

Determination of Optimum Temperature and Moisture Content for Crop Germination

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Abstract

The global warming due to climate change has effect on temperature and water availability which are necessary for crop germination. A study was carried out to determine the optimum temperature and moisture content required for crop germination. Maize, bean and okra were sown in containers filled with loamy sand, sandy loam and sandy clay loam. Temperatures used for the study were 5, 7, 15, 21, 25, 29, 35, 40 and 45°C while the water applied were 100, 80, 60, 40 and 20% of the field capacity. There was no germination at 5, 7 and 45°C even at 100 and 80% water application. At 15°C, germination only occurred at 100% water application and percentage germination was very low. The three crops germinated at 21°C but percentage germination of the crops were high at 25, 29 and 35°C when water applications were 100, 80, and 60% and declined at 40°C. Bean failed to germinate at 40°C and germination of the three crops was affected at 20 and 40% water applications.

Keywords: germination, germination temperature, germination moisture content, irrigation requirement, irrigation interval.

1. Introduction

Soil is a natural medium essential for plant growth. It is a store-house of plant nutrients, a habitat for micro-organisms, an anchorage for plants and a reservoir that holds water needed for plants growth (Michael, 2008). Soil contains plant nutrients, water and air which are necessary for seed germination and plant growth. The top soil contains high percentage of organic material and it is regarded as agricultural soil. Dark soils absorb more energy from sun than light coloured soil and red or yellow soil shows more rapid temperature rise than the white soil (Hillel, 1982). Globally, $3,240 \times 10^9 \text{ m}^3$ of fresh water is withdrawn and used annually out of which 69% is used for agriculture, 23% for industries and 8% for domestic use (Michael, 2008).

The global warming due to climate change has effect on temperature and water availability which are indispensable for crop production. The climate change will increase temperature, reduce the water availability for irrigation and other domestic uses. The effects of the climate change would be more pronounced in the tropics particularly the African countries where the temperatures were high before the climate change. Temperature affects cellular metabolic and growth rate. Seeds of different species and seed from same plant germinate over a wide range of temperatures. Seeds have temperature range within which they will germinate and they will not germinate at temperature above or below this range (Birkeland, 1999). Many seeds germinate at temperatures slightly above room temperature, others germinate only in the

response to alternation in temperature between warm and cool temperature. Rosenzweig and Hillel (1995) stated that higher temperature will lengthen the growing season and germination days.

There is need to carry out a research at this period of climate change to know the actual quantity of water that is required for germination and the temperatures at which germination would occur and temperatures when germination would be affected in Nigeria.

The uptake of water by seed (imbibition) leads to swelling and breaking of the seed coat. Hydrolytic enzymes break down the stored food materials into metabolically useful chemicals. Oxygen is required for aerobic respiration which provides the needed energy for germination of the seeds.

2. Materials and Methods

2.1 Description of the project site

The study was carried out in the laboratory of the Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria. Ilorin lies on the latitude $08^{\circ}30'N$ and longitude $04^{\circ}35'E$ at an elevation of about 340 m above mean sea level (Ejieji and Adeniran, 2009). Ilorin is in the Southern Guinea Savannah Ecological zone of Nigeria with annual rainfall of about 1300 mm. The wet season begins towards the end of March and ends in October while the dry season starts in November and ends in March (Ogunlela, 2001, Ejieji and Adeniran, 2009). Temperature of Ilorin between December, 2009 and June, 2010 ranged from $16^{\circ}C$ to $41^{\circ}C$ (Amusan, 2010).

2.2 Materials

Maize, bean and okra were sown in plastic containers, five containers for each crop and the containers were filled with loamy sand, sandy loam and sandy clay loam. Each of the containers was 130 mm diameter and 150 mm high but filled with soil to a depth (D) of 100 mm from the bottom. Water application used during the experiment as the treatments were 100%, 80%, 60%, 40%, and 20% of the field capacity. Germination rates of the three crops were monitored using the temperatures $5^{\circ}C$, $7^{\circ}C$, $15^{\circ}C$, $21^{\circ}C$, $25^{\circ}C$, $29^{\circ}C$, $35^{\circ}C$, $40^{\circ}C$, and $45^{\circ}C$ for two weeks. To achieve a wide range of temperature, refrigerator and electric oven were used. Temperatures of $5^{\circ}C$, $7^{\circ}C$, $15^{\circ}C$, $21^{\circ}C$, and $25^{\circ}C$ were achieved by putting the plastic containers with the seeds in a refrigerator and set at the desired temperature. Temperatures of $29^{\circ}C$, $35^{\circ}C$, $40^{\circ}C$ and $45^{\circ}C$ were achieved by putting the containers with the seeds in an electric oven.

Field capacity of the each soil was determined using the method given by Michael (2008). Wilting point is the moisture content at which plants can no longer obtain enough water to meet the evapotranspiration requirement and the plant is wilted. The values of wilting point used were obtained from Equation (1) reported by Sani (2003).

$$W.P = \frac{F.C}{F} \quad (1)$$

where,

W.P is the wilting point (%),

F.C is the field capacity (%) and,

F is a factor ranging from 2.0-2.4 depending on percentage content of silt in the soil. The value of wilting point used for this study was 2.2. Michael (2008) recommended some values of wilting points with their respective field capacity range for a view soil types.

Bulk density is the ratio of mass of oven dry soil to total volume of the soil sample (volume of core sampler). Equation (2) was used to determine the bulk density of the soil which is needed for converting moisture content in percentage (%) to volumetric moisture content (m^3/m^3).

$$\rho_b = \frac{M_d}{V_c} \quad (2)$$

where,

ρ_b is bulk density of the soil (g/cm^3),

M_d is mass of oven dry soil (g),

V_c is volume of the core sampler used for taken the soil sample (cm^3).

2.3 Theory

The depth of water requirement at 100% field capacity if the initial moisture content of the soil is 0%, this could be determined using Equation (3), but this is unusual. Subsequently, depth of initial water application, depth of water required at different percentage of field capacity, volume of water required at different percentage of field capacity, depth of available water, net depth water requirement, volume of water application and irrigation interval were determined from the following Equations (4), (5), (6), (7), (8), (9) and (10) respectively.

$$d_f = \frac{\rho_b}{\rho_w} \left(\frac{F.C}{100} \right) D \quad (3)$$

$$d_i = \frac{\rho_b}{\rho_w} \left(\frac{F.C - \theta_i}{100} \right) D \quad (4)$$

$$d_p = p_n \text{ of } d_i \quad (5)$$

$$V_p = d_p \times A_c \quad (6)$$

$$d_a = \frac{\rho_b}{\rho_w} \left(\frac{F.C - WP}{100} \right) D \quad (7)$$

$$d_n = P_n \text{ of } d_a \quad (8)$$

$$V = d_n \times A_c \quad (9)$$

$$i_v = \frac{d_n}{ET_{\max}} \quad (10)$$

where,

d_f is the depth of water required at 100% of field capacity if the initial moisture content of soil is 0%, d_i is the initial depth of water application, (mm),

d_p is the depth of water applied at different percentage of field capacity at the beginning of the experiment, (mm),

V_p is the volume water required at different percentage of field capacity (cm^3),

ρ_b is the bulk density of soil (g/cm^3),

ρ_w is the density of water (g/cm^3),

d_a is the depth of available water (mm),

d_n is the net depth of water application (mm),

F.C is the field capacity of the soil (%),

θ_i is the initial moisture content of the soil before irrigation (%),

D is the depth of the soil in the plastic container (mm),

P_n is the percentage of available water depletion at which water was applied to soil in the container, value of P_n used in this study in Equation(8) was 30%, values of P_n used in Equation (5) were 100, 80, 60, 40 and 20%,

V is the volume of water application (cm^3),

A_c is the area of the plastic container used (132.75 cm^2),

i_v is irrigation interval (day), and

$ET_{\max}$ is the maximum evapotranspiration of the crop (mm/day). For this study, 3mm/day was assumed as the value of evapotranspiration ($ET_{\max}$).

3. Results and Discussion

The soils used for the experiment were loamy sand, sandy loam and sandy clay loam and pH of the soils were 6.6, 6.6 and 6.5 respectively. The field capacity of the each soil, bulk density, wilting point, initial moisture content of the soils at the beginning of the experiment, percentage contents of sand, silt and clay were shown in Table 1. Depth and volume of water required at different percentage of field capacity at the beginning of the experiment were shown in Table2. Depth of water applied at the beginning of the experiment and subsequent net depths of water application, irrigation interval and volume of water applied were shown in Table 3.

The results of Percentage germination and number of days of germination of the three crops at different levels of field capacity and temperature on each soil were shown in Tables 4, 5, and 6. Number of days of germination in Tables 4, 5 and 6 were outside the bracket while the percentage germination of the six seeds sown per container was enclosed in the bracket. Maize, bean and okra failed to germinate at 5°C and 7°C within two weeks even at 100% and 80% of water application. At 15°C , no germination at 20, 40 and 60% water application while at 80 and 100% water application, germination was 17% for sandy loam and loamy sand at 15°C . With sandy clay loam at 15°C , the percentage germination increased to 33% as shown in Table 6. From the study, it was discovered that germination of maize and okra is between 21°C and 40°C while bean failed to germinate at 40°C . The three crops failed to germinate at

45°C meaning that the temperature above the germination temperature for the crops no matter level or quantity of water application. Temperatures of 25°C, 29°C and 35°C had high percentage germination and number days of germination were short.

Water is another factor that is necessary for crop germination. Germination occurred at 100%, 80%, 60% and 40% of field capacity water application but that at 100, 80 and 60% were better than 40 and 20%. Germination was affected at 20% field capacity but it was a little bit better with sandy clay loam which could hold water than other two soil types. Bean is more sensitive to the factors necessary for germination than maize and okra as shown in Tables 4, 5 and 6.

4. Conclusions

From the study, maize, bean okra can germinate at temperature between 21 and 35°C but they failed to germinate at 5, 7 and 15°C. At 40°C bean did not germinate while maize and okra germinated with germination percentage ranged from 17 to 67%. Maize, bean and okra could germinate at 100%, 80%, 60% and 40% of field capacities. Germination was better at 100%, 80% and 60% of field capacities than 40% and 20%. Bean is more sensitive to factors that are necessary for germination than the maize and okra. Germination of the crops was affected at 20% and percentage of germination was low at 40% field capacity.

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Table 1: Soil physical properties

Properties	Loamy sand	Sandy loam	Sandy clay loam
Bulk density (g/cm ³)	1.585	1.312	1.420
Field capacity (%)	14.29	20.62	25.00
Wilting point (%)	6.50	9.36	11.36
Initial moisture content (%)	3.50	4.00	4.00
Sand (%)	78.48	62.48	68.48
Clay (%)	15.52	15.52	21.00
Silt (%)	4.00	22.00	10.52

Table 2: Depth and volume of water requirements at different percentage of field capacities

Percentage	Loamy sand		Sandy loam		Sandy clay loam	
	Depth (mm)	Volume (cm ³)	Depth (mm)	Volume (cm ³)	Depth (mm)	Volume (cm ³)
100	17.10	227.00	21.81	289.53	29.82	395.86
80	13.68	181.61	17.45	231.65	23.86	316.74
60	10.26	136.20	13.09	173.77	17.89	237.49
40	6.84	90.80	8.72	115.76	11.93	158.37
20	3.42	45.40	4.36	57.88	5.96	79.12

Table 3: Depths of water application and irrigation interval for the soils

Water application	Loamy sand	Sandy loam	Sandy clay loam
Initial depth of water (mm)	17.10	21.81	29.82
Depth of available water (mm)	12.35	14.77	19.37
Net depth of water (mm)	3.71	4.31	5.81
Volume of water at the beginning (cm ³)	227.00	289.53	395.86
Volume for net depth (cm ³)	49.25	57.22	77.13
Irrigation interval (day)	1.24	1.48	1.94

Table 4: Percentage germination, number of days of germination for maize, bean and okra at different levels of field capacities and temperatures for a loamy sand.

F.C (%)	Crop	Temperature (°C)								
		5	7	15	21	25	29	35	40	45
100	Maize	0(0)	0(0)	6(17)	5(33)	6(33)	6(67)	3(67)	6(50)	0(0)
	Bean	0(0)	0(0)	7(17)	5(50)	3(83)	6(50)	6(17)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	6(50)	5(67)	4(67)	5(50)	6(33)	0(0)
80	Maize	0(0)	0(0)	0(0)	5(17)	6(33)	5(50)	3(50)	6(33)	0(0)
	Bean	0(0)	0(0)	0(0)	6(50)	4(67)	5(17)	7(17)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	6(50)	5(67)	5(67)	5(50)	7(33)	0(0)
60	Maize	0(0)	0(0)	0(0)	6(17)	6(17)	6(50)	4(33)	7(17)	0(0)
	Bean	0(0)	0(0)	0(0)	6(33)	4(50)	4(33)	0(0)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	6(33)	6(50)	5(50)	6(50)	7(17)	0(0)
40	Maize	0(0)	0(0)	0(0)	6(17)	6(17)	6(33)	4(33)	7(17)	0(0)
	Bean	0(0)	0(0)	0(0)	7(33)	6(50)	7(33)	0(0)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	6(17)	7(33)	6(33)	7(33)	7(17)	0(0)
20	Maize	0(0)	0(0)	0(0)	0(0)	0(0)	7(17)	4(17)	0(0)	0(0)
	Bean	0(0)	0(0)	0(0)	0(0)	7(33)	0(0)	0(0)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	7(17)	7(33)	7(33)	7(17)	0(0)	0(0)

Table 5: Percentage germination, number of days of germination for maize, bean and okra at different levels of field capacities and temperatures for a sandy loam.

F.C (%)	Crop	Temperature (°C)								
		5	7	15	21	25	29	35	40	45
100	Maize	0(0)	0(0)	6(17)	5(33)	6(50)	6(67)	3(83)	6(67)	0(0)
	Bean	0(0)	0(0)	6(17)	4(50)	3(83)	7(67)	6(33)	0(0)	0(0)
	Okra	0(0)	0(0)	6(17)	5(50)	(50)	4(83)	4(67)	6(33)	0(0)
80	Maize	0(0)	0(0)	0(0)	6(33)	7(67)	4(50)	3(67)	6(50)	0(0)
	Bean	0(0)	0(0)	0(0)	5(50)	7(83)	5(50)	7(33)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	6(50)	5(50)	5(100)	5(67)	6(17)	0(0)
60	Maize	0(0)	0(0)	0(0)	7(33)	5(33)	6(50)	4(33)	5(33)	0(0)
	Bean	0(0)	0(0)	0(0)	6(50)	6(67)	4(33)	7(17)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	6(33)	6(33)	4(67)	5(50)	7(17)	0(0)
40	Maize	0(0)	0(0)	0(0)	7(17)	5(33)	6(33)	4(17)	5(33)	0(0)
	Bean	0(0)	0(0)	0(0)	6(17)	6(50)	4(17)	0(0)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	7(33)	6(33)	5(50)	6(50)	7(17)	0(0)
20	Maize	0(0)	0(0)	0(0)	0(0)	6(17)	5(33)	7(33)	6(17)	0(0)
	Bean	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	7(17)	7(33)	6(67)	7(33)	0(0)	0(0)

Table 6: Percentage germination, number of days of germination for maize, bean and okra at different levels of field capacities and temperatures for a sandy clay loam.

F.C (%)	Crop	Temperature (°C)								
		5	7	15	21	25	29	35	40	45
100	Maize	0(0)	0(0)	5(17)	5(33)	6(67)	4(100)	3(83)	4(50)	0(0)
	Bean	0(0)	0(0)	6(33)	5(67)	3(100)	4(83)	5(50)	0(0)	0(0)
	Okra	0(0)	0(0)	6(33)	6(50)	5(83)	4(100)	5(50)	0(0)	0(0)
80	Maize	0(0)	0(0)	7(17)	6(33)	6(67)	4(83)	4(83)	6(67)	0(0)
	Bean	0(0)	0(0)	7(17)	5(67)	3(83)	6(67)	5(33)	0(0)	0(0)
	Okra	0(0)	0(0)	7(17)	7(50)	6(67)	3(83)	5(67)	6(33)	0(0)
60	Maize	0(0)	0(0)	0(0)	6(17)	7(50)	3(50)	4(67)	6(33)	0(0)
	Bean	0(0)	0(0)	0(0)	6(50)	4(83)	6(50)	6(17)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	7(33)	6(50)	6(83)	6(50)	6(17)	0(0)
40	Maize	0(0)	0(0)	0(0)	7(17)	7(33)	3(67)	4(50)	6(33)	0(0)
	Bean	0(0)	0(0)	0(0)	7(33)	5(67)	5(33)	7(33)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	7(17)	5(33)	5(67)	6(33)	7(17)	0(0)
20	Maize	0(0)	0(0)	0(0)	7(17)	7(33)	6(50)	5(33)	0(0)	0(0)
	Bean	0(0)	0(0)	0(0)	7(17)	4(50)	6(33)	7(17)	0(0)	0(0)
	Okra	0(0)	0(0)	0(0)	0(0)	5(17)	6(67)	7(17)	0(0)	0(0)