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Identification and Quantify of the Main Climatic Factors Affecting Potato Growth and Yield

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Abstract: Potato growth and development are affected strongly by weather and simple ways of normalizing growth at a location for seasonal differences in weather are useful for management decision. To acquire information about climatic factors affecting growth and yield of potato, a stepwise regression analysis was conducted. Moreover, collected data about climatic factors and vegetative growth parameters were subjected to the stepwise regression analysis. Considered climatic factors in the study were maximum, minimum and average air temperature (°C), maximum, minimum and average relative humidity (%), maximum, minimum and average soil temperature (°C) and solar radiation (cal/cm^2). However, studied vegetative growth parameters were plant length, number of leaves, leaves area, canopy fresh and dry weight. Hartz and Moore model was used to predict productivity of potato crop using the weather elements is the most influential using the weather elements is the most influential. Results indicated that vegetative growth parameters could be predict using specific elements of the weather i.e. maximum relative humidity is a predictor for plant height, minimum air temperature and maximum soil temperature are predictor for number of leaves. Moreover, total leaves area could be predict depending on average relative humidity, maximum soil temperature and minimum air temperature. Finally potato crop yield could be predict using Hartz and Moore prediction model which is mainly depend on revised growing degree days (RGDD), total solar radiation and daily air temperature range.

Key words: Potato · Climatic Factors · Vegetative Growth · Yield Prediction · Predictor Model

INTRODUCTION

In Egypt, potato is one of the most important horticulture crops for export and local consumption, it occupancy about 20% of total cultivated vegetables area. Potato crop is very important to Egyptian economy any disturbance in its production affects on both local and export markets [1]. In addition, total cultivated area with potato reached 334.6 thousand feddan in 2012 year, the total production is 3634.2 tons of tubers averaged 10.9 tons/feddan. Moreover, potato export has reached 299691 and 637434 tons of potato in years 2010 and 2011, respectively.

Potato (*Solanumtuberosum* L.) is the world's most important non-grain food crop and is essential to global food security. Vandermermeiren [2] reported that potato is a major and important crop for human nutrition. Potato ranks number fourth on a global scale after wheat, rice and maize.

Currently there is a great deal in estimating growth, development and potential yield for plants as a function of climatic factors which, directly regulating plants transpiration, photosynthesis and respiration processes, which is mean to control the growth and development of plants through the physiological cycle. Therefore, all physiological process reflected on the plant shape and the potential yield.

Hartz and Moore [3]reported that, temperature and radiation govern the rate of photosynthesis and respiration; the problem is devising a prediction system that accurately represents the influence of these variables. Moreover, several research studies have been

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conducted aiming to quantifying the effects of the climatic factors on growth, crop stage and yield of several crops.

Coelho and Dale [4] found that, among the main climatic factors that strongly govern all physiological processes of the plants should be in mind global solar radiation density and air temperature.

Research study [5] stated that the effect of elevated temperatures on potato growth and final yield is determined by complicated interaction between soil temperature, air temperature and solar radiation.

Pereira [6] identify the potential yield as the maximum crop yield of a given species or cultivar possible achievable under the existing conditions of solar radiation density, other environmental factors considered to be optimal.

Bannayan and Sanjani [7] conclude that, improving knowledge related to the relationship between climate and crop yield could assess the potential yield.

Currently, advanced computer programs software and simulation models are presented to predict the crops yield using information and detailed data about climate and other factors like soil, variety, irrigation, fertilization,..etc. However, a simple pre-harvest method for predicting vegetables crop yield (potato yield in this study) from climatic data would be invaluable to both of the farmers and decision maker; globally such method is already exists but, unfortunately not prove under Egyptian conditions.

The Aim of the Study:

- Quantify the relative effect of air temperature, relative humidity, soil temperature solar radiation and the vegetative growth of potato crop.
- Evaluate the validation of yield prediction model [3] to predict the potato crop yield under Egyptian conditions.

MATERIALS AND METHODS

Potato tubers, cv. Valor, were cultivated and grown during Autumn seasons 2010/2011 and 2011/2012 at Dokki protected cultivation experimental site, Central Laboratory for Agricultural Climate (CLAC), Agriculture Research Center (ARC), Dokki, Giza. Site located at, 30.0(°N) latitude, 31.2(°E) longitudes and 22.5(m) altitude.Climatic factors considered in the study were maximum, minimum and average air temperature (°C), maximum, minimum and average relative humidity (%), maximum, minimum and average soil temperature(°C)and solar radiation (cal/cm^2).All climatic factors were measured and recorded by automatic weather station (Campbell scientific, Inc) (Table 1).

Studied parameters of vegetative growth were plant height, number of leaves, leaves area, canopy fresh weight and canopy dry weight.Quantifying the relationship between climatic factors effects and vegetative growth parameters, the recorded climatic

Table 1: weather data during growing seasonsof 2010/2011 and 2011/2012.

Period	Max. air temp.	Min. air temp.	Average air temp.	Max. RH%	Min. RH%	Average RH%	Max. soil temp.	Min. soil temp.	Average soil temp.
Season 2010/2011									
1/10-15/10	24.71	22.77	23.74	58.67	22.77	40.72	21.25	19.89	20.57
16/10-30/10	23.03	18.97	21.00	52.23	18.97	35.60	19.98	16.86	18.42
31/10-14/11	27.53	22.93	25.23	50.00	22.93	36.47	24.86	22.31	23.59
15/11-30/11	21.00	18.07	19.53	49.33	18.07	33.70	18.95	17.60	18.28
1/12-15/12	25.00	19.10	22.05	60.67	19.10	39.88	22.54	20.68	21.61
16/12-30/12	21.23	18.90	20.07	66.67	18.90	42.78	19.23	17.85	18.54
31/12-14/01	21.70	21.00	21.35	57.00	21.00	39.00	18.93	16.23	17.58
Season 2011/2012									
1/10-15/10	31.66	19.93	25.55	60.50	23.97	42.23	26.83	25.31	26.08
16/10-30/10	27.75	17.39	22.37	53.70	19.97	36.83	25.40	21.11	23.44
31/10-14/11	25.21	14.36	19.64	51.95	24.53	38.24	24.17	17.82	20.98
15/11-30/11	21.49	11.76	16.33	51.33	20.07	35.70	22.26	15.60	18.51
1/12-15/12	20.70	10.59	15.49	61.30	21.10	41.20	23.09	9.03	17.02
16/12-30/12	20.33	9.83	14.58	64.67	20.45	42.56	21.55	10.39	15.92
31/12-14/01	13.82	12.73	13.27	56.89	22.50	39.70	16.07	13.01	14.43

factors and vegetative growth parameters were analyzed by the GLM procedure [8]and Duncan multiple range tests[9] was used to measure the significant differences. Regarding to crop yield prediction, recorded climatic data were applied in linear polynomial model [3]. Obtained results were compared to the actual harvested crop yield (g/plant). The applied crop yield prediction model was:

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3$ Where:

Y = Plant yield of tubers > 1 cm diameter (g/plant)

X_1 = Revised growing degree days (RGDD) =

$$\frac{\text{Max temp. } (\leq 30^{\circ}C) + \text{Min temp. } (\geq 4.4^{\circ}C)}{2}$$

$$\frac{\text{Min temp. } (\geq 4.4^{\circ}C) - (4.4^{\circ}C)}{2}$$

X^2 = Total solar radiation in cal cm^{-2}

X^3 = Mean daily air temperature range in°C

$\beta_0 = -247.89$, $\beta_1 = 0.6035$, $\beta_2 = 0.0088$, $\beta_3 = -8.06$

Obtained values of the potential yield calculated according toHartz and Moore [3] prediction model were compared with the actual data from the experimental fields.Correlation between the predicted and actual crop yield were calculated to test relationship between predicted and actual crop.

RESULTS AND DISCUSSION

Plant Length: Results of the step wise regression analysis for the relationship between tested climatic factors and plant height showed that minimum soil and air temperature, maximum and minimum relative humidity and solar radiation were the main climatic factors affecting the plant height during both studied seasons (Table 2). Moreover, statistical procedure (chick the significance to be predictor) reflected a significant relationship between plant length and maximum relative humidity.Prediction equation for the plant length (cm) was concluded from the statistical analysis and presented as follow:

Plant length = *2.85 + (0.21 * maximum relative humidity)*

In order to confirm the stability of the relationship between the studied character and selected climatic factors, effect of seasons were studied and statistically tested. No significant effect was found between both studied seasons, which may mean obtained relationship could not change from season to another. Therefore, maximum relative humidity showed a correlation with an adjusted R^2 of 0.5895 (Figure 1).

Number of Leaves: From data in Table (2) it's concluded that, minimum air temperature, maximum and minimum relative humidity, maximum soil temperature and solar radiation were the major climatic factors affected number of potato leaves.

Factors could be used to predict number of potato leaves was statistically selected from the major climatic factors affecting the studied characteristics. Both minimum air temperature and maximum soil temperature were presented. Moreover, both predictor climatic factors correlated with the number of leaves with an adjusted R^2 of 0.3333 and 0.6878, minimum air temperature and maximum soil temperature, respectively (Figure 2).

Prediction equation for number of leaves was concluded according to the statistical analysis and presented as follow:

*Number of leaves = 1.95 – (0.31 * minimum air temperature) + (0.24 * maximum soil temperature)*

In addition, significant effect regarding both seasons was found meanwhile, effect of climatic factors changed from year to another. In addition, the mentioned significance may be due to the interaction between the studied climatic factors and other invisible factors.

Plant Leaves Area: Stepwise regression results (Table 2) showed that the average relative humidity, maximum soil temperature and minimum air temperature were the most driving climatic factors for potato total leaves area throughout the two studied seasons. Moreover, the three determinate climatic factors could be considered as predictors for plant leaves area.Prediction equation was used to predict potato leaves area as follow:

*Leaves area = 30.9 – (0.62 * average relative humidity) + (0.76 * maximum soil temperature – 0.45 minimum air temperature)*

There was no significant effect regarding both seasons. All climatic factors selected as predictor were correlated with leaves area with adjusted R^2 of 0.3332for average relative humidity, 0.6008for maximum soil temperature and 0.6614for minimum air temperature (Figure 3).

Table 2: Summary of stepwise regression analysis results.

Character	Effective climatic factors	Predictor	R^2
Plant length	Minimum air and soil temperatures, maximum and minimum relative humidity, solar radiation	Maximum relative humidity	0.5895
leaves area	Average relative humidity,	Average relative humidity, maximum soil	0.3332
	maximum soil temperature,	temperature, minimum air temperature	0.6008
	minimum air temperature		0.6614
No.of leaves	Minimum air temperature, minimum and maximum relative humidity, maximum soil temperature, solar radiation	Minimum air temperature	0.3333
		Maximum soil temperature	0.6878
Canopy fresh weight	Minimum and average soil temperatures, maximum and minimum relative humidity, solar radiation, maximum air temperature	Minimum soil temperature	--
		Maximum relative humidity	--
		Average soil temperature	0.6761
Canopy dry weight	Minimum air temperature, minimum and maximum relative humidity, solar radiation, average soil temperature	Minimum air temperature	--
		Average soil temperature	0.6057

Table 3: Partial correlation coefficients between studied vegetative growths characters

	Plant length	No. of leaves	Leaves area	Canopy fresh weight	Canopy dry weight
Plant length	1.000	-0.4691	0.4785	0.7570	0.4864
	---	0.105	0.098	0.002	0.919
No. of leaves	-0.4691	1.000	0.5038	-0.1407	0.4577
	0.105	---	0.079	0.646	0.115
Leaves area	0.4785	0.5038	1.000	0.5914	0.8162
	0.098	0.079	---	0.033	0.0007
Canopy fresh weight	0.7570	-0.1407	0.5914	1.000	0.6265
	0.002	0.646	0.033	---	0.021
Canopy dry weight	0.4864	0.4577	0.8162	0.6265	1.000
	0.091	0.115	0.0007	0.021	---

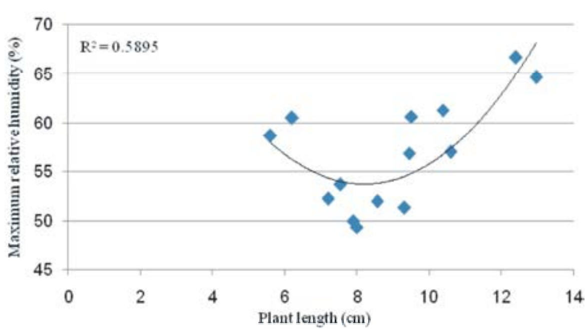

Fig. 1: Response of potato plant length (cm) to maximum relative humidity (%)

Canopy Fresh Weight: Regarding the climatic factors that affected the behavior of potato canopy fresh weight, the step wise regression showed, minimum soil temperature, maximum relative humidity, solar radiation, average soiltemperature minimum relative humidity and maximum air temperature were the major effective climatic factors (Table 2). Unfortunately, none of the studied climatic factors were statistically valid to be a predictor for the studied character. Potato canopy fresh weight recorded a high correlation with average soil temperature, minimum relative humidity and maximum air temperature with adj. R^2 of 0.6761, 0.7417 and 0.8368, respectively (Fig. 4).

Canopy Dry Weight: From all studied climatic factors, minimum air temperature, minimum and maximum relative humidity, solar radiation and average soil temperature were statistically selected to be effective factors on potato canopy dry weight. Moreover; minimum air temperature and average soil temperature were statistically valid to be predictors for the studied character. Both predictors statistically employed to present a prediction equation as follow: *Canopy dry weight = 6.21 – (0.6 * minimum air temperature) + (0.29 * average soil temperature)*

In addition, significant effect was found regarding both studied seasons which could mean effect of studied climatic factors changed from year to another. In addition, the mentioned significance may be because of the interaction between the studied climatic factors and other non studied factors.

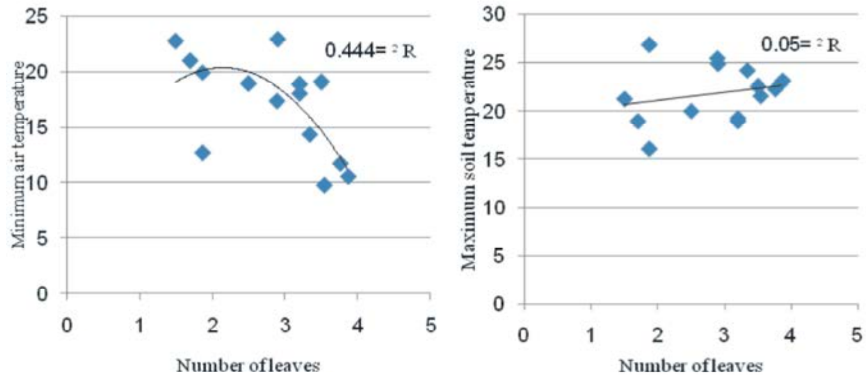

Fig. 2: Response of potato number of leaves to minimum air temperature and maximum soil temperature

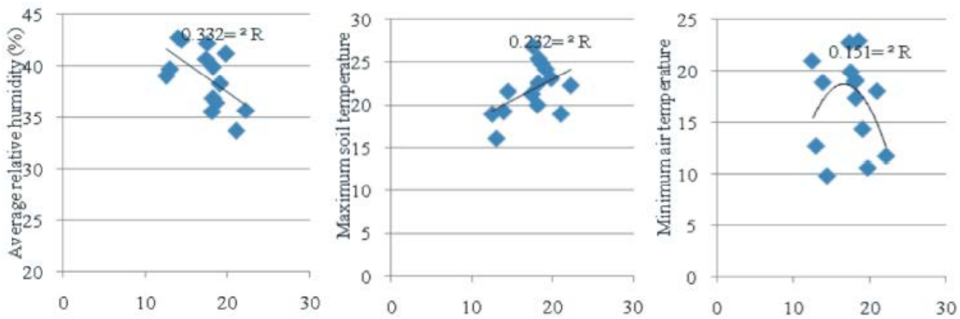

Fig. 3: Response of potato leaves area to average relative humidity, maximum soil temperature and minimum air temperature.

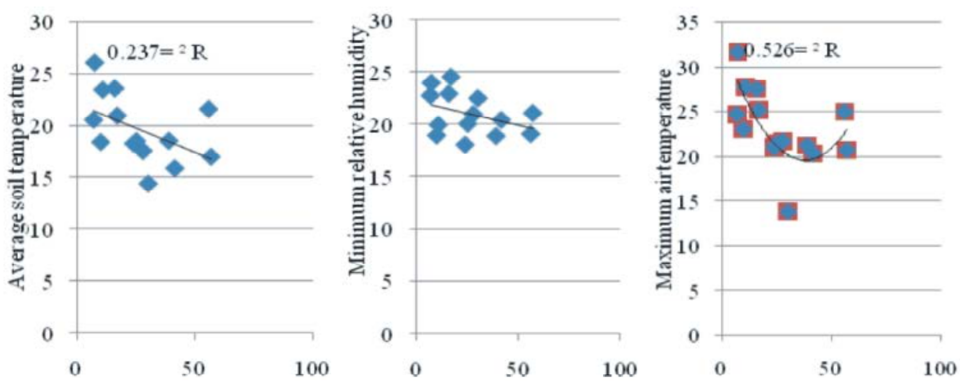

Fig. 4: Response of canopy fresh weight to average soil temperature (°C), minimum relative humidity (%) and maximum air temperature (°C).

Regarding to correlation between canopy dry weight and studied climatic factors, both average soil temperature and maximum relative humidity were the only climatic factors with high correlation between them and potato canopy dry weight with adj. R^2 of 0.6057 and 0.6738, respectively (Figure 5).

Interrelation among vegetative growth parameters: Partial correlation coefficients between all studied vegetative growths characters were tested to determinate strengthen of the relationship between studied characters and direction of the relationship (Table 3). It's concluded form data in Table (3) that a strong relationship between plant length and canopy fresh weight (0.76^{***}), which is mean it was enough to study one character from the two. Moreover, a good relationship between canopy fresh weight and number of leaves (0.59^{*}), canopy fresh weight and canopy dry weight (0.62^{*}). Finally, a strong relationship was found between canopy dry weight and number of leaves (0.81^{***}).

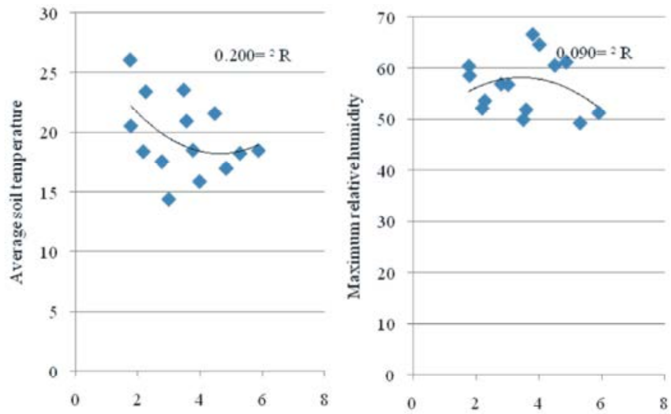

Fig. 5: Response of canopy dry weight to average soil temperature (°C), and maximum relative humidity (%).

Predicting Crop Yield: Potential yield of potato was estimated by polynomial model presented by Hartz and Moore [3]were to be 485.50 g/plant in the year 2010/2011 and 529.96 g/plant in the year 2011/2012.

However, actual yields harvested from the experimental fields were 502.61 g/plant in the year 2010/2011 and 548.41 in the year 2011/2012. High correlation was found between the predicted yield and actual harvested potato yield with adjusted R^2 = 0.785. The recorded correlation between actual and predict potato yield give a good prove that, Hartz and Moore [3] prediction model is valid and suitable simple prediction model under Egyptian conditions.

CONCLUSION

Its concluded from obtained results that vegetative growth parameters could be predict by specific climatic factors i.e. maximum relative humidity is a predictor for plant length, minimum air temperature and maximum soil temperature are predictor for number of leaves. Moreover, total leaves area could be predicted by average relative humidity, maximum soil temperature and minimum air temperature. concerning canopy dry weight, it could be predicted by minimum air temperature and average soil temperature. Finally potato crop yield could be predicted using Hartz and Moore, [3] prediction model which is mainly depend on revised growing degree days (RGDD), total solar radiation and daily air temperature range.

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