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# Prediction of Seed Germination and Seedling Growth of Four Crop Plants as Affected by Root Zone Temperature

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**Abstract:** The present study monitored variations of seed germination and seedling growth of four important crop plants in Egypt along root zone temperature gradient. This study aims at investigating the ability of these cultivars to germinate and grow under the projected rise in temperature associated with the expected global warming scenarios. The study crops are Cotton (*Gossypium barbadense* L.), Wheat (*Triticum aestivum* L.), Rice (*Oryza stiva* L.) and Maize (*Zea mays* L.). The tolerances to increased temperatures as well as the optimum temperature range for seedlings of the study crop cultivars were investigated using a thermo-gradient table. Minor differences were found between cultivars of the different study crops. The temperature range resulting in maximum values of most growth parameters was 30-35°C in case of Rice, 25-30°C for Maize and Cotton and 20-25°C for Wheat seedlings. If the negative response of the study crop cultivars to the global warming due to expected climate change is taken as a measure, the following sequence (from the least to the most affected) of the study crops is observed: Rice < Maize < Cotton < Wheat.

**Key words:** Thermo-gradient table · rice · maize · cotton · wheat · soil temperature

## INTRODUCTION

Physiological processes in crop plants may be positively and/or negatively affected by changes in temperature, carbon dioxide concentration, ozone layer, ultraviolet radiation and nutrient and water availability that are associated with climatic changes [1, 2]. When temperatures exceed the optimum for biological processes, crops often respond negatively with steep drop in net growth and yield [3, 4]. Soil temperature, which is highly correlated to air temperature [5], was reported to largely influence biological soil activity and root growth and physiological activity of plants [6]. It was found that root zone temperatures are more critical to plant growth than leaf temperatures [7].

The climate in Egypt is semi-desert characterized by hot dry summers, moderate winters and few rainfalls. The study crops in this investigation, namely: Cotton, Wheat, Rice and Maize were chosen for their economic importance in Egypt and worldwide. Cotton (*Gossypium barbadense* L.) is the first important economic crop in Egypt and it is the most important fiber crop in the world, which is best adapted to sub-tropical climates [8]. Wheat (*Triticum aestivum* L.) is the most important crop on a global scale in terms of total harvested weight and amount used for human and animal nutrition [9, 10]. In terms of global production, Rice (*Oryza stiva* L.) comes in the second position followed by Maize (*Zea mays* L.) [11].

Among the most sensitive plant growth stages to high temperatures in crop plants is the seed germination and seedling emergence stages. The objective of the study is to monitor the seed germination and seedling growth along root zone temperature gradient under the projected rise in temperature associated with the expected global warming scenarios.

## MATERIALS AND METHODS

**Plant material and experimental design:** The study crops are Cotton (*Gossypium barbadense* L. cultivar Giza 89, family: Malvaceae), Wheat (*Triticum aestivum* L. cultivar Gemiza 9, Sakha 61 and Sakha 69, family: Poaceae), Rice (*Oryza stiva* L. cultivar Sakha 101 and Sakha 103, family: Poaceae) and Maize (*Zea mays* L. cultivar Hybrid 10, family: Poaceae).

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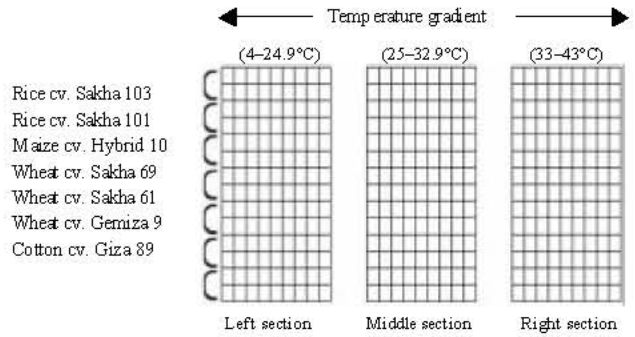


Fig. 1: Schematic illustration of pot arrangement on the thermo-gradient table

The experiment was conducted in the greenhouse of the Central Laboratory for Agricultural Climate (CLAC), Ministry of Agriculture and Land Reclamation, Dokki, Giza. A thermo-gradient table is used to investigate the response of germination and seedling growth of the study cultivars to the variation in root zone temperature (Fig. 1). The thermo-gradient table is made of steal frame with dimensions of 3 m length, 2 m width and 26 cm height. The table is provided with a Ferion cooling unit in one side and an electrical heater unit in the other side. Water is used as a media transferring heat throughout the table filled with washed sand up to 5 cm high from the base of the table. The table is equipped by two inner thermostats for manual control and adjustment of the cold and hot temperature set points. The minimum temperature was set at 4°C and maximum temperature at 43°C.

Seeds of the study cultivars were sown in plastic pots of 8 cm diameter and 6 cm height. Pots were filled with sand sieved through 2 mm mesh. The sand was washed in water before planting. The numbers of used seeds per pot were 10 seeds for Cotton, 16 seeds for Wheat and Rice and 4 seeds for Maize. Pots were arranged in the thermal table within sand. The used irrigation system was a micro net hold over the thermo-gradient table.

The wide range of temperatures in the thermo-gradient table is adventitious in detecting the optimum temperature range of each of the study cultivars as well as their response to the increased temperatures. For a precise record of temperature, thermometer reading in the pots was recorded before taking the growth measurements. The experiment was limited to the emergence and seedling stages where variation in root zone temperatures may be pronounced and more influencing for plants in the thermo-gradient table.

**Measurements and calculations:** The germination percentage ($G_p$) of emerged seedlings was calculated as follow:

$$G_p = \left(\frac{N_g}{N_p}\right) \times 100 \quad (1)$$

where, $N_g$ is the final number of emerged seeds and $N_p$ is the total number of seeds sown.

The leaf area was measured at the end of the experiment. The plants were harvested from the pots by applying gentle water current to get rid of sand. Leaf area was determined manually using chart paper and estimated as $cm^2$ per individual. For dry weight determination the plants were put in oven (70°C) until constant weight.

The total growth rate (GR) was calculated according to [12] as follows:

$$GR = \frac{W_2 - W_1}{T_2 - T_1} \quad (2)$$

where, GR is the growth rate (mg $day^{-1}$), $W_2$ is the dry weight of seedling at the end of the experiment ($T_2$; 22 day) and $W_1$ is the dry weight of seedling after five days from seedling emergence ($T_1$). Three randomly chosen seedlings of each cultivar, growing at different temperature ranges, were harvested for the dry weight determination. Means and standard deviations of seedlings growth rate was calculated. The best-fit equations of the measured parameters were performed using Slide Write Plus program (version 3).

## RESULTS

**Temperature tolerance:** The estimated relationships based on the best-fit equations between temperature and measured parameters of the different crop seedlings revealed varied features (Fig. 2). The increased width of curves indicates the flexibility or ability of species to withstand a wide range of temperature; however the variation between species in the height of curves is a species-specific feature.

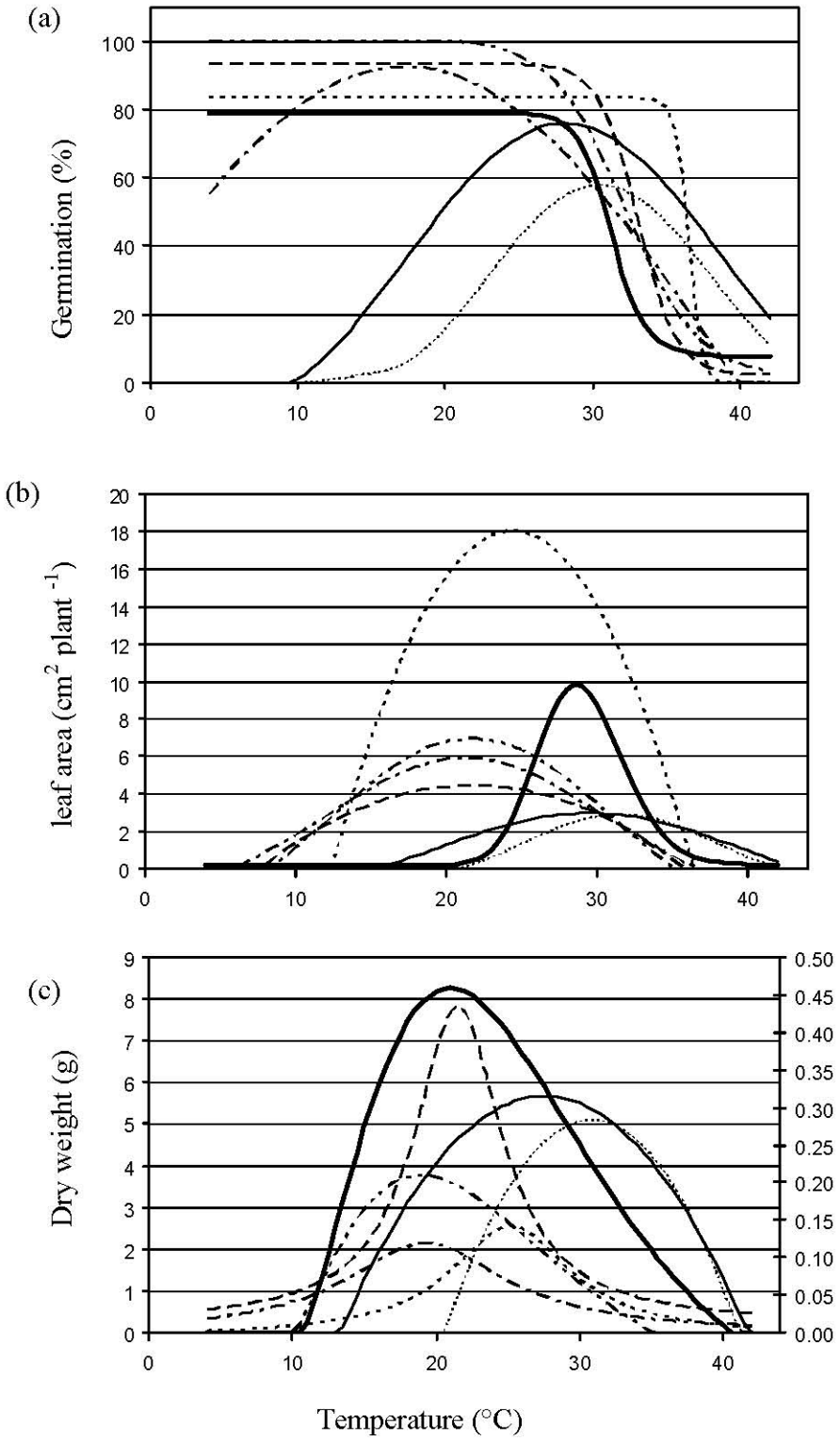


Fig. 2: Estimated relationships, based on the regression equations, between temperature and germination percentage ( a ), leaf area (b), and dry weight (c) of the study crop seedlings ; ——— = Cotton cv. Giza 89, - - - - - = Wheat cv . Gemiza 9, - · - · - = Wheat cv. Sakha 61, — — — = Wheat cv. Sakha 69, ····· = Rice cv. Sakha 101, ——— = Rice cv. Sakha 103 and ····· = Maize cv. Hybrid 10. Note the scale on the right side in (c) is related to the two cultivars of Rice and Cotton

Table 1: Temperature ranges giving maximum values of seed germination and seedling growth parameters. GP = Germination percent, LA = Leaf area per individual seedling, DW = Dry weight and GR = Growth rate. The plus sign indicates maximum value obtained for the measured parameter in the referred temperature range

| | | | Temperature range (°C) | | | | |
|---|---|---|---|---|---|---|---|
| Crop | Cultivar | Parameter | 10-15 | 15-20 | 20-25 | 25-30 | 30-35 |
| Cotton | Giza 89 | GP | + | + | + | | |
| | | LA | | | | + | |
| | | DW | | | | + | |
| | | GR | | | | + | |
| Wheat | Gemiza 9 | GP | + | + | + | | |
| | | LA | | | + | | |
| | | DW | | + | | | |
| | | GR | | + | | | |
| | Sakha 61 | GP | | + | + | | |
| | | LA | | | + | | |
| | | DW | | | + | | |
| | | GR | | | + | | |
| | Sakha 69 | GP | + | + | + | | |
| | | LA | | | + | | |
| | | DW | | | + | | |
| | | GR | | | + | | |
| Rice | Sakha 101 | GP | | | | + | |
| | | LA | | | | | + |
| | | DW | | | | | + |
| | | GR | | | | | + |
| | Sakha 103 | GP | | | | + | + |
| | | LA | | | | | + |
| | | DW | | | | + | + |
| | | GR | | | | + | + |
| Maize | Hybrid 10 | GP | | | | + | |
| | | LA | | | | + | |
| | | DW | | | | + | |
| | | GR | | | + | + | |

In case of the germination percentage, Cotton was the least crop in withstanding high temperatures followed by Wheat, Maize then Rice (Fig. 2 a). Although the two cultivars of Rice can withstand the range of 40-43°C, yet the mean germination percent for cultivars Sakha 101 and 103 is 9 and 11%, respectively. As for Maize, however, the maximum range of temperature where seeds can germinate is 25-30°C which gave 80% germination. Of the three Wheat cultivars, Sakha 69 cultivar showed a wider range of possible germination under high temperatures. Similarly, Rice cv. Sakha 103 tolerated high temperatures more than Sakha 101 cultivar.

Concerning the total leaf area per plant seedling, the three Wheat cultivars (Gemiza 9, Sakha 61 and Sakha 69) are the least of the study species that can tolerate high temperatures followed by Cotton and Maize, then followed by the two Rice cultivars (Fig. 2 b). While the three Wheat cultivars showed a broad range of temperature where seedlings dry weight may have noticeable values, the seedlings of the Rice cultivars can withstand higher temperature greater than 35°C (Fig. 2 c). Cotton and Maize did not differ greatly in the maximum temperature (greater than 30°C) they can tolerate.

**Optimum temperature range:** In this investigation, the Cotton seedlings showed maximum value of growth rate, leaf area and dry weight in the temperature range 25-30°C (Table 1), while the maximum values of germination percent was obtained in the temperature range (15-25°C).

In case of Wheat cultivars, maximum values of the germination percentage were obtained under a wide range of temperature that may extend from 10 to 25°C. Maximum values of all studied growth parameters of the two Sakha cultivars were obtained in the temperature range 20-25°C (Table 1). The Gemiza cultivar, on the other hand, showed maximum values of most of the study parameters in the temperature range 15-20°C.

The temperature range 25-35°C resulted in maximum values of the measured growth parameters of the Rice cultivar Sakha 103 (Table 1). Sakha 101 cultivar, however, attained maximum values of growth parameters in the temperature range 30-35°C.

The temperature range 25-30°C resulted in maximum values of the measured growth parameters of the Maize seedlings (Table 1). Maximum growth rate was obtained in the temperature range 20-30°C.

## DISCUSSION

The dependence of much of the world's population on agricultural activities and the significant magnitude and increased rate of climate change created the need for a comprehensive consideration of the potential impacts of global warming on global agriculture [14]. Modeling of crop plant growth has profound benefits on the adaptation to the global warming and other impacts associated with the climate change scenarios. Especially for seed germination and seedling establishment stages that are greatly dependent on the root zone temperature and may be considered as the most critical and sensitive stages in the plant life cycle.

Cotton is a summer crop plant. It was reported that Cotton development rate was maximized at temperature range of 25 to 30°C [15, 8]. In this investigation, the Cotton seedlings showed maximum value of growth rate, dry weight and leaf area under the same temperature range. The maximum values of germination percent was obtained, however, in the temperature range (15-25°C). Temperatures higher than 30°C was found to cause reduction in germination percentage and other growth parameters in Cotton seedlings. Similarly, it was reported that high temperatures beyond 40°C caused negative effects on growth of the Cotton plants [8]. These effects were rendered to the disadvantageous effect of high temperature on photosynthesis and the enhancement of photorespiration where gross and net photosynthesis decline greatly when temperature exceeds 32°C. Increasing temperature affects also life span; 5°C expected increase in average global temperature will speed the crop development life span from emergence to maturity by 35 days [16, 17, 15].

Wheat is a temperate zone crop plant. Several authors [*e.g.* 18-22] found that higher temperatures of about 30-35°C shortens the duration of all developmental stages and reduce the duration of Wheat growth, which results in lower seed yield and may have negative effects on growth as demonstrated by the reduction of growth parameters in the present investigation. Wheat cultivars were found to vary in their response to the increased temperature [19, 21-23]. In the present study, maximum values of the germination percentage were obtained under a wide range of temperature (10-25°C) in the three Wheat cultivars, however, maximum values of all other study growth parameters of the two Sakha cultivars were obtained in the temperature range 20-25°C. The Gemiza cultivar, on the other hand, showed maximum values of the growth parameters in the temperature range 15-20°C which agreed with the findings of [24, 25].

Rice is a summer crop plant and as a result of the ecophysiological diversity of its genotypes, the crop can be raised under a wide range of environmental conditions [26]. In the present study, the temperature ranges 20-35°C and 30-35°C resulted in maximum values of the measured growth parameters of the Sakha 103 and Sakha 101 Rice cultivars, respectively. This finding agreed with [27] who reported that the appropriate temperature range for vegetative growth of Rice is generally from 12 to 38°C, with an optimum between 25 and 30°C. Similarly, [28] suggested that the temperature range 27-30°C is the optimum temperature for maximum growth rate of Rice, above or below this range, longer period is required for the crop to reach heading. It was suggested also that the optimum temperature range for the Rice crop growing season is 25-30°C [29]. Moreover, Rice plants that grow at a root temperature of 30°C had more than double the chlorophyll content of plants grown at a root temperature of 10°C after only 1 week [30].

The Maize crop is best adapted to intermediate climates of the earth and coupled with global climatic change. The crop is potentially allowed to be extended into yet higher latitudes [31, 11]. The temperature range 25-30°C resulted in maximum values of the measured growth parameters of the Maize seedlings. Maximum growth rate was obtained in the temperature range 20-30°C. The temperature range 25-30°C was suggested by several authors to be the optimum temperature for Maize growing season [32, 29, 33].

## CONCLUSIONS

Root zone temperature has direct effect on seed germination and seedling growth of the study crop plants. Each crop has a specific response to variation in root zone temperature, while slight differences may occur between cultivars of the same crop.

Rice seedlings may occupy the first position as compared to other study crop seedlings in withstanding higher temperatures greater than 35°C. In this case, the temperature range resulting in maximum values of most growth parameters is from 30 to 35°C in case of the Sakha 101 cultivar. The Sakha 103 cultivar showed a wider range of temperature (25 to 35°C). Maize came in second position with an optimum temperature range of 25 to 30°C, the seedling showed greatly reduced values of the study parameters in temperatures greater than 35 °C. The third position was taken by Cotton that demonstrated high negative response in growth parameters under temperatures greater than 30 °C, with an optimum temperature range of 25 to 30°C. The Wheat seedlings came in the last position with great decrease in growth parameters in temperatures greater than 25°C and an optimum temperature range of 20 to 25°C.

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