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Prediction of long-term fertilizer nitrogen requirements of maize in the tropics using a nitrogen balance model

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Abstract

A simple N balance model was used to calculate fertilizer requirement for a target N uptake by maize. Nitrogen uptake from soil sources and target uptake of N with fertilizer N additions were obtained from fertilizer trials in Africa and Latin America. Most experiments had data for only one cropping period, although some from Latin America had data for four to six crops. The transfer coefficient of fertilizer N to the crop was adjusted to realize maximum recovery of fertilizer N under best methods of fertilizer application. The time constants of transfer of soil N to the crop were allowed to vary and were affected mainly by soil texture. Where 4 to 6 cropping periods were available good agreement between actual and predicted fertilizer N requirements was obtained. With this approach long-term fertilizer N requirements for 14 sites were predicted using first cropping period N uptake. This study showed that pools of organic N in more coarse-textured soils were usually smaller and declined more rapidly than in fine-textured soils. Labile organic N pools declined with time under all simulations, but approached equilibrium within 10 croppings seasons. Equilibrium N uptake from the soil organic N pool was predicted to be 31 kg ha^{-1} for the more coarse-textured soils and 36 kg ha^{-1} for the fine-textured soils. Long-term projections of fertilizer requirements using input data of the field experiments were reasonable, and effects of legume green manures and other amendments could be clearly evaluated.

Introduction

In most farming regions of the world, N is often considered the single most limiting element in crop production. This is especially true in tropical regions where organic N undergoes rapid transformations, and loss from the soil system is therefore likely. Comprehensive simulation models have been developed to predict N behavior in soils, but due to the complexity of the models their use in improving soil crop management has been limited. In contrast, Wolf et al. (1989) have developed a simple summary model describing the main processes in N transformations. This model operates with time steps of one year or one growing season. Using data from three long-term field trials in temperate regions, Wolf and van Keulen (1989) applied their summary model to calculate annual changes in total soil organic N, N uptake by crops, and recovery of applied N. Even though completely adequate data sets were not provided by all of the experiments, they found that the agreement between observed and computed values was generally satisfactory.

In this paper, we apply the model of Wolf et al. (1989) to data sets from tropical regions. Data from 11 field experiments examining maize production under different N fertilizer levels conducted in Africa and Latin America provided 14 sets of experimental results that were adequate to test the model. The model is then used to predict long-term N uptake from soil sources and to calculate long-term fertilizer N requirements needed to achieve a target uptake of N.

Experimental methods

Ideally, experiments that had been carried out for an extended number of maize crops would be desirable to test the model of Wolf et al. (1989). Field experiments we were able to utilize had from as few as one maize crop to as many as 6. Published data from our projects done in Puerto Rico (Fox et al., 1974) and at the Cerrado Center (CPAC) at Planaltina, Brazil (Grove et al., 1980) having up to 6 crops were used to verify the model. In addition, data from CPAC (Carsky, 1989); Manaus, Brazil (Melgar, 1989), Nigeria (Igbokwe, 1980), and Cote d'Ivoire (Chabalier and Pichot, 1979) were used to predict long-term fertilizer requirements. Some characteristics of the soils upon which the experiments were conducted are given in Table 1. For details of the various experiments used the reader is referred to the cited publications.

The experimental data used to calibrate and test the model included aboveground N content of the maize crop with and without fertilizer N, and the response curve to fertilizer N. From these data, uptake of N from the untreated soil (BASUP) was obtained and a target uptake (NTARG) of N was estimated from a response curve to added fertilizer N. Usually NTARG was N uptake at the point where no further yield response was obtained, although any point on the response curve could have been used depending on the yield goal. Either yield or grain or N content of above-ground dry matter can be used to obtain BASUP or NTARG, as long as the relationship between these two values remains constant (Grove, 1979).

The input data required for the summary model, described in detail by Wolf et al. (1989), include annual or seasonal N applied in both inorganic fertilizers and plant residues, N supplied in rainfall, and N added by animal manure or biological N fixation, and that mineralized from soil organic N. The assumption is made in this model that there are two pools of soil organic N. One pool is young, labile organic N (LON) and a second is older, more stable organic N (SON) (Sauerbeck and Gonzalez, 1977). As a consequence, two time constants of organic N conversion are involved in the model, one of a few years (TCL) for LON and one of many years (TCS) required for the conversion of SON. LON and SON [Wolf et al., 1989, (Table 2)] were estimated from soil organic N content using a standard surface horizon of 25 cm and bulk density of $1.2\,Mg\,m^{-3}$. N mineralized from LON is considered available to the crop, for leaching loss, and for conversion to SON. N mineralized

Table 1. Soils upon which N experiments were carried out

Location	Series	Great Group	Surface texture (%)	
			Sand content	Clay content
Fine-textured soils (clayey)				
Puerto Rico	Humatas	Tropohumult	6	65
	Torres	Palehumult		
	Coto	Haptorthox	22	71
	Catalina	Haptorthox	6	76
Planaltina, Brazil		Acrustox	18	60
Manaus, Brazil		Acrudox	9	81
Coarse-textured soils (sandy)				
Uyo, Nigeria		Paleudult	87	12
Bouake, Cote d'Ivore		Kandiustalf		25
Gagnoa, Cote d'Ivore		Kandiudult		10–35
Manaus, Brazil		Tropofluvent	11	23

Table 2. Organic N content, and calculated initial and equilibrium (after 50 crops) labile and stable organic N pools in the various soils

Soil-Location	Organic N content ($g\ kg^{-1}$ soil)	Initial LON ($kg\ ha^{-1}$)	Initial SON ($kg\ ha^{-1}$)	Equilibrium LON ($kg\ ha^{-1}$)	Equilibrium SON ($kg\ ha^{-1}$)
CLAYEY					
Oxisols					
Puerto Rico, Catalina	2.4	1200	3857	675	3436
Puerto Rico, Coto	1.0	500	1500	359	1348
Manaus	1.4	600	1800	270	1450
Planaltina[a] (−LGM)	2.1	1000	3000	490	2450
Planaltina[b] (+LGM)	1.9	1000	3000	527	2490
Ultisols					
Puerto Rico, Humatas	1.7	1000	3214	654	2936
Puerto Rico, Torres	2.4	1200	3000	354	1738
SANDY					
Alfisols					
Bouake (−OM)	1.2	500	1250	250	880
Bouake (+OM)	1.2	500	1250	300	950
Ultisols					
Gagnoa (−OM)	1.4	700	1750	265	1100
Gagnoa (+OM)	1.4	700	1750	400	1300
Uyo (pH 3.9)	0.85	350	1050	225	920
Uyo (pH 5.1)	0.85	350	875	184	630
Entisol					
Manaus	1.9	700	1750	235	1060

[a] From Grove, 1981.
[b] From Carsky, 1989.

from SON is added to LON. Data on N added by indigenous biological fixation (NFIX) and rain (NRAIN) were unavailable at these sites, but these quantities were likely to be small and were arbitrarily assigned values of 10 $kg\ ha^{-1}$.

Transfer coefficients are required to partition the N sources to the crop, to losses, and to the organic N pool (Table 3). We fixed the transfer coefficient from inorganic fertilizer N (FERTN) to the crop at 0.5 as this is the value reported by Grove (1979) for properly fertilized and well managed maize grown in a number of tropical soils. The experiments we used in our model runs were consistent with a transfer coefficient of 0.5. Factors such as excessive fertilizer N rates for the conditions, large quantities of residual inorganic N in the soil profile, or poor soil and crop management can, however, result in lower values of N transfer from fertilizer to the crop. The transfer coefficient from legume green manures or animal manures to the crop was variable depending on the source. Where manure was applied, a transfer coefficient of 0.35 was used. This was based on a measured decay constant of 0.35 for freshly applied dairy manure for New York farm conditions (Klausner, 1987), as no tropical data were available. Rainfall and temperatures are not greatly different during the

Table 3. Transfer coefficients used in the model for the following inputs

Input	Transfer coefficients: Crop	Loss	Labile pool	Stable pool
FERTN	0.50	0.20	0.30	
ORGN	0.20	0.30	0.50	
NFIX	0.20[a]	0.30	0.50	
NRAIN	0.32	0.48	0.20	
LON	0.34	0.51		0.15

[a] Varied from 0.20 to 0.50 depending on source of N added. Transfer to labile pool changed accordingly.

height of the growing season in the temperate regions as compared to tropical regions, so the assumption of 0.35 was accepted. In studies of maize grown at CPAC on Brazilian Oxisols, it was found that legume green manure N mineralized at a rate sufficient to make it about as available to maize as inorganic fertilizer N (Carsky, 1989; Quintana, 1987), so we used a transfer coefficient of 0.5 for this N source. Other transfer coefficients for plant uptake and for loss were fixed by Wolf et al. (1989). Since these calculated coefficients were best estimates using data from long-term experiments and appeared reasonable, we used them without modification.

The parameters BASUP and NTARG were obtained from the field experiments. Time constants of conversion of the soil organic N pool (TCL and TCS) for each experiment were varied until measured BASUP and calculated BASUP for the first crop agreed. Since TCL is the reciprocal of the mineralization constant of that pool we are effectively changing the rate of soil N mineralization in the various experiments. Model runs were made to predict the quantity of fertilizer N required to achieve NTARG found in field experiments. BASUP and FERTN are reported for crops 1, 3, 5, 10, 25, and 50, and LON and SON are reported for crop 50.

Results

N uptake

Nitrogen uptake by maize was obtained from field experiments where a N response curve and both grain yield and above-ground N content of the maize crop were available. Grain yields of 7000 kg ha^{-1} or higher were measured on several of the soils of Puerto Rico and Brazil, and at Gagnoa in Cote d'Ivoire. Grain yields of 4000 to 5000 kg ha^{-1} were possible on forest region soils of Nigeria and Manaus, Brazil. Though most of the data available fit the relationship between grain yield and above-ground N content described by Grove (1979), measured N content of above-ground dry matter at optimum sustainable yield was used as it is less likely to be influenced by variety and external conditions. N content (NTARG) at the point where no furtner yield increase occurred was estimated from the response curve. NTARG (Table 4) ranged form 70 kg ha^{-1} to 160 kg ha^{-1}.

Measured N uptake from the soil organic N pools (BASUP) varied widely in these experiments (Table 4). BASUP was especially high where either a legume green manure (Brazil) or animal manure (Gagnoa) had been previously applied and was unaccountably high on the Torres soil of Puerto Rico. Model runs were made to predict BASUP using the transfer coefficients given in Table 3 and the time constants given in Table 5. As shown in Table 4, in each experiment we were able to vary TCL and TCS so that calculated BASUP for the initial crop was in good agreement with measured BASUP. BASUP in subsequent crops was predicted using these TCL and TCS values. Thus, for each experiment TCL and TCS determined from the first crop were used to predict BASUP in successive crops. However, BASUP by the first crop on the Catalina and Humatas soils was much higher than by subsequent crops. These soils contained large quantities of residual inorganic N in the profiles at the initiation of the experiments so that apparent inorganic N recovery was much reduced in the first crop. It proved impossible to adjust TCL and TCS to match first crop uptake, and predict BASUP by subsequent crops. TCL and TCS therefore were estimated using the second crop and calculated BASUP agreed with measured BASUP, so that BASUP by subsequent crops could be predicted. The Torres soil from Puerto Rico also had a very high BASUP, giving rise to small time constants which may not be typical of longterm N release.

The Acrustox of Brazil averaged 67 kg ha^{-1} BASUP (measured) for the first 6 crops compared to our calculated 62 kg ha^{-1}. Maize grain yields averaged 3.4 Mg ha^{-1}. Excluding the first crop for the Catalina and Humatas soils of Puerto Rico, BASUP (measured) averaged 64 and 52 kg ha^{-1} for four succeeding crops, while predicted BASUP was 58 and 49 kg ha^{-1}, respectively. Maize grain yields for 4 crops averaged 2.8 and 2.4 Mg ha^{-1} for Catalina and Humatas, respectively. For 4 crops on the Manaus Acrudox a measured BASUP averaged 32 kg ha^{-1}, while predicted BASUP was 39 kg ha^{-1}. On the Entisol measured BASUP averaged 54 kg ha^{-1} and pre-

Table 4. Target N uptake (NTARG) by maize from field experiments and N uptake without fertilizer N additions (BASUP), actual and predicted

Soil-Location	N uptake (NTARG) ($kg\ ha^{-1}$)	Base Uptake (BASUP), Crop 1	
		Actual	Predicted
CLAYEY			
Oxisols			
Puerto Rico, Catalina	140	62	64
Puerto Rico, Coto	110	43	39
Manaus	75	45	46
Planaltina[a] (−LGM)[c]	140	70	73
Planaltina[b] (+LGM)	160	150	146
Ultisols			
Puerto Rico, Humatas	140	52	54
Puerto Rico, Torres	160	142	140
SANDY			
Alfisols			
Bouake (−OM)[d]	125	59	62
Bouake (+OM)	140	77	75
Ultisols			
Gagnoa (−OM)	125	89	85
Gagnoa (+OM)	164	136	130
Uyo (pH 3.9)	68	30	29
Uyo (pH 5.1)	92	44	45
Entisol			
Manaus	110	86	85

[a] From Grove, 1981.
[b] From Carsky, 1989.
[c] LGM – Legume green manure.
[d] OM – Organic matter.

dicted BASUP was 64 $kg\ ha^{-1}$. BASUP for crop 3 was abnormally low on both soils, accounting for much of the difference. Average grain yields for 4 crops on the Acrudox averaged 0.8 $Mg\ ha^{-1}$, while on the Entisol the yield was 2.1 $Mg\ ha^{-1}$. Model runs predicted that BASUP would decline fairly rapidly initially and more slowly until an equilibrium was approached. For the few crops of these experiments, decline in BASUP or grain yield occurred somewhat more slowly than was predicted by the model. Data for only one crop were available from the other experiments, but time coefficients could be adjusted so that measured and predicted BASUP for the first cropping period could be matched very closely.

Calculated BASUP values for crops 1, 3, 5, 10, 25, and 50 for each experiment on different soils are given in Table 6, and show that it changes very little beyond crop (or year) 10. For the clayey Oxisols and Ultisols, an equilibrium BASUP ranged from 24 for the Oxisol at Manaus to 45 for the Torres and averaged 36 $kg\ ha^{-1}$. For the sandy soils, values ranged from 21 for the acid Uyo soil to 35 for the Gagnoa soil and averaged 31 $kg\ ha^{-1}$. Two values stand out: those for the Acrustox (Planaltina, Brazil) where a legume green manure contributed 150 kg of $N\ ha^{-1}$ per crop, and where animal manures were used on the Gagnoa site which added an estimated 135 $kg\ N\ ha^{-1}$ per crop. The 135 kg was calculated from BASUP with and without manure using a transfer coefficient to the crop of 0.35. A transfer coefficient of the legume green manure N to the crop of 0.5 was used as shown by the experiments of Carksy (1989) and Quintana (1987). For the most part, equilibrium BASUP (+10 crops or years) was higher on the

Table 5. Time constants for transfer of organic N from labile (TCL), and stable (TCS) pools

Soil-Location	Time constants per crop	
	TCL	TCS
CLAYEY		
Oxisols		
Puerto Rico, Catalina	7	150
Puerto Rico, Coto	5	100
Manaus	5	100
Planaltina[a] (−LGM)	5	100
Planaltina[b] (+LGM)	5	100
Ultisols		
Puerto Rico, Humatas	7	150
Puerto Rico, Torres	3	50
SANDY		
Alfisols		
Bouake (−OM)	3	50
Bouake (+OM)	3	50
Ultisols		
Gagnoa (−OM)	3	50
Gagnoa (+OM)	3	50
Uyo (pH 3.9)	5	100
Uyo (pH 5.1)	3	50
Entisol		
Manaus	3	50

[a] From Grove, 1981.
[b] From Carsky, 1989.

finer-textured soils and was sufficient to produce maize yields from 2000 to 3000 kg ha^{-1}. On the sandy soils or those from forested regions (more humid), BASUP was sufficient to produce maize yields of about 1000 to 2000 kg ha^{-1}.

Organic N pools

The sum of the organic N pools (LON + SON) for the various soils were estimated from the organic N content reported with the various data sets (Table 2). The clayey Oxisols and Ultisols had a higher organic N content than the coarse-textured Oxisols and Ultisols initially. Estimates of organic N content in the soil at equilibrium for the clayey Oxisols and Ultisols of Puerto Rico and Brazil ranged from about 0.8 g kg^{-1} for the Coto to 2 g kg^{-1} for the Catalina soils. In the sandy soils of West Africa the equilibrium soil organic N content was somewhat lower ranging from 0.4 g kg^{-1} for the pH 5.1 Uyo, Nigeria soil to 1.1 g kg^{-1} for Gagnoa, Cote d'Ivoire soil receiving manure. These values agree with those found by Lathwell and Bouldin (1981) and those reported by Sanchez (1976).

Wolf et al. (1989) found the equilibrium ratio between SON and LON to be about 3. Using the time constants developed from the first crop in these experiments we calculated an equilibrium SON/LON ratio of about 3 for coarse-textured soils while for the clayey soils the calculated ratio was 4.

To estimate the effects of cropping on soil organic matter pools (LON and SON), the model was implemented assuming the soil would be continuously cropped to maize with residues being recycled. In most of the experiments reported, one crop was grown annually although in the few instances when 2 crops were grown annually, this was maintained over the entire simulation. The values of LON and SON are given for the end of a 50 crop run, although changes occurred only slowly after 10 crops and equilibrium was essentially reached after 30 to 50 crops. Most of the soils used in these experiments had been cleared and/or cultivated for a few to many years, especially those of Puerto Rico. All sites for which the model was implemented, however, showed that both LON and SON declined with cropping from the initial levels and reached a somewhat lower equilibrium level. Even where legume green manures or animal manures were assumed to be added for each crop grown, some decline was found.

Time constants of LON and SON

Time constants (TCL) for turnover of LON (Table 5) for the clayey Oxisols and Ultisols estimated from BASUP and LON were found to be 5 or 7 cropping periods except for possibly the Torres soil. The TCL values for the coarse-textured soils were 3 cropping periods, except for the acid (pH 3.9) soil at Uyo, Nigeria, where a value of 5 was more reasonable. Since TCL is the reciprocal of the mineralization rate, the smaller is TCL the more rapid is the mineralization rate. Time constants (TCS) for turnover of SON were from 100 to 150 cropping periods for the clayey Oxisols and Ultisols. The value of TCS for the sandy Ultisols was found to

Table 6. Calculated BASUP for crops 1, 3, 5, 10, 25, and 50

Soil-Location	BASUP (kg ha^{-1})					
	1	3	5	10	25	50
CLAYEY						
Oxisols						
Puerto Rico, Catalina	64	56	51	43	39	38
Puerto Rico, Coto	39	36	33	31	30	30
Manaus	46	37	32	29	24	24
Planaltina[a] (−LGM)	73	60	52	42	39	39
Planaltina[b] (+LGM)	146	134	126	118	115	114
Ultisols						
Puerto Rico, Humatas	54	49	46	40	38	37
Pueto Rico, Torres	141	87	66	52	49	45
SANDY						
Alfisols						
Bouake (−OM)	62	46	40	36	35	34
Bouake (+OM)	75	66	60	58	57	56
Ultisols						
Gagnoa (−OM)	85	56	46	39	37	35
Gagnoa (+OM)	130	110	103	99	97	96
Uyo (pH 3.9)	29	26	24	22	21	21
Uyo (pH 3.9)	29	26	24	22	21	21
Entisol						
Manaus	85	55	43	36	34	32

[a] From Grove, 1981.
[b] From Carsky, 1989.

be 50, except for the Uyo pH 3.9 soil where 100 was more appropriate. Changes in TCS had only minimal effects on the results obtained.

In general, then, for fine-textured soils there was a slower turnover of the organic N pools as shown by the larger time constants when compared to the coarse-textured soils where shorter time constants were required to show the more rapid turnover of smaller total organic N pools.

Fertilizer N requirements to achieve NTARG

Agreement between calculated inorganic fertilizer N and observed inorganic fertilizer N required to achieve NTARG for the first crop was quite good (Table 7), and fell within the guidelines used by Osmond (1991), except for the site in Nigeria. At this site, response curves indicated a somewhat higher first crop N requirement than the calculated requirement.

Calculated inorganic fertilizer N requirements to achieve NTARG with time using the transfer coefficient of 0.5 of fertilizer N to the crop are given in Table 8. These rates are calculated on the premise that NTARG derived from the field experiments can be maintained over the period of the model run (50 crops). Grain yields of 7000 kg ha^{-1} or higher have been achieved on the fine-textured Ultisols of Puerto Rico and the Oxisols of Puerto Rico and Brazil using inorganic fertilizer N rates similar to those calculated in the model runs. Likewise, grain yields of 7000 kg ha^{-1} were achieved on the sandy Ultisol at Gagnoa, Cote d'Ivoire. Whether NTARG can be achieved routinely on this soil may be questioned, but experiments from IITA (1988) and other national organizations in West Africa show that maize grown in the Savanna regions routinely yields 7000 kg ha^{-1} or more. The effects of manures and residues and legume green manures on reducing inorganic fertilizer N requirement are readily apparent.

Table 7. Actual quantity of fertilizer N added and predicted fertilizer N added to achieve NTARG, crop 1

Soil-Location	Fertilizer N added to achieve NTARG, Crop 1	
	Actual ($kg\ ha^{-1}$)	predicted ($kg\ ha^{-1}$)
Clayey		
Oxisols		
Puerto Rico, Catalina	125	125
Pueto Rico, Coto	130	120
Manaus	60	66
Planaltina[a] (−LGM)	133	106
Planaltina[b] (+LGM)	0	0
Ultisols		
Puerto Rico, Humatas	134	136
Puerto Rico, Torres	0	0
SANDY		
Alfisols		
Bouake (−OM)	100	101
Bouake (+OM)	100	84
Ultisols		
Gagnoa (−OM)	50	56
Gagnoa (+OM)	50	36
Uyo (pH 3.9)	100	64
Uyo (pH 5.1)	100	76
Entisol		
Manaus	30	29

[a] From Grove, 1981.
[b] From Carsky, 1989.

Discussion

In these sets of experiments, the only parameters adjusted to fit the data were time constants for N mineralization from LON and SON. The values for BASUP and NTARG were obtained from the field experiments, while values for LON and SON were calculated from the reported soil organic N levels. Calculated changes in N uptake and in the pools of soil organic N follow those reported by Wolf and van Keulen (1989). Since they used long-term experiments to verify the model, agreement with their analyses gives us confidence in the results reported in this paper.

A transfer coefficient for applied fertilizer N to the crop of 0.5 was used for all calculations of fertilizer N requirement. In a summary of results of experiments done in both temperate and tropical regions Grove (1979) has shown that under the most effective methods of application of fertilizer N, recovery of applied N in the above-ground dry matter averages 50 to 55%. Rarely in field experiments does recovery exceed these values and when management is less than ideal it usually is less than 50%. A small application of fertilizer N at planting followed by a post-planting application of the remaining N requirement is necessary to achieve highest efficiency (Lathwell et al., 1970). Usually a single post-planting application is sufficient but in tropical regions, especially where rainfall is high, splitting the post-planting N into 2 or more applications may increase efficiency. In our work done in Puerto Rico (Fox et al., 1974) and Brazil (Grove et al., 1980) using the most effective fertilizer N management, recovery of applied fertilizer N averaged 50%. For this reason we have used only a transfer coefficient of 0.5 for fertilizer N to the crop in our use of the N balance model.

The calculated fertilizer N requirements using TCL = 3, TCS = 50 for the coarse-textured En-

Table 8. Calculated inorganic fertilizer N requirement to achieve NTARG for crops 1, 3, 5, 10, 25, and 50

Soil-Location	Fertilizer N requirement (kg ha^{-1})					
	1	3	5	10	25	50
CLAYEY						
Oxisols						
Puerto Rico, Catalina	125	140	150	165	175	175
Puerto Rico, Coto	120	125	130	135	140	140
Manaus	65	75	80	85	90	90
Planaltina[a] (−LGM)	105	130	150	165	175	175
Planaltina[b] (+LGM)	0	20	35	55	60	60
Ultisols						
Puerto Rico, Humatas	135	155	160	170	175	180
Puerto Rico, Torres	0	115	160	185	190	195
SANDY						
Alfisols						
Bouake (−OM)	100	135	145	155	155	160
Bouake (+OM)	100	120	130	135	135	135
Ultisols						
Gagnoa (−OM)	55	110	135	150	150	155
Gagnoa (+OM)	35	75	90	100	100	105
Uyo (pH 3.9)	65	70	75	80	80	80
Uyo (pH 5.1)	75	100	105	110	110	115
Entisols						
Manaus	30	90	115	125	130	135

[a] From Grove, 1981.
[b] From Carsky, 1989.

tisol and the coarse-textured Ultisols and Alfisols and TCL = 5 to 7, TCS = 100 to 150 cropping periods for fine-textured Ultisols and Oxisols resulted in close agreement with actual and predicted NFERT requirements. Thus, if NTARG and BASUP are known or can be estimated, NFERT can be calculated for the range of conditions of experimental data quite reliably using soil texture to assign TCL and TCS values.

Two exceptions for time constants for Ultisols are notable. The low pH Nigerian soil had larger TCL's and TCS's than its higher pH counterpart and the other coarse-textured soils. The low-pH soil has a slower turnover of soil N since soil N processes occur more slowly at lower pH's and less inorganic N is mineralized from LON. The Humatas soil of Puerto Rico also had a larger TCL and TCS, thus behaving more like the Oxisols of the region.

The field experiments used for model verification had a sufficiently wide range of conditions to provide a satisfactory test of the model. NTARG values of the first crop, for both humid forested soils and savanna region soils, were within expected ranges for the data from both Africa and South America. Initial pools of organic N in coarse-textured soils generally are lower, and decline more rapidly (smaller time constants) than in fine-textured soils, at least in soils used in these experiments. This results in lower equilibrium organic N contents and lower BASUP values in the coarse-textured soils as compared to finer-textured soils. It has been demonstrated that an equilibrium organic N content is achieved depending on gains and losses of organic N into the soil system. Frequently, the equilibrium level achieved is lower under tropical conditions than under temperate conditions. This is due to the influence of climate, as well as cropping systems on the equilibrium level (Jenkinson, 1977).

The influence of legume green manures, animal manure, and other organic residues on fertilizer N requirements were estimated. At the Planaltina site (Acrustox) in Brazil, the long-term N requirement using legume green manures was 85 kg ha^{-1} compared to 175 kg ha^{-1} of N without legume green manures. At Gagnoa and Bouake, animal manure use also reduced fertilizer-N requirement substantially. This affords the opportunity to make an economic analysis of the benefits of legume green manure or manure to achieve yield goals were only legume green manures or manures may be available. Reductions in inorganic fertilizer N requirement, as influenced by management systems, are obviously predictable, but only by using an N balance model like the Wolf et al. (1989) model can long-term quantitative estimates be made.

This simple N balance model can be used then with a modest amount of initial input data to provide long-term information on N fertilizer requirements under a wide range of conditions. Target yield (NTARG) can be set for different conditions and only the soil organic N content and N uptake without fertilizer (BASUP) need to be known to estimate fertilizer N requirements. Initial fertilizer N requirements varied from 0 to 145 kg ha^{-1} and from 60 to 180 kg ha^{-1} on a longterm basis.

These nitrogen fertilizer recommendation rates, although approximate, are the best estimate that can be arrived at short of conducting nitrogen fertilizer trials at each of the sites. Even if these levels are only approximate, they are extremely useful as an initial guideline for estimating fertilizer usage on maize for various regions or for planning long-term demands and supplies. Using this balance model provides a reasonable estimate of fertilizer requirement for a target N uptake and thus, should have a wide range of applicability in tropical regions.

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