ΕΔΑΦΟΛΟΓΙΑ.— **Modelling potassium uptake by wheat toots from field soils,** *By I. K. Mitsios - A. D. Simonis**, διὰ τοῦ 'Ακαδημαϊκοῦ κ. 'Ιωάννη Παπαδάκη.

A B S T R A C T

A mathematical model is derived to make possible the calculation of the uptake of potassium by a wheat crop in the field.

This model id based on the potassium supply characteristics of the soil using measurements with onion roots and the Heming and Rowell model and is applied to field situations for known root densities. A computer programme is written for solution of the mathematical model. The computer programme calculates potassium uptake by the growing wheat root system at time intervals for (two British and two Greek clay-rich soil) Abbots Ripton soil, Boxworth soil, a vertisol and an Endisol. The four soils supply potassium from the 0-10 cm layer in amounts adequate for the wheat crop.

I N T R O D U C T I O N

The relative contributions of exchangeable and non-exchangeable K to potassium uptake by onion roots at varying roots densities in two British and two Greek clay rich soils have been established by Mitsios and Rowell (1987 a,b). The Heming and Rowell model (1987 a) allows calculations of release and uptake of exhangeable K from soil near the root in the presence of exchangeable K moving from further away. It can be adjusted to give values for longer times than those used in the single onion root experiments and for different moisture conditions similar in some cases to field situations (Mitsios and Rowell 1987 a,b). However an understanding of root growth and activity in the field is necessary before a comprehensive study of potassium uptake is possible. Gregory (1976) in a field experimentation with winter wheat showed the importance of field studies in understanding root growth and activity. He showed how root growth may be changed by soil conditions.

It is generally accepted that potassium uptake by crops depents on (i) morfology and rate of growth of the root system (ii) the potassium absorption characteristics of the root system, and (iii) the potassium supplying characteristics of the soil. There is therefore a need to have a mathematical model based on fundamental principles that organize the mechanismus involved in the process of ion uptake by plant roots growing in the field.

A computer model was written by Claassen and Barber (1976) based on the Nye and Marriott (1976) theory for flux by mass flow and diffusion of nutrients to the root.

---

* Ι. Κ. ΜΗΤΣΙΟΣ - Α. Δ. ΣΙΜΩΝΗΣ, **Μοντέλο πρόσληψης τοῦ καλίου τοῦ ἐδάφους μὲ τὶς ρίζες σιταριοῦ.**

TABLE 1

Properties of the soils

	Abbots Ripton	Boxworth	Vertisol	Entisol
Chemical analysis				
PH	7.45	7.50	6.70	7.60
$CaCO_3$ (%)	0.80	1.08	0.08	4.10
Organic carbon (%)	1.70	1.30	0.89	1.37
C.E.C. (meq kg^{-1})	242.0	307.0	282.0	349.0
Phosphorus:				
resin extraction ($mgkg^{-1}$)	50.0	36.0	33.0	6.0
Magnesium ADAS method ($\mu molg^{-1}$)	>250	192	>250	128
Pottasium:				
i. ADAS method ($\mu molg^{-1}$)	7.80	6.11	4.65	11.25
ii. NH_40AC leaching μmol^{-1})	8.30	6.30	4.13	11.90
Particles size analysis (%)				
Clay (<2 μm)	43	45	39	74
Silt (2-50 μm)	30	26	50	24
Fine sand (50-200 μm)	13	16	10.2	1.4
Coarse sand (>200 μm)	14	13	0.8	0.6
Mineralogy of <2 μm fraction				
Dominant minerals	K	SM-M, K	M, SM*	K, V-ch, M
Secondary minerals	SM, M, CH	M, Q	K	-
Trace minerals	Q	ped ch	Q, Fd	Q

KEY: K= Kaolinite, SM= smectite, M= mica, SM-M= interstratifield-mica, V-ch= interstratifield vermiculite-chlorite, ped ch= pedological chlorite, SM*= smectite with some hydroxy interlayers, Q= quartz, Fd= feldspar

TABLE 2

The soil properties and fitted parameters of the Heming and Rowell model (1985a)

	Abbots Ripton	Boxworth	Vertisol	Entiso
Θ, Volumetric soil water content, cm3cm-3 (saturated)	0.48	0.49	0.48	0.48
fl, impendance factor for saturated soil	0.34	0.43	0.43	0.43
Θ, volumetric soil water content, cm3cm-3 (mid-way between field capacity and wilting point)	0.28	0.29	0.28	0.28
fl, impendance factor, (soil water content mid-way between field capacity and wilting point)	0.146	0.18	0.185	0.18
K concentration before cropping (μM)	285	113	134	175
Kex (isotherm) $\mu molg^{-1}$)	4.8	2.7	3.2	5.7
Buffer capacity ($\mu molg^{-1}$ μM^{-1})	0.016	0.024	0.024	0.032
Buffer power, b' (dimensionless)	14.39	20.02	24.1	35.08
Calculated D values before cropping (10^{-7} cm^2 s^{-1})	2.22	2.06	1.68	1.15
Surface K ($\mu molg^{-1}$, resin suspension)	5.4	3.5	3.5	7.7
Release rate, $\mathcal{K}$ (10^{-3} $\mu molg^{-1}$ $s^{-1/2}$ resin suspension)	4.1	3.8	4.02	4.35
Fitted release rate $\mathcal{K}$ Heming and Rowell model (10^{-3} $\mu molg^{-1}$ $s^{-1/2}$)	5	4.2	5	7
Critical release concentration (K)c ($\mu molg^{-1}$)	1.4	0.8	0.9	1.7
(μM)	85	33	37	53

However, they assumed that potassium uptake parameters remain constant during the growth period inaninfinite volume of soil. Also a mathematical model was derived by Nye (1979) for the uptake of nutrients by root system growing in uniformly mixed soil assuming average values for absorption and steady state conditions.

In this paper the supply of exchangeable and non-exchangeable potassium to wheat crop in the field is examined. Further aim of the paper is to be used as basis for future thought and development.

SOIL CHARACTERISTICS

Four arable soils have been used. Two were Chalky Boulder Clays of the Hanslope series. The first, taken from the Abbots Ripton Experimental Husbandry Farm, Cambridgeshire, has a history of non-fertilization and adequate natural potassium supply. The second was a subsoil from Boxworth Experimental Husbandry Farm. It has less exhangeable K than the previous one but a similar texture. The other two were Greek clay soils. The first was a Vertisol on alluvium parent material and the second an Entisol on dolomitic parent material. This soil had the highest exchangeable K. Table 1 gives the soil properties. Air dry soil (<2mm) was crushed gently to pass through a 0.5 mm sieve and was uniformly moistened to about 25% and stored aerobically for 3 months before use. The onion root experiments as well as soil and plant analysis were done in the same way as those described by Mitsios and Rowell (1987 a). Potassium uptake data for the four soils was presented by Mitsios and Rpwell (1987 a,b). The potassium concentration in solutions before cropping were 285, 113, 134 and 175 μM for Abbots Ripton, Boxworth, Vertisol and Entisol respectively. The exchangeable K (Kex) measured by the extrapolation of the straight line part of the desorption isotherm differs significantly and it is between 2.7 and 5.7 $\mu molg^{-1}$ (Table 2).

DIFFUSION OF EXCHANGEABLE K AND RELEASE OF NON-EXCHANGEABLE K: HEMING AND ROWELL MODEL

The soil parameters that are involved in the Heming and Rowell model (1985a) are as follows:

$\mathcal{K}$= release rate, derived from a straight line fitted to the second stage of the release to Ca-resin by soil suspension over nine days (accumulative release v$\sqrt{T}$),

Kex = exchangeable K measured by the exctrapolation of the straight line part pf the desorption isotherm,

Knex = non-exchangeable K which is both slowly release K, and desorbed K represented by the lower curved part of the isotherm,

(K) c= critical value of Kex in any cylindrical shell around the root below which the slow release of Knex occurs,

D = diffusion coefficient for exchangeable K.

The model was fitted to the plant uptake data (Mitsios and Rowell 1987 a,b) to give the best fit values (Table 2) as follows. Kex is the best estimate of the total amount of exchangeable K (μmolg^{-1}) giving diffusion coefficients (D) that fit well to those calculated using the Nye and Tinker equation (1977) from the (adjusted) buffer power. The lower buffer capacity and tortuosity factor (fl) of Abbots Ripton soil is propably the results of the kaolinite dominated clay fraction.

For all soils the fitted slow release rate,($\mathcal{K}$), is higher than the values measured by Ca-resin (between 10% and 61% higher). The fitted (K)c values are between 0.8 and 1.7 μmolg^{-1}. However, if the above values of (K)c are re-expressed in μM the potassium concentration at which release of Knex occurs varies significantly and it is between 33 and 85μM (Table 2). Critical release concentration depents on the type of clay. Rate of release is not directly related to the critical concentration presumably because the rate depents on the amount of K-bearing minerals in the soil as well as the type. Information on clay mineralogy is insufficient. And therefore it can not aid the interpretation of these relationships, although the Entisol with the highest clay percentage does have the highest release rate, and the Abbots Ripton soil with highest critical conentration has the lowest content of smectite and micaceous clays.

A MODEL OF UPTAKE BY DEVELOPING ROOT SYSTEM. THE THEORY

The rate of potassium uptake from unit volume of soil will be influenced by the distribution of roots within it and by the time each root has been exploiting it (Nye and Tinker, 1979 p. 219). Thus, it is difficult to take into account the variation in uptake performance along and between individual roots. The model makes the following assumptions:

–Each root may be assigned a concentric zone of expoitation. In practice the zone expoited by a root will be of irregular shape, but may be approximated by an equivalent cylindrical volume.

–The major part of the uptake of potassium occurs in the upper 20cm of soil. Root density is high in the upper 20 cm of soil layer and the depletion zones of individual roots soon overlap. As new roots appear they increase the root density and have to grow into soil that has already been depleted (see diagram I).

For the new roots the uptake of potassium is assumed to occur as though they had been in the soil from time zero. Uniform depletion between roots is therefore assumed and the uptake rate per unit length is approximately the same as the uptake rate per unit lenght of the old roots. This assumption was necessary because we have no data or calculations available with respect to the amount of potassium taken up by new roots

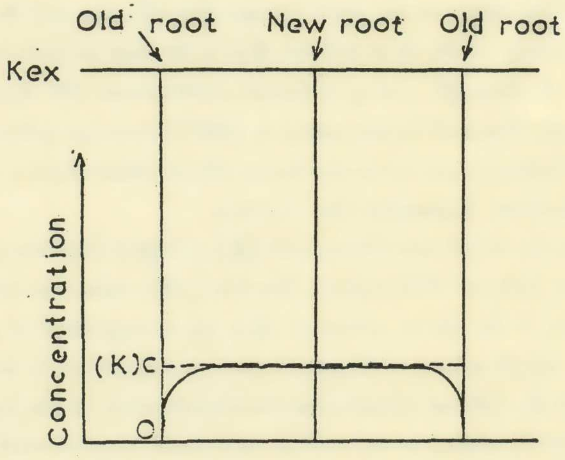


Diagram I

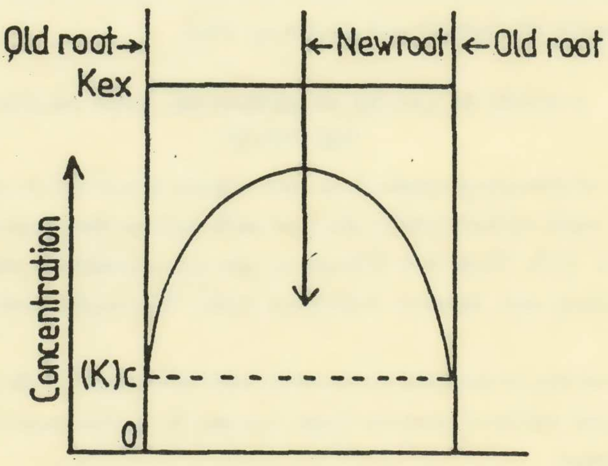


Diagram II

growing into partially depleted soil (diagram II), although the Heming and Rowell model (1985 a) may be developed to give such predictions.

The main assumption must underestimate the supply of potassium to the new roots, since although Kex is soon depleted throughout the soil volume, Knex will only be affected close to the older roots. Thus in a refined model it should be possible to start these new roots from a new zero time with a rate of uptake of Knex dependent on the time. Modelling the uptake by roots deeper in the soil profile is possible with the assumption that no overlap of depletion zones occurs. For each time step a new set of roots would begin to feed with a new zero time. However, because the root length is relatively small, the uptake from deeper layers has not been calculated. This omission needs to be examined because it may be that the rapid uptake of exchangeable potassium per unit lenght by these few roots is significant in comparison to the slower uptake of (predominantly) Knex per unit length by the roots in the upper layer.

DEVELOPMENT OF THE MODEL

The root density (Lv), expressed in cm root / cm3 of soil, has been measured (Fig. 1) in the field (Gregory, 1976) at different times (days) ti (t1, t2...........tn). Let.the root density be Lvi (ti) at time ti. As potassium uptake depents on root density, i.e. K=f (Lv) potassium uptake may be written as follows:

$$K(tn)=f1[Lv1(t2\text{-}t1)]+f2[Lv2(t3\text{-}t2)....fn\text{-}1(Lvn\text{-}1(tn\text{-}tn\text{-}1)] \qquad [1]$$

In this equation it is assumed that the new roots behave like the old ones, as well as that all roots take up potassium at the same rate over the same time interval.

The uptake of potassium in relation to the root density has been evaluated for dry soil conditions (Θ is volumetric soil water content, $cm^3.cm^{-3}$, approximately mid-way between field capacity and wilting point) see Table3 and Fig. 2 and 3, using the following equation:

$$K=AL^2v+BLv+C_{Lv} \qquad [2]$$

where K is potassium uptake, μmolg-1 for 1cm root for a specified time period

Lv is the root density, cm root / cm3 of soil

A, B and C_{Lv} are constants shown in Table 3 for each curve.

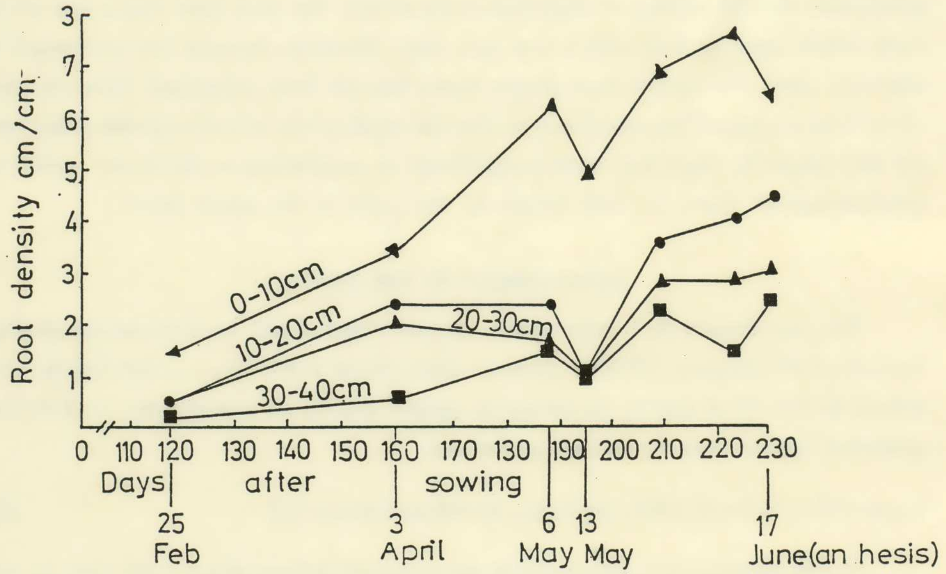
Assung that the root density increases linearly, the mean root density between times t1 anß t2 may be gives as follows:

$$Lvi = ati + C \qquad [3]$$

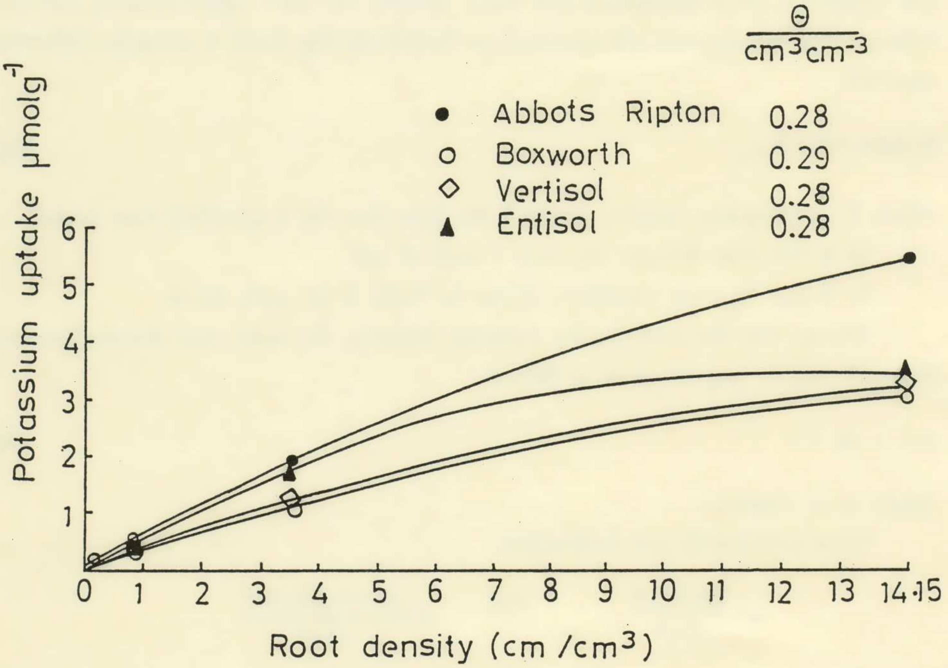
where as is constant

Thus Lv1=at1+C and Lv2=at2+C

$$a=\frac{LV2\text{-}Lv1}{t2\text{-}t1} \qquad \text{and} \qquad C=\frac{Lv1+t2\text{-}Lv2t1}{t2\text{-}t1}$$



1. Distribution of root density (cm$_8$cm3) with depth at intervals, during the growth season (after Gregory 1976).



2. Potassium uptake during zero to 10 days growth period under dry conditions (Θ, volumetric soil water content, cm3cm-3, mid-way between field capacity and wilting point).

The mean value of root density, $\bar{L}v$, between t1 and t2 can be given as follows:

$$\bar{L}v = \frac{Lv1+Lv2}{2} = \frac{(at1+C)+(at2+C)}{2} \quad \text{therefore,}$$

$$\bar{L}v = \frac{a(t2-t1)+C}{2} \qquad [4]$$

TABLE 3

Regression analysis data for four clay soils under dry conditions Potassium uptake μmolg-1 as a function of root density (Lv cm/cm3)

Soils	Period of uptake (days)	Potassium uptake equation	r
Abbots	0-10	$K= 0.0633+0.552Lv-0.012L^2v$	0.999**
Ripton	0-16	$K= 0.102+0.77Lv-0.0185L^2v$	0.998**
Boxworth	0-10	$K= 0.0205+0.337Lv-0.0841L^2v$	1**
	0-16	$K= 0.0437+0.458Lv-0.0117L^2v$	0.999**
Vertisol	0-10	$K= 0.0166+0.372Lv-0.0102L^2v$	1**
	0-16	$K= 0.0213+0.523Lv-0.01555L^2v$	1**
Entisol	0-10	$K=-0.017+0.615Lv-0.0263L^2v$	1**
	0-16	$K=-0.0204+0.862Lv-0.0374L^2v$	1**

Regression analysis must be used to derive equations for intervals up to 112 days of uptake (Table 4). If the equation of the curve fits for the n days period then the potassium uptake per day must be K/n (Snedecor and Cochran, 1980) or:

$$K/n=A/nL^2v+B/nLv+C\ /\ n \qquad [5]$$

where A, B and C are constants shown in Table 4 for each curve

or $$K'=A'L^2v+B'Lv+C' \qquad [6]$$

so, for a period t1 to t2 the cumulative amount of potassium is given as follows:

$$K_{total} = \int_{t1}^{t2} (A'L^2v+B'Lv+C')dt \qquad [7]$$

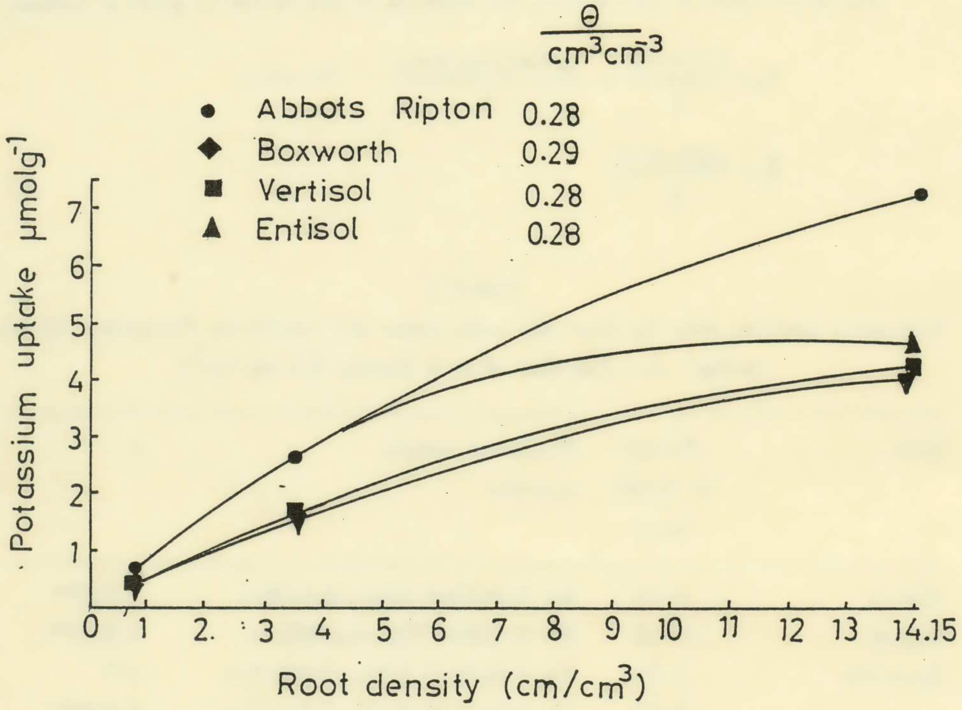


Fig. 3. Potassium uptake during zero to 16 days growth period under, dry conditions (Θ, volumetric soil water content cm3cm-3, mid-way between field capacity and wilting point).

Substituting [4] into [7] and solving the differential equation we get the analytical solution.

$$K_{total} = \frac{A'a^2}{3}(t2-t3)^3+(A'aC+B'a/4)(t2-t1)^2+(2A'C^2+B'C)(t2-t1). \quad [8]$$

A computer programme was written in BASIC. The computer programme calculates potassium uptake at time intervals, based on uptake data from onion roots measurements (Mitsios and Rowell, Part 1 and part II 1987) and the Heming and Rowell model (1985 a) and applies them to field situations for known root densities of wheat crop. In our case the computer programme calculates potassium uptake at time intervals for the Abbots Ripton soil, the Boxworth, the Vertisol and the Entisol. The results are given in Table 5 for potassium uptake by the growing wheat root system from 0-10cm depth.

TABLE 4

Regression Analysis Data for Abbots Ripton Soil for intervals up to 112 days unter dry conditions (Θ= 0.28 cm3 cm-3). Potassium uptake μmolg-1 as function of root density, Lv cm/cm3.

Days after sowing	Time intervals	Potassium uptake equation	R^2 (%)	r
118	(Time 0)			
128	0-10	$K= 0.0633+0.552Lv-0.012L^2v$	99.9	0.999**
138	10-20	$K= 0.071+0.325Lv-0.00867L^2v$	99.7	0.998**
148	20-30	$K= 0.070+0.268Lv-0.00788L^2v$	99.5	0.997**
160	30-42	$K= 0.078+0.282Lv-0.0170L^2v$	99.1	0.995**
168	42-50	$K= 0.0451+0.178Lv-0.00762L^2v$	98.1	0.994**
178	50-60	$K= 0.0427+0.221Lv-0.01L^2v$	99.2	0.996**
188	60-70	$K= 0.0313+0.219Lv-0.0105L^2v$	99.5	0.997**
195	70-77	$K= 0.0192+0.147Lv-0.00716L^2v$	99.5	0.997**
209	77-91	$K= 0.0303+0.293Lv-0.0147L^2v$	99.7	0.998**
223	91-105	$K= 0.0221+0.293Lv-0.0153L^2v$	99.8	0.999**
230	105-112	$K= 0.0166+0.143Lv-0.00752L^2v$	99.5	0.997**

TABLE 5

Calculated Potassium Uptakes from Soils by the Growing Root System for 0-10 cm depth

Days after sowing	Mean Root density during the time period cm/cm3	Abbots Ripton Soil		Boxworth Soil		Vertisol		Entisol	
		K uptake during the time period μmolg-1	Total uptake μmolg-1	K uptake during the time period μmolg-1	Total uptake μmlog-1	K uptake during the time period μmolg-1	Total uptake μmolg-1	K uptake during the time period μmolg-1	Total uptake μmolg-1
118									
118-128	1.74	0.99	0.99	0.58	0.58	0.63	0.63	0.98	0.98
128-138	2.21	0.75	1.74	0.44	1.02	0.49	1.12	0.77	1.75
138-148	2.69	0.73	2.47	0.42	1.44	0.46	1.58	0.71	2.46
148-160	3.22	0.87	3.34	0.56	2.00	0.60	2.18	0.92	3.38
160-168	3.54	0.58	3.92	0.36	2.36	0.40	2.58	0.62	4.00
168-178	4.08	0.78	4.70	0.50	2.86	0.53	3.11	0.80	4.80
178-188	5.44	0.91	5.61	0.52	3.38	0.66	3.77	0.95	5.75
188-195	5.65	0.62	6.23	0.52	3.90	0.45	4.22	0.66	6.41
195-209	6.00	1.26	7.49	0.80	4.70	0.92	5.14	1.33	7.74
209-223	7.40	1.36	8.85	1.00	5.70	1.02	6.16	1.48	9.22
223-230	7.15	0.65	9.50	0.40	6.10	0.48	6.64	0.72	9.94

DISCUSSION

The amounts of K uptake calculated with the proposed model are presented in Table 5. This model is based on potassium characteristics of the soil using measurements with onion roots and the Heming and Rowell model and it is applied to known root densities of wheat crop in the field. These predictions are given for water content (Θ) which is approximately mid-way between field capacity and wilting point in all cases.

Entisol soil contributes to wheat crop the highest amount of exchangeable (K) (Kex) and this seems to be the most important factor in controlling the contribution of non-exchangeable K (Knex) to K uptake by plant because the other properties of the soil suggest that it should supply Knex easily (Mitsios and Rowell 1987b). Also, it has the highest release rate and (K)c, and its low D value (Table 2) would cause the developemnt of steeper concentration gradients near the root than the other soils. The uptake by the root is more rapid from Entisol soil but with its large amounts of exchangeable K(Kex) the release of no-exchangeable K(Knex) is delayed. Thus the contribution of Knex in that soil seems to be less than the contribution of the other soils. However, the proposed model does not differentiate between exchangeable and non-exchangeable K. Nevertheless it calculates potassium uptake from the soil by growing wheat root system in the field.

The Abbots Ripton soil contributes potassium to wheat crop, 9.50 μmolg-1. However, the Boxworth and Vertisol contribute less potassium than the Abbots Ripton soil, 6.10 and 6.64 μmolg-1 respectively. The Abbots Ripton soil larger amount of exchangeable K, and diffusion coefficient (D) as well resulting in higher potassium supply than the Boxworth soil and Vertisol.

Assuming that the 0-10 cm depth layer weighs 1666t. ha-1 the potassium supply of Abbots Ripton, Boxworth, Vertisol and Entisol soils, will be 617, 396, 431 and 645kg. ha-1 respectively for the indicated period (25th February until anthesis i.e. 118-230 days after sowing).

The wheat plants in Gregory's experiment needed 206 kg. ha-1 potassium to give a grain yield of 6.45 t. ha-1.

The above calculated amounts of available K, therefore may be considered sufficient to cover the needs of a wheat crop for a good grain yield.

CONCLUSION

A mathematical model has been proposed for predicting potassium uptake from soil by a growing wheat root system in the field. The model uses potassium uptake data from onion root experiments and the Heming and Rowell model (1985a) and applies them to a field situation. The main assumption of the model is that in the topsoil roots are developed in a finite soil volume and that as new roots appear they increase the root density and grow into uniformly depleted soil. So the uptake rate per unit length of the new roots is approximately the same as the uptake rate per unit length of the old roots. However, the model does not take into account the amount of potassium taken up by new roots growing into partially depleted soil, resulting in an underestimation of the potassium supply to the new roots.

A copy of the computer programme can be supplied on request.

REFERENCES

Claassen N. and Barber, S. A., Simulation model dor nutrient uptake from soil by a growing plant root system. Agronomy Journal **68,** 961-964. 1976.

Gregory, P. J., The growth and activity of wheat root system. Ph. D. thesis: Nottingham University. 1976.

Heming, S. D. and Rowell, D. L., Soil structure and potassium supply. I. The release of potassium from soil aggregates to Ca-resin. Journal of Soil Science **36,** 45-60. 1985a.

Heming, S. D. and Rowell, D. L., Soil structure and potassium supply. II. The efect of ped size and root density on the supply to plants of exchangeabe and non-exchangeable potassium from a Chalky Boulder Clay Soil. Journal of Soil Science **36,** 61-69. 1985b.

Mitsios I. K. and Rowell D. L., Plant uptake of exchangeable and non-exchangeable potassium I. Measurement and modeling for onion roots in a Chalky Boulder Clay Soil. Journal of Soil Science **38,** 53-63. 1987a.

Mitsios I. K. and Rowell, D. L., Plant uptake of exchangeable and non-exchangeable potassium. II. Influence of soil type on uptake by onion roots. Journal of Soil Science **38,** 65-70. 1987b.

Nye P. H. Soil properties controlling the supply of nutrients to the root surface. The Root-Soil Interface. Publishers J. L. Harley and R. Scott Russel, 39-49. 1979

Nye P. H. and Marriott, F. H. C., A theoretical study of the distribution of substances around roots resulting from simultaneous diffussion and mass-flow. Plant and Soil **30,**459-472. 1969.

Nye P. H. and Tinker, P. B., Solute movement in the Soil-Root system. Blackwell Scientific, Oxford. 1977.

Snedecor G. W. and Cochran, W. G., Statistical Methods, 7th edn. The Iowa State University Press. 1980.

ΠΕΡΙΛΗΨΗ

Μοντέλο πρόσληψης τοῦ καλίου τοῦ ἐδάφους μὲ τὶς ρίζες σιταριοῦ

Ἕνα μαθηματικὸ μοντέλο κατασκευάστηκε γιὰ τὸν ὑπολογισμὸ τῆς πρόσληψης καλίου τοῦ ἐδάφους μὲ τὴν καλλιέργεια τοῦ σιταριοῦ. Τὸ μοντέλο βασίζεται στὰ χαρακτηριστικὰ παροχῆς καλίου τοῦ ἐδάφους, ποὺ προσδιορίστηκαν μὲ ρίζες κρεμμυδιοῦ καὶ τὸ μοντέλο τῶν Heming καὶ Rowell καὶ ἰσχύει γιὰ γνωστὲς πυκνότητες ριζῶν τοῦ σιταριοῦ στὸν ἀγρό. Ἡ ἐπίλυση τοῦ μαθηματικοῦ μοντέλου ἔγινε μὲ τὴ βοήθεια προγράμματος ἠλεκτρονικοῦ ὑπολογιστῆ. Τὸ πρόγραμμα ὑπολογίζει τὴν πρόσληψη καλίου μὲ τὸ ἀναπτυσσόμενο ριζικὸ σύστημα σιταριοῦ, σὲ διάφορα χρονικὰ διαστήματα, ἀπὸ τέσσερα ἐδάφη —δυὸ ἀπὸ τὴ Μεγάλη Βρεταννία (Abbots Ripton ἔδαφος καὶ Boxworth ἔδαφος) καὶ δυὸ πλούσια σὲ ἄργιλλο ἑλληνικὰ ἐδάφη (ἕνα Vertisol καὶ ἕνα Entisol)—. Τὰ τέσσερα ἐδάφη παρέχουν τὸ κάλι ἀπὸ τὸν ἐπιφανειακὸ ἐδαφικὸ ὁρίζοντα (0-10cm), σὲ ποσότητες ἐπαρκεῖς γιὰ τὴν καλλιέργεια τοῦ σιταριοῦ.