoes, as the maximum weight of the haulms (leaves and stems) and maximum leaf area are achieved more quickly. An economically optimal tuber yield can also be harvested earlier. However, physiologically younger plants can be more viable and even form a greater tuber yield, although slightly later. The physiological age of the tuber affects the number of sprouts and the sprout behaviour, the growth pattern of the plant that originates from it and, sometimes, the tuber yield of the crop produced from it (Van der Zaag & Van Loon, 1987).

MATERIALS AND METHODS

The experiment was carried out for three years (2000, 2001 and 2002) using two pre-planting treatments on three potato plant varieties. The location was the Plant Biology experimental station of the Department of Field Crop Husbandry (58°23′N, 26°44′E) in EMU IAES. Random block-placement in 4 repetitions was used (Little & Hills, 1972). The size of a test plot was 21 m^2, the distance between furrows was 70 cm and the distance between seed tubers, 25 cm. Seed tubers with a diameter of 35–55 mm were used in the experiment.

Seed tuber treatments were as follows:

1. Untreated variant (0) – no thermal treatment was conducted;
2. Thermal shock (TS) – a week before planting the seed tubers were kept for 2 days at 30°C, then for 5 days at 12–15°C in a lighted room (Lõhmus et al., 1999). Thermal treatment of seed tubers means that they are exposed to higher temperatures for a short time. Compared to the tubers from the cellar, strong (3–4 mm) sprouts appear on the tubers treated with TS. Under certain conditions the TS treatment may be less labour- and energy-consuming than pre-sprouting, for example by using thermo-regulated storehouses (Jõudu et al., 2002);

3. Pre-sprouting (PS) – the tubers were kept for 35–38 days before planting in a sufficiently humid (85–90%) and lighted room at 12–15°C. Seed tubers were pre-sprouted in wooden boxes (in 1 or 2 layers).

The late variety 'Ants' and the middle-maturing variety 'Piret', both bred at the Jõgeva Plant Breeding Institute in Estonia, and the early variety 'Agrie Dzeltenie', bred at the Latvian Priekuli Plant Breeding Institute, were used in the experiments. Local varieties were used because they are better adapted to our climatic conditions and are therefore able to produce relatively high yields with good quality. Also, we have extensive experience with optimum fertilization and chemical plant protection for these varieties at our department fields in EMU.

The soil of the experimental field was *Stagnic Luvisol* by WRB classification (Deckers et al., 1998); the texture is sandy loam with a humus layer of 20–30 cm (Reintam & Köster, 2006). The soil data of the experimental field was as follows: pH ≈6.2; C 1.4%; Ca 674 mg kg^{-1}; Mg 101 mg kg^{-1}; P 183 mg kg^{-1}; K 164 mg kg^{-1}; N 0.11%.

The amount of precipitation during the vegetation period (from May to September) of the experimental years was above average in June and July, and less than average in May, August and September (Table 1). The air temperature remained similar to the average of 32 years (1966–1998); only July was significantly warmer.

Table 1. Average monthly temperatures (ºC) and precipitation (mm) in Estonia during the vegetation period.

Month	Temperatures, ºC		Precipitation, mm	
	Average of 2000–2002*	Average of 1966–1998**	Average of 2000–2002*	Average of 1966–1998**
May	12.0	11.6	42.7	55
June	15.2	15.1	75.7	66
July	19.8	16.7	101.2	72
August	17.1	15.6	75.6	79
September	10.8	10.4	22.2	66

* according to the Eerika weather station
** (Jaagus 1999)

Agrotechnics were typical for potato experiments (Table 2). Composted manure (60 t ha^{-1}) was used as organic fertilizer before autumn ploughing. Mineral fertilizers were applied locally, concurrently with planting of the potatoes in spring. In 2000–2002, compound mineral fertilizer (78 kg N, 72 kg P, 117 kg K ha^{-1}) was applied at planting. For plant protection, insecticide Fastac and fungicides Ridomil Gold, Acrobat Plus and Shirlane were used. All active ingredients for plant protection were used with 400 l of water per ha^{-1}.

The dynamics of the weight of the haulms (leaves and stems), leaf area index (LAI) and tuber yield were determined at a 3–5 day interval; each sample consisted of 4 plants from the test plot.

As various tuber thermal treatment methods were used, the first samples were taken at different times. The number of samplings also depended on the duration of the vegetation period.

Table 2. Agrotechnics of the experiment.

	Year		
	2000	2001	2002
Application of organic fertilizer	12th October	9th October	15th October
Ploughing of red clover Aftermath	13th October	10th October	19th October
Cultivation	20th, 25th April	8th May	7th May
Deep cultivation	2nd May	8th May	7th May
Furrowing	3rd May	9th May	8th May
Application of mineral fertilizers and planting of potatoes	4th May	10th May	9th May
Number of harrowing	1	1	1
Number of hilling	3	3	3
Spraying against late blight	2 times	5 times	5 times
Final harvest	5th September.	22nd September	4th September

Statistical data analysis by regression methods were carried out (Mead et al., 1993; Lauk, 1995; 1996; Lauk et al., 1996).

The following formula was used:

$$y = a + bx + cx^2,$$

wherein: *y* – argument function, the index that is calculated on the basis of the equation: LAI, haulm weight, or tuber yield, *a* – constant term of the equation, *b* and *c* – regression coefficients, *x* – argument; number of days after planting (DAP).

For every variant, separate regression formulas were found and based on their differentials it was possible to calculate the average formulas for multiple years. Standard errors (SE) and confidence limits (CL_{05} – level of statistical significance $P = 0.05$) were calculated by using the relevant methodology (Lauk & Lauk, 2000). The calculation of confidence limits was based on the Student's theoretical criterion (Mead et al., 1993).

All the data in the figures are calculated according to the regression formulas of regression analysis. To assess the probability of differences between test variants the least significant differences (LSD_{05}) were calculated according to the corresponding methodology (Lauk et al., 2004).

The derivative of this function (b–2c) indicates the estimated increase per day. In this paper all the experimental data presented are based on the average of 2000–2002.

RESULTS AND DISCUSSION

Physiological aging advanced sprout growth, crop emergence, crop establishment and usually improved tuber yield (Burke and O'Donovan 1998). The arrival of developmental stages and their duration is often quite varied, depending on the biological characteristics of a variety, the quality of seed potato, climatic and soil conditions and the agrotechnical measures used (Christiansen et al., 2006). It usually takes 20–35 days for a potato plant to emerge in Estonian climatic conditions (Jõudu et al., 2002), depending on the treatment of seed tubers.

Earlier studies at the Department of Field Crop Husbandry indicated that PS and TS increased the physiological age of seed tubers and initiated their earlier emergence. Plants from seed tubers treated before planting emerged 1–4 days (late varieties) and 1–7 days (early varieties) earlier than the untreated ones (Lõhmus et al., 1999, Eremeev et al., 2001). In the present study, the TS accelerated the emergence of plants by 2–5 days and PS by 7–12 days (Fig. 1). The TS had a positive effect on potato plant during its early developmental phases. The length of periods from planting to emergence depended on the physiological age of seed tubers (Struik & Wiersema, 1999). The faster growth of the haulm of the plants that developed from thermally treated seed tubers provided furrow coverage nearly a week earlier. As a result, the last intertillage could be eliminated at the critical time when there were very favourable conditions for the growth of weeds.

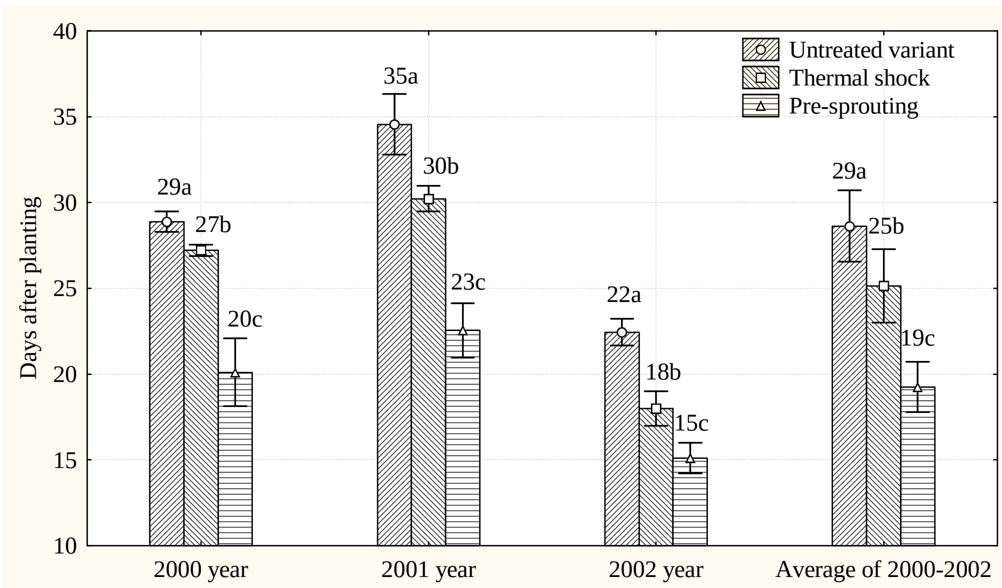

Fig. 1. The emergence of potato plants. Vertical bars denote 0.95 confidence intervals. Different letters indicate significant differences ($P < 0.05$) between planting dates.

Leaf area index indicates the ratio of assimilative area of the leaf and the surface area (Watson, 1947). For optimal photosynthetic rate it is necessary that the LAI would be over 4 for as long a period as possible, otherwise the use of photosynthetically active radiation and the resulting production of organic matter decreases (Scott & Wilcockson, 1978; Allen & Scott, 1980; Khurana & McLaren, 1982).

The pre-planting treatment of the seed tubers had different effects on the leaf area formation of the varieties. At first, the 0-variant developed more slowly, causing the prolongation of its growing period. The LAI in untreated variants could be determined until 110 DAP while the assimilative leaf area of treated variants was destroyed by 105 DAP (Fig. 1). According to Jõudu et al. (2002), plants developed from pre-sprouted tubers are better able to assimilate nutrients from the mother tuber. The pre-planting thermal treatment of seed tubers (TS and PS) accelerated the growth and development of the leaves and leaf area from the beginning of sprouting until 60 DAP (statistically significant until 45 DAP). Later, there was a similar increase of the leaf area in the different variants (Fig. 1). Earlier experiments with late varieties indicate that the maximum LAI (average 3.7 units) increased until 72 DAP and then started to decrease (Eremeev et al., 2001). In the present research the maximum LAI (3.9 units) was reached 74 DAP and on the 50th day after emergence. The maximum LAI in variant PS was achieved by 72 DAP (3.7 units), in TS (3.8 units) and 0 (4.1 units) respectively by 73 and 76 DAP. In varieties with a shorter growth period the leaf area reaches its maximum earlier.

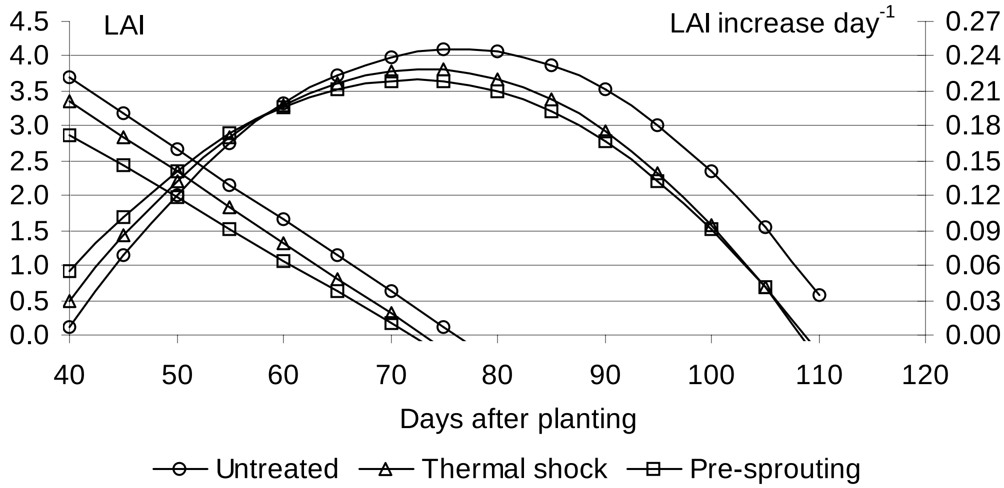

Fig. 1. Influence of the seed tuber pre-planting preparation method on the LAI (the average of 2000–2002, t ha^{-1}).
0 = Untreated variant: $y = -13.7+0.468x-0.00307x^2$, n=123, $R^2 = 0.953$, SE=0.09, $CL_{05}=0.20$;
TS = Thermal shock: $y=-12.5+0.446x-0.00306x^2$, n=123, $R^2=0.917$, SE=0.11, $CL_{05}=0.24$;
PS = Pre-sprouting: $y=-10.3+0.389x-0.00271x^2$, n=123, $R^2=0.911$, SE=0.10, $CL_{05}=0.22$.

Thus, the weight of the haulms of the plants that developed from physiologically older seed tubers formed more quickly and remained smaller. The pre-planting treatment of seed tubers (*i.e.* increasing the physiological age) provided earlier field emergence. The later the potato plants attained the maximum weight of the haulms, the bigger their size. On physiologically older plants obvious signs of senescence started to appear earlier (partial wilting and yellowing of the lower leaves). According to Putz (1986), after the death of the haulms, the growth of tubers ceases, the peel hardens and starts to suberizate.

The leaf areas increased most intensively in all variants at 40 DAP, whereas in the variants that sprouted later the increment of the LAI was bigger (in variant 0 – 0.22 units, in TS – 0.20 units, in PS – 0.17 units per day). After 40 DAP the increment of the LAI gradually decreased. All varieties that were used in the experiment demonstrated relatively even speed of the growth of the LAI throughout the vegetation period.

Weight of the haulms. The pre-planting thermal treatment of seed tubers (PS and TS) accelerated the development of the haulms, and the weight of the latter was higher than in variant 0–50 DAP (Fig. 2). The haulms reached its maximum weight in variant PS by 76 DAP, in TS by 77 DAP and in 0 by 81 DAP. The later the maximum weight of the haulms was achieved, the bigger it was, because the visible signs of aging appeared earlier in physiologically older plants. Thus, the maximum weight of the haulms in variant 0 was 31.9 t ha^{-1}, exceeding PS and TS respectively by 4.2 and 2.9 t ha^{-1}. Therefore the weight of the haulms in plants formed from physiologically older seed tubers developed faster and was smaller.

The growth of the weight of the haulms was the most intensive in all variants at 40 DAP (variant 0 – 1.43 t day^{-1}, TS – 1.26 and PS –1.06 t day^{-1}).

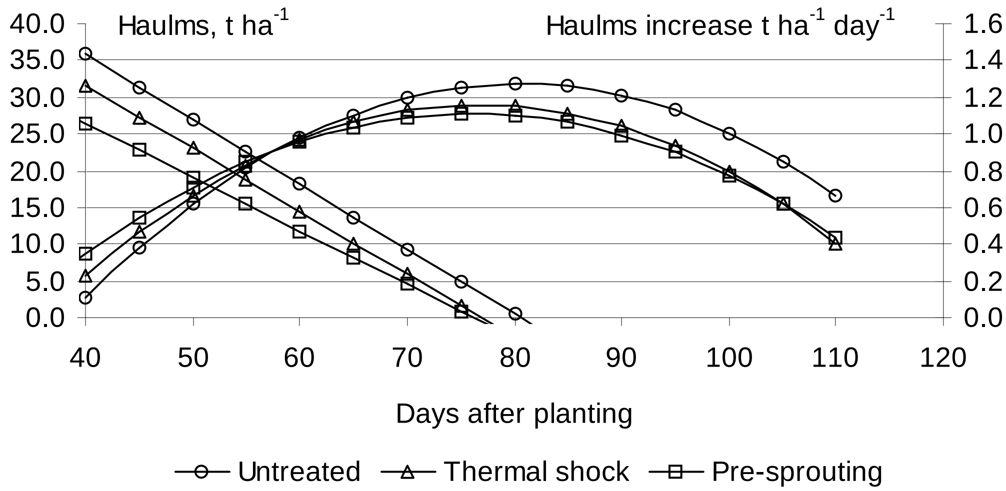

Fig. 2. Influence of the seed tuber pre-planting preparation method on the weight of the haulms (the average of 2000–2002, t ha^{-1}).
0 = Untreated variant: $y = -82.8+2.849x-0.01769x^2$, n=117, $R^2 = 0.985$, SE=0.45, $CL_{05}=1.02$;
TS = Thermal shock: $y=-72.3+2.63x-0.01715x^2$, n=117, $R^2=0.946$, SE=0.55, $CL_{05}=1.24$;
PS = Pre-sprouting: $y=-57.1+2.227x-0.01462x^2$, n=117, $R^2=0.946$, SE=0.46, $CL_{05}=1.04$.

Tuber yield. The pre-planting thermal treatment of seed tubers (TS) accelerated the beginning of tuber yield formation and ensured its increase during the initial growth period (until 60 DAP). The positive effect of pre-sprouting on the tuber yield was longer (until 110 DAP) (Fig. 3). All TS- and PS-variants reach maximum yield by 120 DAP.

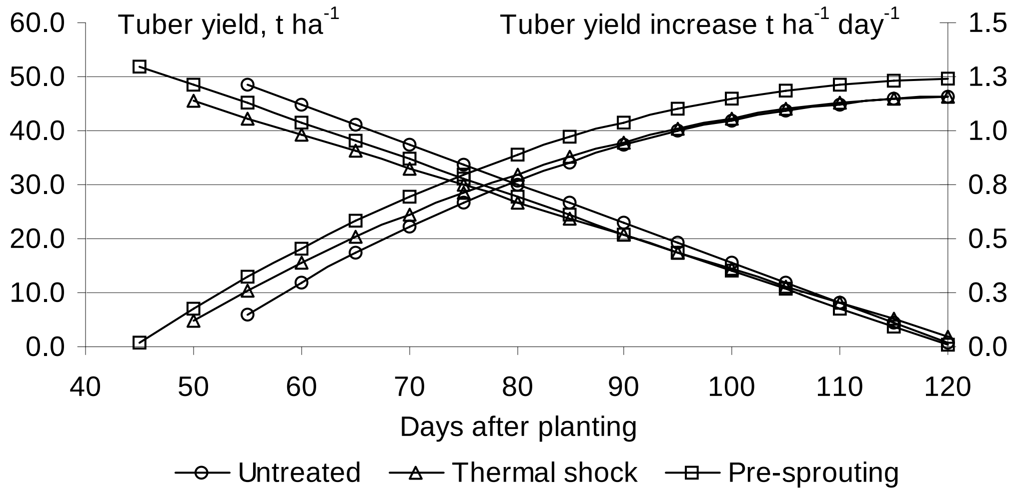

Fig. 3. Influence of the seed tuber pre-planting preparation method on the tuber yield (the average of 2000–2002, t ha^{-1}).
0 = Untreated variant: $y=-88.2+2.216x-0.00914x^2$, n=126, R^2 =0.960, SE=0.88, CL_{05}=1.93;
TS = Thermal shock: $y=-71.4+1.915x-0.00778x^2$, n=130, R^2=0.965, SE=0.79, CL_{05}=1.72;
PS = Pre-sprouting: $y=-75.2+2.073x-0.00861x^2$, n=137, R^2=0.968, SE=0.80, CL_{05}=1.73.

In the variants that started forming tubers later, the tuber yield was growing faster. By 55 DAP the increment of the tuber yield was larger in variant 0 (1.2 t ha^{-1} per day), exceeding variants TS and PS respectively by 0.15 and 0.08 t day^{-1}. The growth increment speed of the tubers became unified in different variants by 95 DAP.

CONCLUSIONS

The physiological age of potato plants could be increased by either, 1. pre-sprouting of seed tubers, or 2. thermal shock to the deeply dormant seed tubers. In variants with physiologically older seed tubers, the higher growth rate of accumulation to the developing tubers is achieved.

In the development of the leaf area and tuber yield formation, the thermal shock treatment was not as effective as pre-sprouting. Nevertheless treated seed tubers were physiologically older than non-treated samples, enabling quicker leaf area and tuber growth and development.

By pre-sprouting seed tubers before planting, the development of plants was faster during the entire vegetation period, but with thermal shock treatment only the first stages of vegetation was affected. The pre-sprouted variant gave a significant tuber yield increase during the whole vegetation season.

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