NUTRIENT MANAGEMENT FOR FOOD CROP PRODUCTION IN TROPICAL FARMING SYSTEMS.

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ROOTING DEPTH IN CROPPING SYSTEMS IN THE HUMID TROPICS IN RELATION TO NUTRIENT USE EFFICIENCY

key words alley cropping, leaching model, rooting depth, shifting cultivation, synchronization.

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ABSTRACT

A simple model is presented for calculating the rooting depth of a crop or crop combination required to intercept leaching nutrients for different climatic and soil conditions. Important parameters in this model are the amount of water moving through the soil, which depends on excess of rainfall over evapotranspiration, and the apparent adsorption constant, which depends on the nutrient and soil type involved. Calculations for three time patterns of nutrient supply in relation to nutrient demand show moderate effects of the degree of synchronization on rooting depth required if a high interception fraction is desired.

In shifting cultivation systems a deep-rooted fallow vegetation can recover nutrients leached to the subsoil during the cropping phase. The simple leaching model can indicate the combinations of climate zone and apparent adsorption constant for which such interception is possible. It appears that recovery of leached nitrate is only possible in the subhumid zone. In the humid tropics the continuous presence of a deep root system as part of the crop combination on the field is necessary to use nitrogen efficiently, except when acid soil conditions keep all nitrogen in the ammonium form or when an almost ideal synchronization exists of nitrogen supply and demand during the growing season.

Some data are discussed on the root distribution of food crops and on the possibilities to establish a "safety-net" under the crops grown in alleys between deep-rooted hedgerow trees.

INTRODUCTION

Methods to increase the often low nutrient use efficiencies obtained in the humid tropics should be based on an understanding of nutrient availability in the soil, nutrient demand by the crop and nutrient losses to the subsoil and to the atmosphere. Knowledge of the root distribution of all components of a cropping system is important in this context. A simple model of nutrient leaching, rooting depth and nutrient recovery by the crop will be discussed here for conditions in the humid tropics. Available data on root distribution of crops and hedgerow trees for alley cropping will be briefly reviewed.

Detailed models of nutrient transport in the immediate root environment (De Willigen and Van Noordwijk, 1987) suggest that effective transport rates of nutrients are dominated by the "apparent adsorption constant" and that for P, K and N different aspects of the root system are the most important. For P, with an apparent adsorption constant K_a in the range of 100 - 1 000 ml/cm³, any increase in root length density (cm root length per cm³ of soil) up to the high values found in a grass sod (10 - 20 cm/cm³) will improve possibilities of using available resources in the soil. Mycorrhizal hyphae function as extension of the root length. Effective transport of P in the soil strongly depends on the water content of the root zone and on the degree of soil-root contact. For K, with an apparent adsorption constant K_a of 5 - 25 ml/cm³, root length densities of agricultural crops in the topsoil (1 - 5 cm/cm³) usually allow uptake of a considerable part of the available amount. Water content of the soil, root distribution pattern in coarse-structured soils and soil-root contact are important for K-uptake. Subsoil K can be only partial utilized at the root length densities normally found in the subsoil (< 1 cm/cm³), even under wet conditions. For NO_3, with an apparent adsorption constant of 0 - 1 ml/cm³, low root length densities of about 0.1 cm/cm³ as found in the subsoil are sufficient for utilizing virtually all available supplies, if current crop demand is not satisfied by N-supply to other parts of the root system. For NH_4 a situation intermediate between NO_3 and K may be expected.

In the humid tropics, with a net downward movement of water through the root zone throughout the growing season, the leaching rate of nutrients depends on their apparent adsorption constant. The apparent adsorption constant thus influences the rooting depth required for interception of nutrients leached during the start of the growing season. Even under conditions of shallow rooting and a high leaching rate of water, no leaching of nutrients will occur if nutrient demand by the plants always exceeds the current nutrient supply. For tropical rain forests this appears to be the case (Jordan and Escalante, 1980). Under agricultural conditions supply usually exceeds demand at the start of the growing season. The degree of synchronization of supply and demand then determines the severity and time-pattern of leaching (figure 1).

A simple model description of this relation is possible by assuming "piston flow" of water through a column of soil, neglecting two-dimensional aspects of water flow on sloping land. In this description newly infiltrating water pushes the soil solution downwards, without mixing. The nutrients that are temporarily in excess in the first week of the growing season will be found at the greatest depth at the end of the growing season. The distribution of nutrients with depth at the end of the growing season thus is a reflection of the history (time-pattern) of the excess of supply over demand in the topsoil. Deep rooted crops may recover part of these nutrients in the second part of the growing season, when supply in the topsoil is smaller than current demand.

In the model the process is simplified by first distributing all available nutrients over the zone between the soil surface and the annual leaching depth and then considering uptake from the root zone. By assuming that all nutrients within the root zone will be taken up, we restrict the use of the model to nutrient-limited growth. When other factors are growth-limiting, nutrient use efficiencies will be lower than calculated here. Losses of nutrients from the soil other than by uptake and leaching are not considered here. Nutrients are considered separately, each with an "apparent adsorption constant" K_a; in fact interactions exist, especially between anion and cation movement, and absence of anions may restrict cation leaching, for instance at low soil pH when most of the nitrogen is in the ammonium form. Such complications can be smoothed out by adjusting the parameter value for K_a to current conditions. A further major simplification in the model is that all soil layers are assumed to have the same soil physical and soil chemical characteristics.

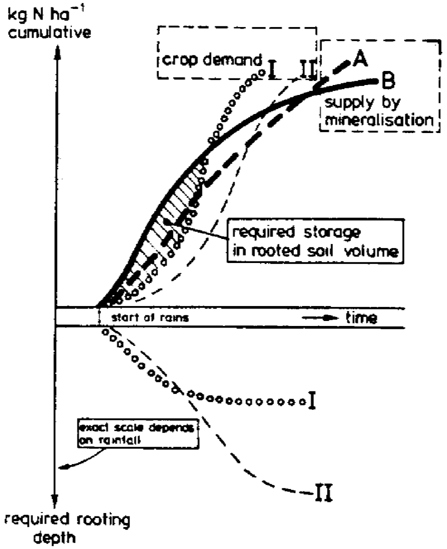


Figure 1. Schematic interaction between the rooting depth required for recovery of leached nitrogen and the (lack of) synchronization of supply of nitrogen by mineralization and crop demand; crop demand curves are typically S-shaped as shown by line I and II, while mineralisation of crop residues show a logarithmic decrease as shown by line A and B; for demand curve I and supply line A the temporary excess of nutrients in the top soil is indicated; depending on the amount of excess rainfall this temporary excess of nutrients will leach into the soil; recovery by the crop is possible if the roots have reached the leaching front by the time crop demand exceeds nitrogen supply in the top soil; for the later crop demand curve II thus a deeper root development is required.

REQUIRED ROOTING DEPTH FOR INTERCEPTION OF LEACHED NUTRIENTS

The depth, $Z_\ell(T)$, of the leaching front of a nutrient at time T is determined by the integral up to T of the flux density of leachate, $l_w(t)$, the saturated moisture content of the soil, θ_{sat}, and the retardation due to apparent adsorption:

$$Z_\ell(T) = \frac{\int_0^T l_w(t)\,dt}{(1 + K_a)\,\theta_{sat}} \qquad [cm] \qquad (1)$$

The notation and "standard" parameter values are given in table 1; $l_w(t)$ can be estimated from the amount of rainfall - evapotranspiration - run-off + run-on, all expressed in m/year. For the transport of nutrients we only consider convection and we do not consider the bypass of water occurring in cracked soils or dispersion and diffusion. A moderate degree of bypass, as described by Grimme and Juo (1985) as a two-phase transport, can be incorporated in the term K_a which should then be called retardation constant. Retardation due to immobilization-mineralization cycles can betreated in the same way.

The distribution of nutrients between $Z_\ell(1)$ and the soil surface depends on the degree of synchronization of supply and demand. We will consider three (linear) distributions here (fig. 2): a situation of relatively early supply, with the highest concentration at $Z_\ell(1)$, an evenly distributed supply and a relatively late supply with the highest concentration near the soil surface. Although these three distributions cannot be directly translated into actual field situations, a comparison of the three may be used to investigate the relative importance of the degree of synchronization.

TABLE 1. List of symbols and parameter values used.

Symbol	Description	Dimension	Value
f_i	interception fraction of nutrient i by the root system in one growing season	[-]	-
θ_{sat}	saturated volumetric water content	[-]	0.33
K_a	apparent adsorption constant	[ml/cm³]	0 (NO_3) 3 (NH_4) 10 (K)
$l_w(t)$	flux density of leaching water	[(m³/m²)/year]	
$L_w(1)$	leaching intensity in one year $= \int_0^1 l_w(t)dt$	[m³/m²]	
t,T	time	[year]	
z	depth below soil surface	[m]	
$Z_\ell(T)$	leaching depth at time T	[m]	
$Z_\ell(1)$	leaching depth after one year	[m]	
$Z_{r,i}$	effective rooting depth for nutrient (i)	[m]	
$Z_{r,N}$, $Z_{r,K}$	idem, for N and K respectively	[m]	
$Z_r(c)$	idem, of the crops in a shifting cultivation system	[m]	
$Z_r(f1)..Z_r(f3)$	idem in year 1 .. 3 of the fallow.	[m]	

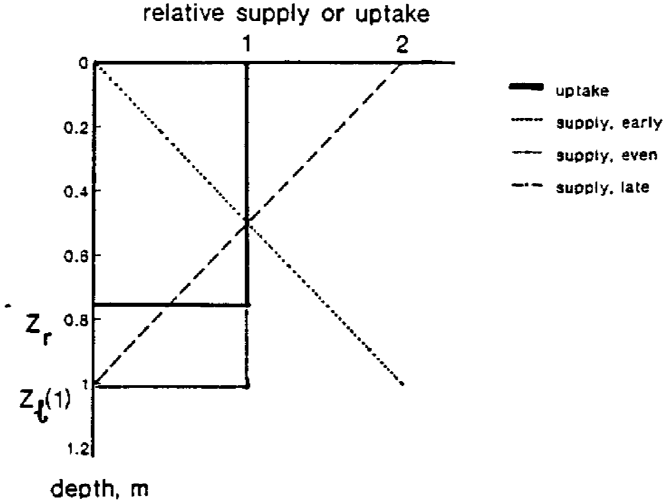


Figure 2. Distribution of nutrients with depth at the end ot the growing season, for a relatively early, an evenly distributed and a late supply in the top soil; complete uptake is assumed up to effective rooting depth $Z_{r,i}$ and no uptake beyond that depth.

For each nutrient i a different "effective rooting depth" $Z_{r,i}$ can be defined above which the possible uptake of available nutrient resources meets a set criterion. Except for P, we can take complete utilization of available nutrients as the criterion. The definition of $Z_{r,i}$, similar to the one often used for water uptake, assumes compensation for incomplete uptake for $z < Z_{r,i}$ by partial uptake from below $Z_{r,i}$. In a schematic description we may state that for $z < Z_{r,i}$ complete uptake of available resources and for $z < Z_{r,i}$ no uptake is possible. From the available theory (De Willigen and Van Noordwijk, 1987) we may estimate that $Z_{r,N}$ equals the depth at which the root length density has decreased to 0.1 cm/cm³ and $Z_{r,K}$ the depth at which the root length density has decreased to 1 cm/cm³; more precise values require knowledge of soil water content, relative root distribution and apparent adsorption constant.

Using this definition of $Z_{r,i}$ we can now define the possible interception fraction, f_i, of leached nutrients by integrating the function describing the nutrient concentration with depth from 0 to $Z_{r,i}$. For the three types of nutrient release the result is:

$$\text{for } Z_{r,i} \geq Z_\ell(1): \quad f_i = 1 \tag{2a}$$

$$\text{for } Z_{r,i} < Z_\ell(1): \quad f_i = (Z_{r,i}/Z_\ell(1))^2 \quad \text{for the early release,} \tag{2b}$$

$$f_i = Z_{r,i}/Z_\ell(1) \quad \text{for the even release,} \tag{2c}$$

$$f_i = 2(Z_{r,i}/Z_\ell(1))-(Z_{r,i}/Z_\ell(1))^2 \text{ for late release.} \tag{2d}$$

The lower part of figure 3 shows the relation between rainfall surplus, $L_w(1)$, and annual leaching depth $Z_\ell(1)$ for various values of the apparent adsorption constant K_a; in the upper part annual leaching depth $Z_\ell(1)$ is plotted against interception fraction f_i for three values of

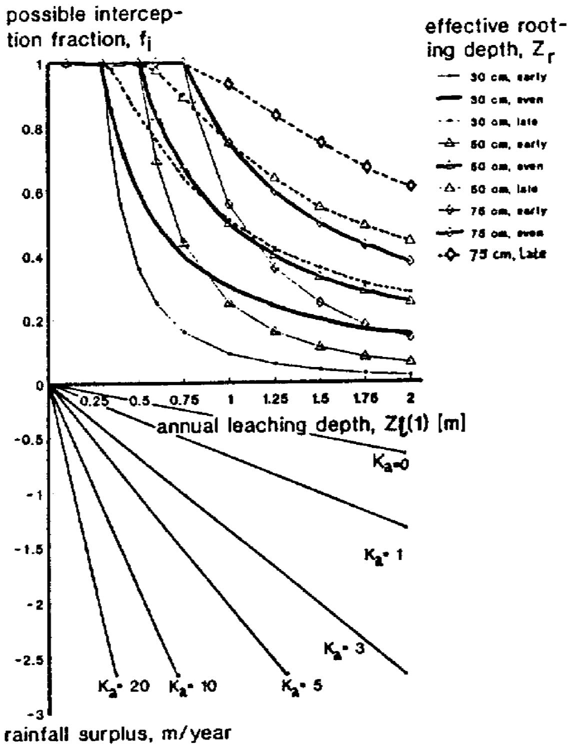


Figure 3. Relation between annual rainfall surplus L_w, annual leaching depth $Z_\ell(1)$ and possible interception fraction f_i, according to equations (1) and (2), for $\theta_{sat} = 0.33$.

effective rooting depth Z_r and three types of nutrient supply. An interception fraction of about 50% under conditions where $Z_\ell(1)$ just exceeds 1 m can be obtained by three combinations of rooting depth and nutrient supply: 0.30 m with "late" supply, 0.50 m with "even" supply and 0.75 m with "early" supply.

If we specify a target interception fraction f_i, the required rooting depth can be expressed as a fraction of $Z_\ell(1)$. By solving the quadratic function in $(Z_{r,i}/Z_\ell(1))$ in equations (2b) and (2d), table 2 was constructed. In combination with equation (1) we now obtain:

$$Z_{r,i} = \frac{Z_{r,i}\, Z_\ell(1)}{Z_\ell(1)} = \frac{(Z_{r,i}/Z_\ell(1))\ {}_0\!\int^T l_w(t)\, dt}{(1 + K_a).\theta_{sat}} \tag{3}$$

where $Z_{r,i}/Z_\ell(1)$ can be obtained as a function of f_i in table 2.

An example of results for 80% interception is given in table 3. It shows that the required rooting depth for 80% interception strongly depends on the apparent adsorption constant K_a and on the local climate via the excess of rainfall over transpiration. The "late" pattern of nutrient supply allows a rooting depth of 62% of that required for the "early" supply; for the "even" supply it is 90% of this value.

TABLE 2. Ratio of effective rooting depth and annual depth of leaching front, $Z_{r,i}/Z_\ell(1)$, as a function of interception fraction f_i for three patterns of nutrient supply (equation 2a-d).

	Interception fraction f_i					
supply	1.00	0.90	0.80	0.70	0.60	0.50
late	1.0	0.68	0.55	0.45	0.38	0.29
even	1.0	0.90	0.80	0.70	0.60	0.50
early	1.0	0.95	0.89	0.84	0.77	0.71

TABLE 3 Required effective rooting depth $Z_{r,i}$ (m) for 80% interception of nutrient i for three values of apparent adsorption constant K_a, roughly corresponding to nitrate, ammonium and potassium, respectively.

	------ K_a = 0 ---			----- K_a = 3 ---			--- K_a = 10 ml/cm³		
$L_w(1)$ m	$Z_\ell(1)$	$Z_{r,0}$ early	$Z_{r,0}$ late	$Z_\ell(1)$	$Z_{r,3}$ early	$Z_{r,3}$ late	$Z_\ell(1)$	$Z_{r,10}$ early	$Z_{r,10}$ late
0.25	0.75	0.67	0.41	0.19	0.17	0.10	0.07	0.06	0.04
0.50	1.5	1.34	0.82	0.37	0.33	0.21	0.14	0.12	0.08
0.75	2.25	2.00	1.24	0.56	0.50	0.31	0.20	0.18	0.11
1.0	3.0	2.67	1.65	0.75	0.67	0.42	0.28	0.25	0.15
1.5	4.5	4.00	2.47	1.12	1.00	0.62	0.42	0.37	0.23
2.0	6.0	5.34	3.30	1.5	1.33	0.83	0.55	0.49	0.30

POSSIBLE RECOVERY BY A DEEP-ROOTED FALLOW

As in many cases food crops grown on the acid soils usually found under high-rainfall conditions will not have the required rooting depth as calculated above, losses of nutrients to the subsoil will occur. In shifting cultivation systems the cropping phase, with presumably shallow-rooted crops, is alternated with a natural fallow vegetation which is usually supposed to be deep-rooted. Nutrients leached downward during the cropping phase may then be recovered from the subsoil by the subsequent fallow vegetation. The validity of this concept can be investigated with the simple leaching theory outlined above. As numerical examples we will use a rooting depth of 0.3 m for the crop $Z_r(c)$ and rooting depths of 0.75, 1.5 and 2.5 m in year 1, 2 and 3 of the fallow $Z_r(f_1)$, $Z_r(f_2)$ and $Z_r(f3)$, respectively. These parameter values probably represent a rather exaggerated difference between crop and fallow rooting depths. For the calculations an "even" distribution pattern of nutrients is assumed.

Nutrients lost from the root zone of the crop in the last year of cropping can be found within depth interval $[Z_r(c)$ to $Z_\ell(1)]$. At the end of fallow year 1 these nutrients occur at depth $[Z_r(c) + Z_\ell(1)$ to $2.Z_\ell(1)]$ and at the end of year T in the depth interval $[Z_r(c) + T.Z_\ell(1)$ to $(T+1).Z_\ell(1)]$. The possible recovery by the fallow vegetation can now be quantified:

a. for $Z_\ell(T) \leq Z_r(c)$ no losses during the crop phase are expected, unless total supply exceeds crop demand, so no recovery by the fallow will occur ($f_i = 0$),

b. complete recovery in fallow-year T is possible for:

$$Z_r(c) < Z_\ell(1) \leq \frac{1}{T+1} Z_r(T), \quad f_i = 1$$

c. for intermediate leaching intensities, partial recovery is possible:

$$\text{for} \quad \frac{1}{T+1} Z_r(T) \leq Z_\ell(1) \leq \frac{Z_r(T) - Z_r(c)}{T},$$

$$f_i = \frac{Z_r(t) - Z_r(c) - T.Z_\ell(1)}{Z_\ell(1) - Z_r(c)},$$

c. no recovery is possible ($f_i = 0$) for high leaching rates, when

$$Z_\ell(1) \geq \frac{Z_r(t) - Z_r(c)}{t}. \tag{4}$$

Similarly, recovery from the last-but-x year of cropping can be worked out. Complete recovery in fallow year t is possible for $Z_\ell(1) < Z_r(T)$ / $(T + x + 1)$. Numerical results for the recovery fraction f_i are shown in figure 4. Figure 4A shows the possible interception of nutrients lost in the last year of cropping in fallow years 1, 2 and 3; figure 4B shows the recovery in fallow years 1 till 3 of nutrients lost in the last five years of cropping. Both figures show that recovery by a deep-rooted fallow of nutrients lost in the cropping phase is confined to a relatively narrow range of annual leaching depths $Z_\ell(1)$ and hence annual rainfall surplus L_w. Under conditions of faster leaching (lower K_a or higher [illegible]), the depth of the leaching front exceeds the rooting depth of the fallow vegetation. For the rather exaggerated numerical example chosen with a shallow-rooted crop and a deep-rooted fallow, the range of conditions where recovery is possible is confined to an annual leaching depth of 0.3 to 0.7 m. The climatic zone in which this leaching depth occurs depends on the apparent adsorption constant K_a as shown in table 4.

For example for sites in the humid tropics with L_w of 1 - 1.5 m, a deep-rooted fallow might recover nutrients with a K_a of about 5, but no nutrients of a higher mobility. Possibilities for a deep-rooted fallow

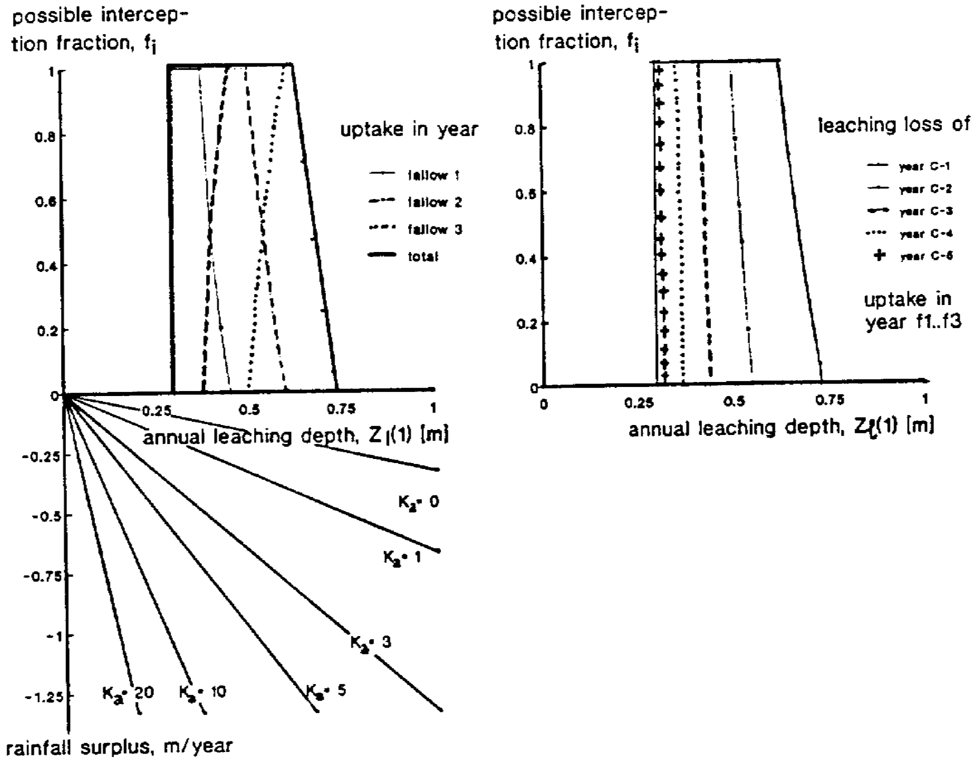


Figure 4. A. Fraction of nutrients leached in the last year of cropping which can be recovered by a subsequent fallow in a shifting cultivation system, in relation to annual leaching depth and rainfall surplus; equations (1) and (4); B. Recovery of leached nutrients in the last 5 years of the cropping cycle.

TABLE 4. Range of values of the annual excess rainfall, $L_w(1)$, for which the concept of nutrient loss from a shallow-rooted crop and recovery by a deep-rooted fallow can be valid, as a function of apparent adsorption constant K_a.

K_a ml/cm³	$L_w(1)$ m
0	0.1 - 0.25
1	0.2 - 0.5
3	0.4 - 1.0
5	0.6 - 1.5
10	1.1 - 2.75
20	2.1 - 5.25

to recover nitrate-nitrogen apparently are confined to the savannah zone, with L_w of 0.5 m or less. For the rain forest zone deep-rooted components of the cropping system are required within each growing season to minimize losses of nutrients with low K_a, as recovery in a later stage is impossible. Mixed cropping of shallow and deep-rooted crops may be part of the solution; under really high-rainfall conditions growth of deep-rooted crops towards the ultimate rooting depth would have to be rapid. Trees with a permanently deep root system and potentially high nutrient demand early in the growing season may perform this function best. Alley-cropping with deep-rooted hedgerow trees thus seems a realistic option under high rainfall conditions, especially for nutrients with a low apparent adsorption.

SELECTING SUITABLE CROPS, CROP COMBINATIONS AND ALLEY-TREES

For the high rainfall substation of I.I.T.A. in S.E. Nigeria, with an annual rainfall of about 2.4 m, the annual excess of rainfall over rainfall over transpiration in the growing season is estimated to be about 1.2 m (De Willigen, 1985). The experimental site of the nitrogen management project in S. Sumatera has a similar annual rainfall, but differently distributed over the year (figure 5).

Under such high rainfall conditions we may expect a dramatic reduction in nitrogen interception if the soil pH would be changed from a value where ammonium is the dominant nitrogen form to a value where nitrate is the dominant form unless rooting depth increases by a factor 4. Detailed calculations by De Willigen (1985) illustrate this point.

Estimates of effective rooting depths, $Z_{r,N}$ and $Z_{r,K}$ as defined above, of some food crops on a tropical ultisol in S.E. Nigeria are given in table 5. Upland rice was found to have at least double the root

TABLE 5. Estimates of "effective rooting depth" in m for N and K uptake for some food crops on a tropical ultisol in Onne, S.E. Nigeria (Hairiah and Van Noordwijk, 1986); $Z_r(K)$ is based on a root length density of 1 cm/cm³, $Z_r(N)$ on 0.1 cm/cm³.

		$Z_r(K)$	$Z_r(N)$	Remarks
Maize,	2 weeks	0	0.1	
	5 weeks	0	0.2	
	8 weeks	0.1	0.25	
	14 weeks	0.1	0.25	
Upland rice	3 w	0	0.1	
	5 weeks	0	0.2	
	9 weeks	0.2	0.35	
	14 weeks	0.2	0.7	
Cowpea	5 weeks	0.1	0.1	
8 and	14 weeks	0.2	0.4	
Cassava	2 weeks	0*	0	
	5 weeks	0*	0.2	* 30-50% of root length infected with V.A.mycorrhiza
	8 weeks	0*	0.3	
	14 weeks	0*	0.35	
	10 months	0*	0.6	

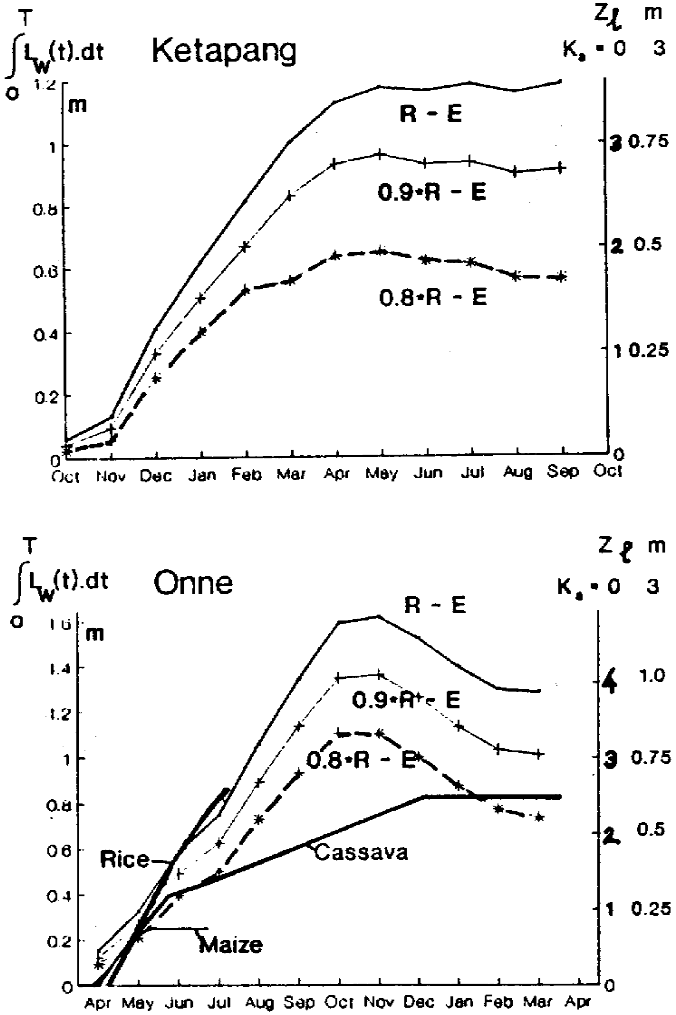


Figure 5.A. Cumulative rainfall surplus during the growing season for the experimental site of the nitrogen management project in S. Sumatera and predicted depth of the leaching front, $Z_{\ell,i}$, for three values of K_a; the three lines indicate three values of the run-off fraction; average rainfall data for the period 1974-1986 about 20 km from the experimental fields; potential evapotranspiration estimated at 4 mm/day. B. *idem*, for Onne, S.E. Nigeria; effective rooting depth for nitrogen uptake is plotted on the K_a=3 axis (data from table 5).

ing depth of maize. The considerably higher nitrogen recovery by rice compared with maize found by Arora and Juo (1982) can at least partly be accounted for by this difference in root development. A monoculture of maize will lose nitrogen beyond $Z_{r,N}$ unless nitrogen is applied in a larger number of split applications. Mixed cropping of maize and cassava provides a possibility for recovering part of the leached N from the subsoil, provided K_a is around 3. Rooting depths of various leguminous cover crops are described by Hairiah and Van Noordwijk (1989).

For the presumed role of alley-trees as nutrient pumps a deep root development would be required; horizontal development in the topsoil should be limited so as to reduce competition from crop roots. Tree species which have this pattern of root distribution and also fulfill other requirements such as tolerance of frequent pruning are scarce, but they exist. Figure 6 shows data on root distribution of shade trees used in tea plantations in Indonesia on deep volcanic soils. *Leucaena leucocephala* showed the deepest root penetration. Coster (1932) studied a large number of trees considered as potential understory trees in *Tectona*-plantations. Trees with a deep root system and few superficial roots generally showed a slow initial growth and a shoot: root ratio of 0.4 to 2.5 (on a dry weight basis); trees with a deep taproot as well as extensive horizontal development in the topsoil showed faster growth and had shoot: root ratios of 2 to 6; a group of trees and shrubs with only shallow rooting had shoot: root ratios of 2 to 30. Apparently trees with the desirable root pattern invest a large fraction of their carbohydrates in root growth and consequently have a slow initial growth (figure 7). On the basis of later root development *Leucaena leucocephala* and *Acacia villosa* appear to be suitable for alley-cropping: after a relatively fast establishment phase with some horizontal roots in the topsoil as well as a deep root, later development is largely confined to the subsoil.

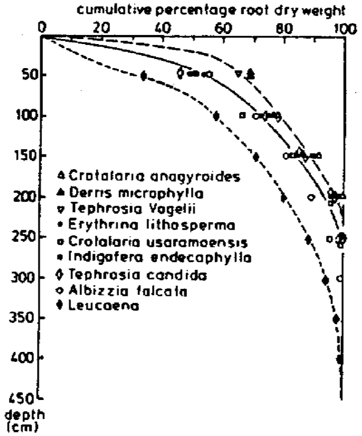


Figure 6. Root distribution of leguminous trees used in tea-plantations in Indonesia (data of Keuchenius (1927), presented in Hairiah and Van Noordwijk, 1986).

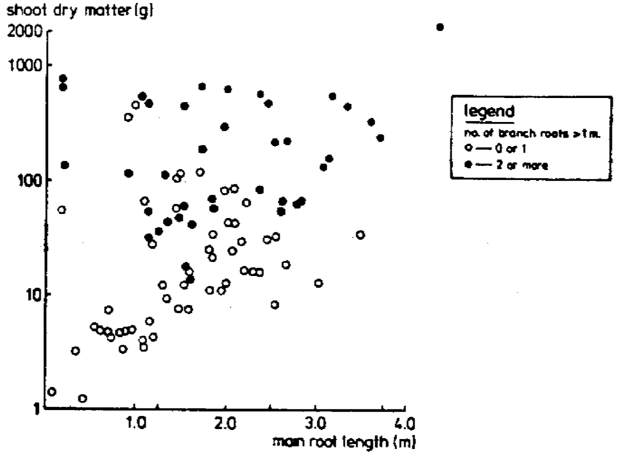


Figure 7. Relation between depth of the main root and shoot dry weight (logarithmic scale) for a large number of trees and shrubs, after 6 months, classified according to horizontal branch root development (data of Coster, 1932).

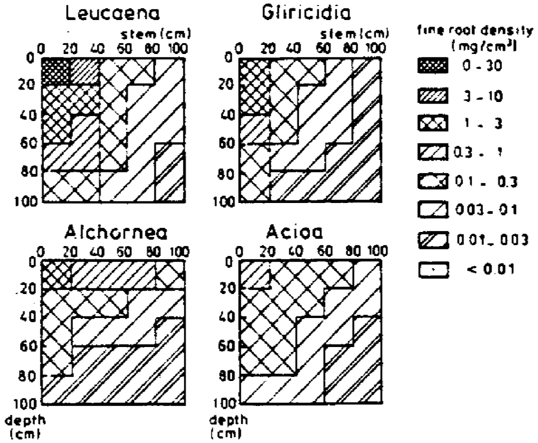
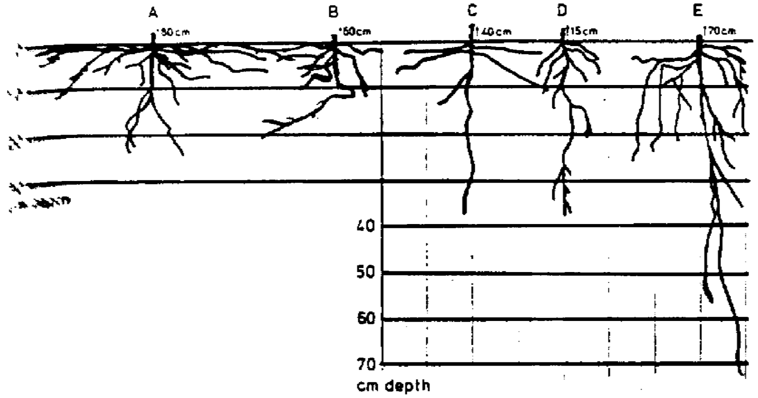


Figure 8. Root distribution with depth and radial distance to the stem of *Leucaena leucocephala*, *Gliricidia sepium*, *Alchornea cordifolia* and *Acioa barteri* in alley cropping experiments at I.I.T.A., Ibadan, Nigeria (data of Cole (1983) presented in Hairiah and Van Noordwijk, 1986).

Root studies in the alley-cropping experiment at I.I.T.A. in Ibadan, Nigeria, showed that *Leucaena leucocephala* comes closest to the desirable root pattern, with *Gliricidia sepium* and *Acioa barteri* as a second choice (figure 8). *Alchornea cordifolia* showed a largely horizontal development and is probably not suitable as hedgerow tree. Limited observations on an acid soil in Onne, S.E. Nigeria (Hairiah and Van Noordwijk, 1986) showed *Alchornea* roots to be even more restricted to the topsoil; *Leucaena* and *Flemingia congesta* formed many roots in the topsoil as well as in the subsoil. *Anthonata macrophylla* hedgerows got established slowly, but had a reasonably deep root system. Of four local tree species investigated in S. Sumatera, *Peltophorum inerme* had the most promising root distribution (figure 9, Van Noordwijk et al. 1989). The search for suitable tree species, especially for acid soils has to continue. Root observations in an early stage may help to select tree species and discard less suitable ones. In view of the long duration of such experiments, early selection is obviously profitable.



Root distribution of some spontaneous tree seedlings in S. Sumatera considered as potential alley-cropping tree; shoot height is indicated; A *Peronema canescens* (local name: Pohon sunjkai); B and C *Commersonia bartramia* (local name Pohon waru); D and E *Peltophorum inerme*; botanical identifications by Dr Riswan, Herbarium Bogoriense.

CONCLUDING REMARKS

The simple leaching model presented here obviously needs refinement and testing. Soil biological, chemical and physical properties generally vary with depth and the linear approximations used here may not be valid. Yet the description of leaching used here is essentially the same as used by De Willigen and Van Noordwijk (1989) in a more elaborate model, which gives reasonable agreement with field experiments. Both the "effective rooting depth" as the annual leaching depth vary considerably for different nutrients on the same soil in the same climate. A more precise use of the term "leaching" in explaining observed changes in nutrient content of the topsoil is desirable (Andriesse, 1987).

Further subdivision of the humid tropics according to rainfall surplus is desirable: in an area with 3 to 5 m annual rainfall (Hancock, 1989) leaching will be at least twice as fast as in an area with 2 m rainfall per year, the excess of rainfall over evapotranspiration will being 2 - 4 and 1 m, respectively.

Details of rain infiltration (run-off and run-on) can be very relevant for nutrient leaching patterns in the humid tropics, while their effect on crop water availability will be much less pronounced than in drier areas.

Root investigations on each experimental site in an initial stage, although labour-intensive and destroying part of the plots, may be worth the time and energy invested, especially where long-term experiments are planned.

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ROOTING DEPTH, SYNCHRONIZATION, SYNLOCALIZATION AND N-USE EFFICIENCY UNDER HUMID TROPICAL CONDITIONS

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SUMMARY

A model is presented with which calculations on the nitrogen balance of a soil can be performed. The processes considered include leaching, transformation of mineral and organic N, adsorption, and plant uptake. Model calculations on the nitrogen balance for conditions of continuous leaching during the growing season in the humid tropics show a reasonable agreement between N uptake as predicted on the basis of observed root distribution and actually measured uptake. Practical possibilities for increasing nutrient use efficiency through better synchronization and synlocalization of nutrient supply in relation to nutrient demand by the crop are discussed.

INTRODUCTION

The traditional upland crop production systems in large parts of the humid tropics rely on a short cropping period followed by a long bush fallow period for soil fertility restoration. This production system is characterized by a low cropping intensity and low crop yields, with little or no input of chemicals. These systems have provided farmers for generations with stable production methods. However, during the last few decades the traditional system is undergoing rapid changes, mainly due to increasing population pressure. This has led to an increase in cropping intensity and shortening or elimination of the much-needed fallow period, resulting in a rapid decline in natural fertility and low yields.

For prolonged or continuous cropping, the loss in soil fertility in the cropping phase must be compensated for by the use of organic nutrient sources and/or fertilizers. Traditional farmers in many parts of the humid tropics cannot afford costly inputs. So-called modern techniques for fertilization are often characterized by low efficiencies, except where they are based on knowledge of local soil, climate and crops. For fertilizer recommendations for tropical countries Janssen et al. (1988) use an apparent N recovery of 20-35%, depending on soil type. With such efficiencies, fertilizer use by small farmers is often not economically justifiable. Therefore, efforts have to be made to reduce dependence on chemical fertilizers by maximizing recirculation of all available waste materials and by maximizing biological N fixation, and/or to increase efficiency of fertilizer use.

In this paper we will use a model for nitrogen uptake by maize in the humid tropics to investigate the effects of rooting depth and method of fertilizer application (synchronization and synlocalization) on the N-use efficiency obtained. The model (based on De Willigen, 1985) will