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Changes in planting environment due to climate change likely to affect the pre-emergent growth of potato (*Solanum tuberosum* L.) having different seed tubers physiological ages

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Abstract. Climate change is attributed to the changes of soil temperature and water availability in the planting environment. To study the effect of changing temperature and moisture condition on pre-emergent growth of potato seed tubers having different physiological age, a range of different temperature and moisture conditions were applied. Three temperatures (10, 15 and 20 ºC) and three water potentials [wet (-0.02 MPa), dry (-0.6 MPa) and fluctuated between wet and dry] were set to two lots of cv Russet Burbank and Atlantic seed tubers that had been treated with storage temperature of 15 ºC before planting to established aging. All possible combinations of seed tuber physiological age, cultivar and moisture treatments were randomized in each temperature level with 25 replications of each. Significant interactions ($p<0.05$) were found between cultivar, temperature, soil moisture in affecting the duration of the lag phase. A decrease in water potential at 10 ºC from -0.02 MPa to -0.6 MPa extended the lag phase for cv Atlantic from 20 days to 23 days. Increasing the water potential from -0.6 to -0.02 MPa shortened the lag phase of younger tuber of cv Atlantic but lengthened the lag phase duration for older tuber. A weak interactions were found between cultivar, temperature and moisture ($p<0.05$) on the rate of linear elongation. In the case of Russet Burbank, linear elongation rate decreased with increasing water potential at 20 ºC only. In contrast, for Atlantic, elongation rate increased from 2 mm/day to 4.5 mm/day with increase in water potential from -0.6 MPa to -0.02 MPa at 20 ºC.

1. Introduction

Climate changes has been thought to cause changes in the planting environment of potato plant including temperature and soil water availability [1]. Global warming has contributed to the increase of air and soil temperature and also altered water availability. According to IPCC [2] runoff is projected to decrease by 10% to 30% over some dry region at midlatitudes and dry tropics due to decreases in rainfall and higher rates of evapotranspiration. In general, the strongest negative impacts of increased temperature to potato production were predicted for the tropical and subtropical lowlands [3].

This study focuses on the effect of planting environment and seed tuber physiological age on the pre-emergent growth of potato. Pre-emergent growth can be broken down into three distinct phases, namely: dormancy, a lag period prior to the commencement of linear elongation of the sprouts and roots.

Dormancy can be defined as the physiological state where there is no cell division and in which autonomous sprout growth will not occur even when the tuber is kept in conditions ideal for sprout growth [4, 5, 6]. Dormancy commences at tuber initiation and reaches its peak at harvest time and then gradually begins to break down during storage [6]. Following the end of dormancy, sprout growth follows a sigmoidal path, commencing with a lag phase followed by a period of linear growth prior to emergence [7]. The duration of these phases is affected by soil temperature and moisture and the physiological age of the seed tuber [6, 7, 8. 9].

Temperature is known to be the key driver of these phases [10]. Cardinal temperatures for sprouting range from 0-3 ºC for base temperature [6, 7, 11], 15-20 ºC for optimum temperature [6] and 30-35 ºC for maximum temperature [12]. Firman *et al.* [7] report that a pre-warming treatment before planting can affect the lag phase duration of sprout growth. High temperatures increase cell activity up to a threshold maximum temperature, beyond which cell growth is impaired.

When soil moisture content is adequate, the time between planting and emergence depends on sprout length at planting and soil temperature [13]. While seed pieces at the recommended size of 50 to 70 g have sufficient moisture to support sprout growth up to emergence, low soil moisture content during planting has been reported to reduce the maximum rate of sprout growth [7]. Conversely, excess soil water in this stage can encourage the growth of pathogenic organisms [14].

Physiologically older tubers have shorter lag and linear phases than younger tubers [6, 7, 15]. The lag phase typically ends with a sprout length of ~10mm, after which linear elongation occurs. Based on this definition these authors estimated the duration of the lag phase to be ~60 ºC d (Tb 1 ºC) while the duration for young tubers may be longer [7].

Vos [8] reports that sprout elongation rate increases with physiological age up to a certain threshold age, beyond which it declines. According to Bohl *et al.* [15], warm temperatures during planting may negate the difference in time to emergence between older and younger seed. King and Stark [16] also argued that wet soil conditions can increase stress for the seed piece and increase the physiological age of the seed tuber. Despite this, no data have been presented on the interaction between planting environment, e.g. temperature and moisture, and seed tuber physiological age on the pre-emergent growth of potato.

2. Materials and Method

2.1. Experimental design and treatments

Three temperatures (10, 15 and 20 ºC) and three water potentials [wet (-0.02 MPa), dry (-0.6 MPa) and fluctuated between wet and dry] were applied to two lots of cv Russett Burbank and Atlantic seed tubers with chronological ages of 154 and 210 days since harvest to the start of the trial.

2.2. Growth media and moisture treatment

The growth medium used in the trials was vermiculite (Grade 2, Australian vermiculite and Perlite Co-P/L). Water potential treatments of -0.6, and -0.02 MPa were utilized. The relationship between soil water content and water potential in a previous study by Whalley *et al*. [17] was calibrated using a psychrometer (SC 10 thermocouple psychrometer Decagon Device, Pullman, Washington) and the following calibration for water potential, Ψ, was obtained:

$$\Psi = 0.0971\theta^{-1.1223} \quad (1)$$

where θ is the gravimetric water content.

Based on the calibration, the moisture treatments were established by equilibrating 0.19 g and 3.36 g water/g dry vermiculite for the driest (-0.6 MPa) and wettest (-0.02 MPa) moisture content, respectively. After a 24 hour equilibration period, the vermiculite for each water potential preparation was placed in plastic containers and sealed with a lid to prevent water loss from the container in order to maintain constant water potential throughout the trial.

The treatment of fluctuating water potential was achieved by moving tubers between two water potential conditions every four days. In the trials utilising the fluctuating water potential treatment, tubers in constant water potential treatments were also removed and then placed back into the same water potential to ensure any differences between fluctuating and constant water potential treatments were not attributable to the movement of tubers.

2.3. Aging treatment

Two seed tuber physiological status (aged and non-aged) were achieved by exposing tubers to 15 °C storage for 28 and 62 days for aged atlantic and russet burbank cultivars, respectively.. Seed tubers for the younger seed physiological age were kept at 4 ºC. Both storage treatments (4 ºC and 15 ºC) were set up in the dark conditions and relative humidity of 80-90%. After aging in the 15 °C storage, seed tubers were carefully placed back into the 4 ºC room until the start of the trial.
Seed age, expressed as degree days or thermal time, is calculated by using base temperature of 2 °C [7] resulted in sum of thermal time of 538 and 1220 ºCd for 'non aged' and 'aged' Russet Burbank cultivar and 537 and 845 ºCd for Atlantic.

A completely randomized block design was employed with temperature as the block strata. All possible combinations of seed tuber physiological age, cultivar and moisture treatments were randomized in each temperature level with 25 replicates of each. To reduce the risk of disease, tubers were dipped in fungicide (Rovral 1 g/L) and dried before planting. Seed tubers were handled with care to avoid the risk of sprouts being knocked off during handling and planting.

2.4. Observations and statistical analysis

The length of the longest sprouts of 3 tubers for each treatment combination were measured prior to planting and at 9, 13, 17 and 21 days after planting. Sprout length was measured with a dissecting microscope fitted with an eyepiece micrometer and ruler. The method for estimating the time of lag phase completion and the rate of linear sprout elongation was based on that reported by Firman *et al.* [7]. The end of the lag phase was taken as the time at which rapid linear sprout growth commenced. The linear growth rate was taken from the slope of the linear regression line fitted to the sprout growth plot beyond a sprout length of 10 mm. F-test analysis was made to identify factors affecting lag phase duration and linear growth rate. Statistical analysis was undertaken using the SPSS v. 14.0 software package (SPSS Inc. 2005).

3. Results and Discussion

Growth of the longest sprout was characterised by an initial period of slow growth up to a sprout length of ~10mm, followed by a period of more rapid linear elongation (figure 1).

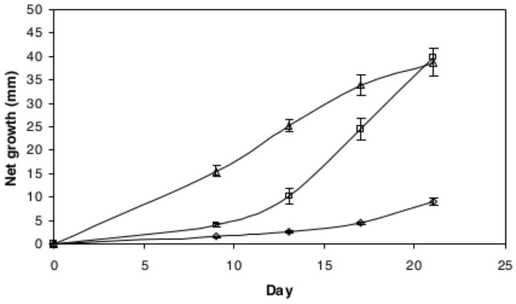

Figure 1. Response of sprout growth to temperatures of 10 º C (◇), 15 ºC (□) and 20 ºC (△). Each data point is an average across all non temperature treatments and replicates. Bar corresponds to the standard error of the mean (N= 36).

3.1. Lag phase duration

Significant interactions ($p<0.05$) were found between cultivar, temperature, soil moisture and the duration of the lag phase (table 1). A decrease in water potential at 10 ºC from -0.02 MPa to -0.6 MPa extended the lag phase for cv Atlantic from 20 days to 23 days. Significant interactions also occurred between cultivar, seed age and soil moisture ($p<0.05$). For cultivar Atlantic, increasing the water potential from -0.6 to -0.02 MPa shortened the lag phase of younger tuber but lengthened the lag phase duration for older tuber. There were no significant differences in lag phase duration across the Russet Burbank moisture treatments.

Table 1. Lag phase duration of sprout growth for different temperature (days) (T_1= 10 °C, T_2=15 °C, T_3=20 °C), cultivar (CV_1 = Russet Burbank, CV_2= Atlantic), water potential (M_1= -0.6 MPa, M_2= fluctuated between -0.6 MPa and -0.02 MPa, M_3= -0.02 MPa) combinations. l.s.d. figures shown with extent of significance (*$p<0.05$, **$p<0.01$, ***$p<0.001$, n.s.=not significant).

	M_1		Ave	M_2		Ave	M_3		Ave
	CV_1	CV_2	M_1	CV_1	CV_2	M_2	CV_1	CV_2	M_3
T_1	20.2	22.7	21.5	21.4	19.3	20.3	22.5	20.6	21.5
T_2	10.8	8.5	9.7	11.2	9.9	10.5	10.9	9.0	10.0
T_3	5.6	2.3	4.0	4.2	3.5	3.9	4.4	3.1	3.8
Ave	12.2	11.2	11.7	12.2	10.9	11.6	12.6	10.9	11.7

Main effect: Temperature (T) = 0.54***, Cultivar (CV) = 0.37 ***. Interactions: CV*T*M = 2.2*.

Despite those interactions, there were highly significant main effects of temperature and cultivar ($p<0.001$). Lag phase duration consistently declined with increasing temperature across all treatment combinations from 20 - 21 days at 10 ºC to 3 - 5 days at 20 ºC (figure 2). Lag phase duration for Russet Burbank (5 - 21 days or 90 - 168 ºCd > T_b 2 ºC) was typically longer than for Atlantic (3-20 days or 54-160 ºCd >T_b 2 ºC.

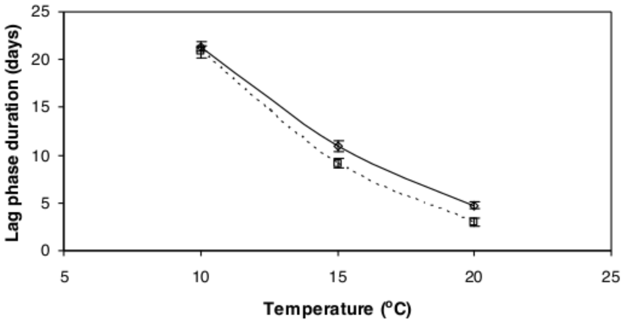

Figure 2. Response of lag phase duration of sprout growth to temperature for cultivar Russet Burbank (◇, ____) and cultivar Atlantic (□, --------). Each point represents an average across all non temperature treatments and replications. Bar corresponds to the standard error of the mean (N= 18).

3.2. Linear sprout elongation

There was a weak interaction between cultivar, temperature and moisture ($p<0.05$) and the rate of linear elongation (table 2). In the case of Russet Burbank, linear elongation rate decreased with increasing water potential at 20 ºC only. In contrast, for Atlantic, elongation rate increased from 2 mm/day to 4.5 mm/day with increase in water potential from -0.6 MPa to -0.02 MPa at 20 ºC. There was no significant difference between moisture treatments at 10 and 15 ºC (figure 3).

Table 2. Linear growth rate for different temperature (mm/day) (T_1= 10 °C, T_2=15 °C, T_3=20 °C), cultivar (CV_1 = Russet Burbank, CV_2= Atlantic), and water potential (M_1= -0.6 MPa, M_2= fluctuated between -0.6 MPa and -0.02 MPa, M_3= -0.02 MPa) combinations. l.s.d. figures shown with extent of significance (*$p<0.05$, **$p<0.01$, ***$p<0.001$, n.s.=not significant).

	M_1		Ave	M_2		Ave	M_3		Ave
	CV_1	CV_2	M_1	CV_1	CV_2	M_2	CV_1	CV_2	M_3
T_1	1.3	1	1.2	0.9	2	1.5	1	1.3	1.2
T_2	4	4.4	4.2	4.1	4	4.1	4.5	4.1	4.3
T_3	4.5	2	3.3	2.8	3.9	3.4	2.3	4.5	3.4
Ave	3.3	2.5	2.9	2.6	3.3	3.0	2.6	3.3	3.0

Main effect: Temperature (T) = 0.34***. Interactions: CV*T*M = 1.47*.

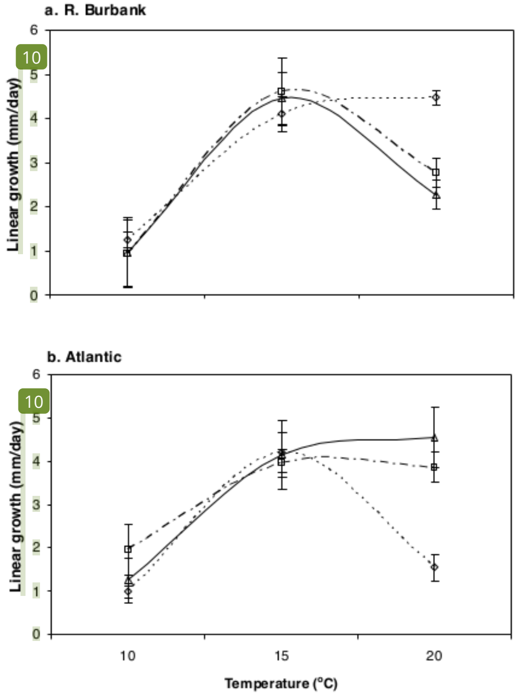

Figure 3. Elongation rate of the longest sprout of cultivar (a) R. Burbank and (b) Atlantic at 10, 15 and 20 ºC and -0.06 MPa (◇, **------**), fluctuated between -0.6 and -0.02 MPa (□, **-.-.-.-.**) and -0.02 MPa (△, ______). Each data point is an average of seed tuber physiological age treatments and replicates. Bar corresponds to the standard error of the mean (N= 6).

The results of this study show that pre-emergent growth of potato can be broken into two distinct phases; a period of slow initial growth (lag phase) followed by a period of faster linear growth. The key driver of these phases is temperature. The lag phase duration for cultivars Russet Burbank and Atlantic in this study (90-160 and 50-160 ºCd (> T_b 2 ºC), respectively) were shorter than those reported by Firman *et al* (1992) which ranged from 160 – 230 ºCd (> T_b 1 ºC) for cultivar Estima. They were however comparable to the 125 ºCd (> T_b 2 ºC) duration reported by MacKerron [11] for unsprouted seed tubers of Maris Piper. The differences are attributable to cultivar differences and/or differences in the sprout length at planting, which is reported by Firman *et al*. [7] to be correlated with lag phase duration.

The rate of linear sprout growth was found to be highest for the 15 ºC temperature treatment. This aligns with the findings of Struik and Wiersema [6] who report an optimum temperature for sprout growth in the range of 15 – 20 ºC. An increase in temperature up to the optimum level can increase the cell temperature and stimulate growth. A further rise in temperature can impair enzyme activity and reduce the growth rate [18]. The linear growth rate measured in this study (4.5 mm/ day) was lower than that reported by Firman *et al*. [7] for cv Estima (> 10 mm/day) but higher than that reported by Sands [19] for cultivars Sebago and Sequoia (3 mm/day).

Moisture and physiological age treatments in this study did not show any main effect both on the duration of lag phase and linear growth rate. Regardless the results, effect of moisture level at planting was more evident in higher temperature where drier conditions resulted in slower sprout growth. According to Blom-Zandstra G and Verhagen [20] water stresses level (i.e., either waterlogging or drought conditions) can be varied with on site-specific heterogeneity of soils, complexity of field-scale topography, soil resource management by the farmer, and availability of water for irrigation.

4. Conclusion

1. Following dormancy, pre-emergent growth of potato can be consisted of two distinct phases; a period of slow initial growth (lag phase) followed by a period of faster linear growth mainly affected by temperature. Therefore, increased temperature at planting will fasten the duration of the phases hence emergence of the plant.
2. Effect of moisture level at planting was more evident in higher temperature where drier conditions resulted in slower sprout growth.
3. The interactions found between genotype, soil moisture and temperature for lag and linear phases and between genotype, seed age and soil moisture for the lag phase, indicate the complex way in which these factors interact to determine the duration of pre-emergent growth.

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