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MODELING NUTRIENTS UPTAKE AS A FUNCTION OF PLANT GROWTH RATE

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ABSTRACT

The present study was carried out at field scale to predicte the relative uptake of some nutrient elements as a function of relative growth rate(RGR). The test crop was Broad bean (Vicia faba, L.) variety Giza 461. The obtained results indicate that the dry matter production can be expressed as a Guissian model. The constants of the model represent the maximum dry matter production and the plant age at maximum dry matter production(R2 = 0.996**). The nutrients uptake (U) was regressed against the dry matter production (DM) .The three-order polynomial equation was found to be the best fitting equation. The relationship between relative growth rate (RGR) and relative accumulation rate(RAR) was fitted for each nutrient as a linear regression model. The model discussed here provides a means for predicting uptake rate if growth rate are known or can be predicted. Further studies must be done to explain the factors that have a significant effect on the slope of RGR-RAR relationship such as plant age, environmental factors, the response of different plant parts to nutrient uptake and the nutrient availability and mobility in soil system as related to soil properties.

INTRODUCTION

The relationship between plant growth rate and nutrient uptake rate has been tested in many studies (Baldwin *et al.*, 1973; Nye *et al.*, 1975; Raper *et al.*, 1977a, 1977b; Ingestad and Lund, 1979; Ingestad, 1982, 1987 and Ingestad and Agren, 1988). The relative accumulation rate (RAR) for the nutrient uptake is equal to the relative growth rate (RGR) of the plant; thus, the RAR becomes a linear function of RGR, with slope 1.0 and intercept 0.0 under steady-state conditions as defined by Ingestad (1987) and Ingestad and Agren (1988). The steady state for a particular element is a case of the internal concentration of that nutrient is unchanging with time. This condition is not true under field conditions, where the element is in limited supply and that this must hold independent of species or climatic variable.

As stated by Willits and Peet (1989), two conditions must be met for RAR to equal RGR : 1) the relative proportions of any plant parts (e.g., leaves, stems, roots, flower)differing in nutrient composition must remain the same throughout the period of interest, and 2) the nutrient composition of the different plant parts must remain constant over time .

In the present paper, we used modeling for predicting the relative uptake rate of some nutrient elements as a function of the plant RGR of Broad bean .

MATERIALS AND METHODS

A field experiment was conducted in the Experimental Station Farm at Abis, Faculty of Agriculture (Saba Bacha), Alex. during the 97/1998 growing season of Broad bean. The texture of the experimental soil is clayey. Some of its physical and chemical properties determined for collected samples (Carter, 1993) are presented in Table (1).

Broad bean (*Vicia faba*, L.) seeds, variety Giza 461 were used in this study. Planting took place at November 9, 1997 and harvesting was done at April 11, 1998. The experimental plot consisted of 5 rows, 5 m long and 0.60 m wide making an area of 15.0 m^2. Seeds were planted at 0.25 m apart within the row. The experiment contained 5 replicates, each replicate represented by 5 plots.

Potassium fertilization was applied at 60 kg K_2O/fed. in the form of potassium sulfate (48% K_2O) at two doses, the first dose was applied with the first irrigation and the second dose at one month later. Calcium super-phosphate (15.5% P_2O_5) was applied at rate of 45 kg P_2O_5 /fed before planting. Nitrogen fertilization as ammonium nitrate (33.5% N) at rate of 120 kg N/fed was divided into two equal doses, the first dose was applied with the first irrigation and the second dose was one month later.

During the growth period, plant samples were taken from each plot as 15 plants per sample at time intervals, 7-10 days. Each sample divided into two portions, the first portion was washed with tap water, distilled water, air-dried and oven dried at 65°C for 72 hrs, then ground in a stainless steel mill and the powder stored for elemental analysis. The second portion of leaf sample (fresh sample) was used to determine the dry weight.

The ground material (plant powder) was digested with conc. sulfuric acid + 30% hydrogen peroxide according to the method described by Evenhuis and DeWaard (1980). In the digest, total nitrogen was determined colorimetrically according to Evenhuis (1976). Total phosphorus was determined colorimetrically according to the method of Murphy and Riley (1962). Total potassium was determined photometrically according to Jackson (1973). Total calcium and magnesium were determined by an Atomic Absorption Spectrophotometer according to Carter (1993).

At the end of the experiment (153 days), disturbed soil samples to a depth of 30-cm were collected for chemical analysis. Soil samples were mixed thoroughly and sieved through a 2-mm mesh screen and air-dried prior to soil chemical analysis. Soil available nutrients: N, P and K were extracted using a 0.5 M $NaHCO_3^-$ extraction method (Schoenau and Karamanos, 1993) then, N and P were determined spectrophotometrically (Carter, 1993) and K was determined photometrically according to Jackson (1973).

The collected data were tabulated and subjected to statistical analysis according to Steel and Torrie (1982). Correlation coefficients and linear regressions were done using the method described in Draper and Smith (1981) and Curve Expert version 1.37 (Hyams, 2001).

Table (1). Some physical and chemical characteristics of the experimental soil used in the present study

Parameters	Soil depth , cm		
	0 – 30	30 - 60	60 - 90
Particle –size distribution , %			
Sand	29.1	26.0	25.2
Silt	27.1	30.0	28.1
Clay	43.8	44.0	46.7
Texture class	Clay	Clay	Clay
Organic matter content , %	1.70	1.78	1.81
$CaCO_3$, %	8.53	9.22	9.11
pH (1: 1 water suspension)	8.45	8.48	8.40
al conductivity (1: 1 water extract) , dS /m)	3.22	3.12	3.18
Soluble Cations , meq/L			
Ca^{2+}	0.79	0.77	0.76
Mg^{2+}	0.64	0.67	0.71
Na^{+}	1.70	1.56	1.58
K^{+}	0.06	0.09	0.09
Soluble Anions , meq/ meq/L			
$CO_3^{=} + HCO_3^{-}$	0.75	0.79	0.74
Cl^{-}	1.98	1.76	1.91
$SO_4^{=}$	0.46	0.53	0.50
Available soil nutrients , mg/Kg			
N	256	279	272
P	15.1	16.3	14.0
K	411	403	416
Fe	3.5	3.4	3.2
Mn	2.6	2.5	2.3
Cu	1.0	1.1	0.9
Zn	1.3	1.4	1.2

Data analysis:

The plant growth with time often obeys a first –order differential equation (Williams, 1948 and Radford, 1967):

$$\frac{\partial D M}{\partial t} = k * D M \quad (1)$$

where k is the plant growth rate. Integration of Eq. (1) yields

$$LnDM_t = LnDM_0 + K(t - t_0) \quad (2)$$

where DM_0 is the initial DM at t_0. Solving Eq. (2) for DM_t yields

$$DM_t = DM_0 e^{k(t-t_0)} \quad (3)$$

From Eq. (2) we can derive the expression for plant growth rate :

$$k = \frac{LnDM_t - LnDM_0}{t - t_0} \quad (4)$$

Mean relative growth rate (RGR) for plant was calculated for each interval for each element as described by (Hunt, 1982):

$$RGR_i = (LnW_{i+1} - LnW_i) / N \quad (5)$$

where i is the interval number, W is dry weight (g), and N is the length of the interval (days).

Weekly relative accumulation rate (RAR) of each plant for any element was calculated as :

$$RAR_{j,i} = (Ln(C_{j,i+1} * W_{i+1}) - Ln(C_{j,i} * W_i)) / N \quad (6)$$

where j represents the element and C is the concentration of that element (g/g).

For each element, the linear model between RGR and RAR was performed as :

$$RAR = a + b * RGR \quad (7)$$

RESULTS AND DISCUSSION

Dry matter production:

Dry matter (DM), growth rate (GR) and relative growth rate (RGR) for Broad bean are presented in Table (2).

The data showed an increase in dry matter production of Broad bean during the growth period, but it showed a decrease effect at the late of growth period.

Dry matter production can be expressed as Gaussian model, Curve Expert Version 1.37 (Hyams, 2001). The mathematical form is:

$$DM(t) = A * e^{\frac{-(t-B)}{2C^2}} \quad (8)$$

where DM (t) is the dry matter production at time (t) ,
e is a natural logarithm and
A, B and C are constants.

The physical meaning of these constants can be expressed as the constant (A) represents the maximum dry matter production, while the constant (B) represents the plant age at maximum dry matter production and C is empirical constant.

This model has highest determination coefficient (R^2 = 0.996**). The values of constants A, B and C are : A= 53.11 , B= 134.57 and C= 26.37. The regression line related the dry matter production against time is shown in Fig. (1).

The growth rate (GR) was calculated according the following equation:

$$GR = \frac{\partial DM}{\partial t} \quad (9)$$

Table (2). Dray matter, growth rate and relative growth rate of Broad bean

Growth Period days	Dry matter (DM) g/plant	Growth rate (GR) g/day	Relative growth rate (RGR)
15	0.286	0.019	
22	0.446	0.020	0.063
30	0.668	0.022	0.050
37	1.086	0.029	0.069
46	1.555	0.034	0.040
56	2.131	0.038	0.032
64	2.861	0.045	0.037
71	4.864	0.069	0.076
79	6.960	0.088	0.045
89	12.396	0.139	0.058
97	18.320	0.189	0.049
105	25.596	0.244	0.042
114	39.484	0.346	0.030
124	51.506	0.415	0.031
133	52.460	0.394	0.030
143	49.742	0.348	-0.018
153	41.730	0.273	-0.018

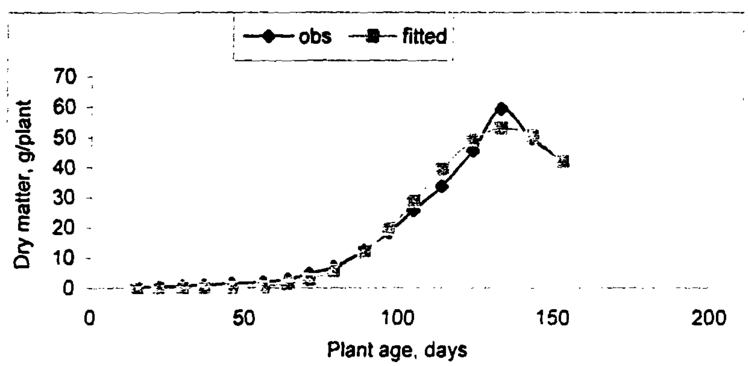

Fig. (1). Observed and fitted values of dry matter production as function of plant age

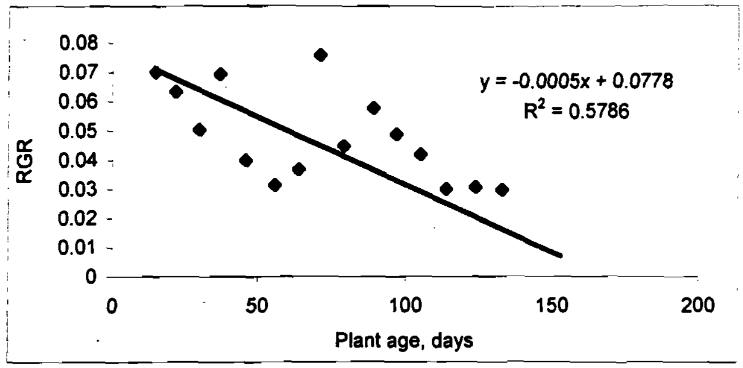

Fig. (2). Relative growth rate(RGR) of Broad bean as related to age.

The values of GR increases with time , but decreases at late of growth period (Table, 2). The present data is fitted to the Gaussian model and the constants are: A= 0.39, B=129.55 and C=28.53 ($R^2 = 0.982^{**}$).

The relative growth rate (RGR) calculated according the Eq. (5) is presented in Table (2). Also the data were fitted to linear model (Fig. 2). The data indicate that RGR tends to decline with increasing the plant age. This is true because the plant at initial stage has a highest growth rate which decreases at the maturity.

Nutrient uptake:

Nutrients content of Broad bean shoot is presented in Table (3) The nutrients uptake is calculated according to the following equation (Table, 4):

$$U = DM * C \qquad (10)$$

where U is the nutrient uptake (mg/plant),
DM is the dry matter (g/plant) and,
C is the nutrient content (mg/g)

The nutrients uptake (U) was regressed against the dry matter production (DM) .The three-order polynomial equation was found to be the best fitting equation. The polynomial coefficients are tabulated in Table (5).

The uptake rate (UR) was calculated with the following equation:

$$UR = \frac{\partial U}{dt} \qquad (11)$$

The nutrient uptake (U) and nutrient uptake rate (UR) were fitted to the Gaussian model and the equation constants are presented in Tables (6 and 7).

The relative accumulation rate (RAR) was calculated with eq. (6) and the data are presented in Table (8). The relationship between RGR and RAR was fitted for each nutrient as a linear regression (eq. 7) and presented in Table (9) and Fig. (3).

As reported by Ingested and Agren (1988), the relative accumulation rate (RAR) of such nutrient is equal to the relative growth rate (RGR). The present data does not support this concept in which the slope value of the linear model in our experiment is > 1.0, but it close to 1.0. This deviation may be attributed to the variations in soil chemical and physical properties at field scale or changes in plant response to nutrient uptake during the growth period, which it is not behave the steady state as required for the concept of Ingestad and Agren (1988).

Slopes < 1.0 suggest that the rate of dry matter production per unit nutrient uptake is not constant with growth rate and would imply that tissue production for these elements is not equally efficient at all rates of growth or ages.

The model discussed here provides a means for predicting uptake rate if growth rate are known or can be predicted. Further studies must be done to explain the factors that have a significant effect on the slope of RGR-RAR relation such as plant age, environmental factors, the response of different plant parts to nutrient uptake and the nutrient availability and mobility in soil system as related to soil properties.

Table (3). Nutrient contents of Broad bean shoot system

Growth Period, days	Macronutrients content, %				
	N	P	K	Ca	Mg
15	2.78	0.25	2.45	0.83	0.64
22	3.11	0.28	2.51	0.93	0.72
30	3.43	0.32	2.64	1.09	0.81
37	3.72	0.38	2.71	1.22	0.87
46	3.85	0.43	2.84	1.29	0.91
56	3.75	0.49	2.85	1.34	0.87
64	3.68	0.53	2.90	1.39	0.82
71	3.65	0.56	3.00	1.42	0.76
79	3.56	0.52	3.12	1.47	0.73
89	3.42	0.45	2.95	1.50	0.64
97	3.25	0.37	2.87	1.52	0.58
105	3.19	0.34	2.79	1.45	0.55
114	3.09	0.32	2.67	1.35	0.52
124	2.95	0.31	2.45	1.24	0.52
133	2.87	0.29	2.24	1.16	0.50
143	2.60	0.27	2.18	1.10	0.47
153	2.39	0.24	2.10	1.07	0.43

Table (4). Nutrient uptake of Broad bean

Growth Period days	Macronutrients uptake, mg/plant				
	N	P	K	Ca	Mg
15	7.95	0.72	7.01	2.37	1.83
22	13.87	1.25	11.19	4.15	3.21
30	22.91	2.14	17.64	7.28	5.41
37	40.41	4.13	29.44	13.25	9.45
46	59.86	6.69	44.16	20.06	14.15
56	79.91	10.44	60.73	28.55	18.54
64	105.28	15.16	82.97	39.77	23.46
71	177.54	27.24	145.92	69.07	36.97
79	247.78	36.19	217.15	102.31	50.81
89	423.94	55.78	365.68	185.94	79.33
97	595.40	67.78	525.78	278.46	106.26
105	816.51	87.03	714.13	371.14	140.78
114	1036.76	107.37	895.84	452.95	174.47
124	1344.43	141.28	1116.56	565.12	236.98
133	1709.12	172.70	1333.95	690.79	297.76
143	1293.29	134.30	1084.38	547.16	233.79
153	997.35	100.15	876.33	446.51	179.44

Table (5). Coefficients of polynomial equations relating total uptake of nutrient elements against dry matter production of Broad bean

Nutrient element	Polynomial coefficients				R^2
	a	b	c	d	
N	-13.8425	45.3422	-0.7610	0.0081	0.991**
P	-1.07430	5.8852	-0.1288	0.0013	0.988**
K	-14.8319	38.1817	-0.5326	0.0045	0.994**
Ca	-12.1501	20.6082	-0.3224	0.0029	0.993**
Mg	0.9954	7.8767	-0.1345	0.0014	0.994**

** Significant at 0.01 probability level

Table (6). Constant of Gaussiam model for fitting the nutrients uptake against growth period of Broad bean.

Nutrient element	A	B	C	R^2
N	1468.52	132.07	26.13	0.978**
P	146.48	131.71	29.21	0.972**
K	1198.36	132.49	27.81	0.990**
Ca	612.98	132.28	27.61	0.989**
Mg	254.37	133.07	27.67	0.973**

** Significant at 0.01 probability level.

Table (7) Constant of Gaussiam model for fitting the nutrients uptake rate against growth period of Broad bean.

Nutrient element	A	B	C	R^2
N	10.84	127.17	30.25	0.956**
P	1.08	125.65	35.16	0.955**
K	8.98	126.78	31.03	0.978**
Ca	4.63	126.52	30.29	0.980**
Mg	1.83	128.37	34.49	0.937**

** Significant at 0.01 probability level.

Table (8). Relative accumulation rates of Broad bean for different nutrient elements.

Growth Period days	RAR				
	N	P	K	Ca	Mg
15					
22	0.079	0.080	0.067	0.080	0.080
30	0.063	0.067	0.057	0.070	0.065
37	0.081	0.094	0.073	0.086	0.080
46	0.044	0.054	0.045	0.046	0.045
56	0.029	0.045	0.032	0.035	0.027
64	0.034	0.047	0.039	0.041	0.029
71	0.075	0.084	0.081	0.079	0.065
79	0.042	0.036	0.050	0.049	0.040
89	0.054	0.043	0.052	0.060	0.045
97	0.042	0.024	0.045	0.050	0.037
105	0.039	0.031	0.038	0.036	0.035
114	0.027	0.023	0.025	0.022	0.024
124	0.026	0.027	0.022	0.022	0.031
133	0.027	0.022	0.020	0.022	0.025
143	-0.028	-0.025	-0.021	-0.023	-0.024
153	-0.026	-0.029	-0.021	-0.020	-0.026

Table (9) . The linear regression between RGR and RAR of Broad bean.

Nutrient element	a	b	R^2
N	-0.0074	1.1799	0.965**
P	-0.0077	1.2105	0.857**
K	-0.0041	1.0873	0.973**
Ca	-0.0048	1.1903	0.947**
Mg	-0.0064	1.1037	0.913**

** Significant at 0.01 probability level.

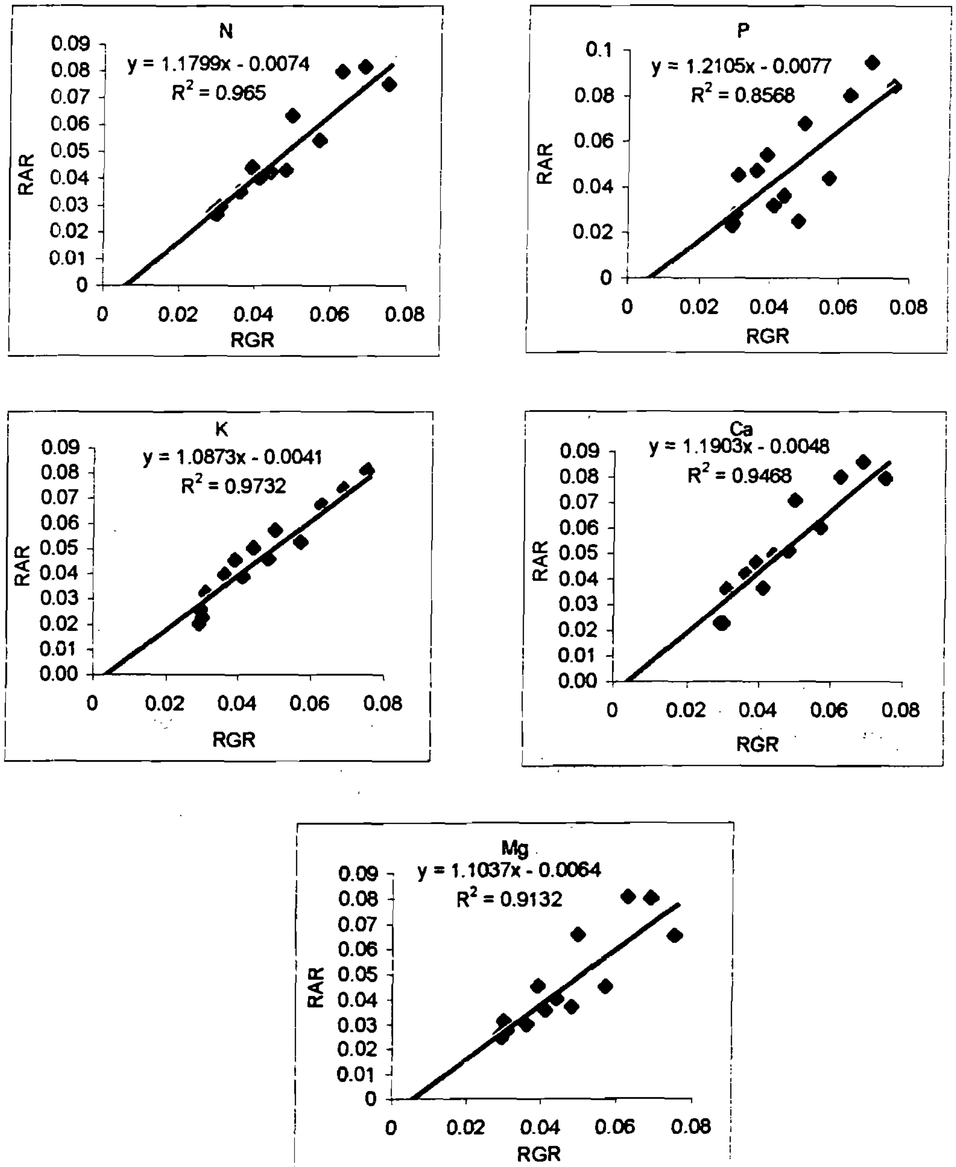

Fig. (3). Relative accumulation rate (RAR) as related to relative growth rate (RGR) of Broad bean for each nutrient element

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نمذجة امتصاص العناصر الغذائية كدالة لمعدل النمو

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قسم الأراضي والكيمياء الزراعية - كلية الزراعة (سابا باشا)- جامعة الإسكندرية

أجريت الدراسة الحالية للتنبؤ بامتصاص بعض العناصر الغذائية كدالة لمعدل النمو النسبي للفول البلدي صنف جيزة ٤٦١. وتشير النتائج إلى أن إنتاج المادة الجافة يمكن التعبير عنه بمعادلة جاوس وثوابت المعادلة تمثل أقصى إنتاج للمادة الجافة وكذلك عمر النبات عند أقصى إنتاج للمادة الجافة (معامل التقدير = ٩٩٦و.) . امتصاص العناصر تم التعبير عنه بمعادلة متعددة الحدود من الدرجة الثانية اعتمادا على إنتاج المادة الحافة . والعلاقة بين النمو النسبي ومعدل تراكم العناصر تم التعبير عنها بمعادلة ارتداد خطي لكل عنصر على حدة والنموذج الذي تمت مناقشته في هذه الدراسة يعطينا وسيلة فعالة للتنبؤ بمعدل امتصاص العناصر الغذائية إذا كان معدل النمو معروف لدينا أو يمكن التنبؤ به. ولابد من إجراء دراسات مستقبلية لتوضيح العوامل التي لها تأثير معنوي على ميل المعادلة الخطية التي تعطى العلاقة بين معدل النمو النسبي ومعدل الامتصاص النسبي مثل عمر النبات و العوامل البيئية و استجابة أجزاء النبات المختلفة لامتصاص العناصر وصلاحية العنصر الغذائي وحركته في نظام التربة وعلاقته بخواص التربة .