Contribution of N uptake and morphological root characteristics to N efficiency in tropical maize cultivars

Heidi T. Heuberger[1], Jennifer G. Kling[2], Walter J. Horst[3]

[1] Technische Universität München, Lehrstuhl für Gemüsebau, Germany,
e-mail heuberger@vegetable.de, Fax 08161-715387
[2] International Institute of Tropical Agriculture, Ibadan, Nigeria
[3] Universität Hannover, Institut für Pflanzenernährung, Germany

Abstract

The aim of the study was to identify indirect criteria and methods for the selection of N-efficient tropical maize (*Zea mays* L.) cultivars. Different sets of cultivars were grown in southern Nigeria in 1993-1995 at different levels of N fertilisation. Under severely N-deficient conditions N efficiency was primarily related to N uptake efficiency at all growth stages whereas N utilization efficiency became more important at higher N supply. Great variation in root-length density existed, however, differences between cultivars were not significant. No consistent relationships between root-length density and N uptake at the respective sampling times was found. Cultivars grown in compacted soil in tubes differed in various seedling root-growth characteristics. However, these traits were not correlated with root characteristics in the field. The results clearly show the importance of N uptake efficiency for overall N efficiency of tropical maize. However, N uptake efficiency could not be related to easily assessible root characteristics at the seedling stage.

Keywords: N efficiency, maize, roots, selection criteria

Introduction

Nitrogen is the most limiting nutrient for maize (*Zea mays* L.) production in the humid and subhumid tropics. The flush of nitrate mineralised at the beginning of the rainy season (Greenland, 1958, Moore and Jaiyebo, 1963) is easily leached into deeper soil layers and thus lost for the crop that is usually planted when the rains become more reliable. In this situation, especially where no additional fertiliser is available, maize cultivars with a rapidly developing deep root system should be more efficient to take up nitrate from the subsoil and thus have a higher grain-yield potential. The objectives of this study were (1) to determine genetic variation in N efficiency defined according to Graham (1984) as grain yield at yield-limiting N supply in tropical germplasm, (2) to clarify whether early N uptake and morphological root characteristics contribute to N efficiency and could serve as selection criteria, and (3) to screen cultivars based on seedling root characteristics under semi-controlled conditions in the screenhouse and evaluate them for root-length density and N efficiency in the field.

Material and methds

Different sets of tropical, open pollinated and hybrid cultivars were grown in southern Nigeria in Ikenne (forest zone, eutric nitisol) in 1993 and in Mokwa (savanna zone, luvisol with high sand content) in 1995 at different levels of N fertilisation: 0, 30, 90 (1993) and 20, 120 (1995) kg N ha^{-1} as calcium ammonium nitrate. P and K were supplied uniformly according to local recommendation as muriate of potash and single super phosphate.

Grain yield, N uptake at the beginning of stem elongation (1993 only), at silking and at maturity, and N utilisation efficiency (*i.e*. grain yield/N uptake at maturity) were determined. Root-length densities and rooting depth of cultivars were assessed by root-auger sampling with subsequent root washing and length estimation according to Tennant (1975).

As a method of cultivar screening at seedling stage, one of the cultivar sets was grown in tubes (5.7 cm inner diameter, 20 cm high, dividable at 15/5 cm hight) at 1.4, 1.55 and 1.7 g cm^{-3} soil bulk density. The seedlings were evaluated at the 4-5 leaf stage for root length in the upper 15 cm and lower 5 cm compartment of the tube, for root growth-rate based on the first appearance of root tips at the bottom of the tube, and for the number of seminal and adventitous roots.

Results and discussion

Maize cultivars differed in grain yield at low and high N supply and N x cultivar interaction was significant in both years in which N deficiency was severe (Figure 1). In a similar experiment conducted in 1994 with less severe N deficiency, no N x cultivar interaction for grain yield was observed (not shown). Also Bänzinger *et al*. (1997) determined an effect of the level of yield reduction due to N deficiency on N x cultivar interaction. This indicates that at very low N supply other factors than yield capacity become of increasing importance for N efficiency.

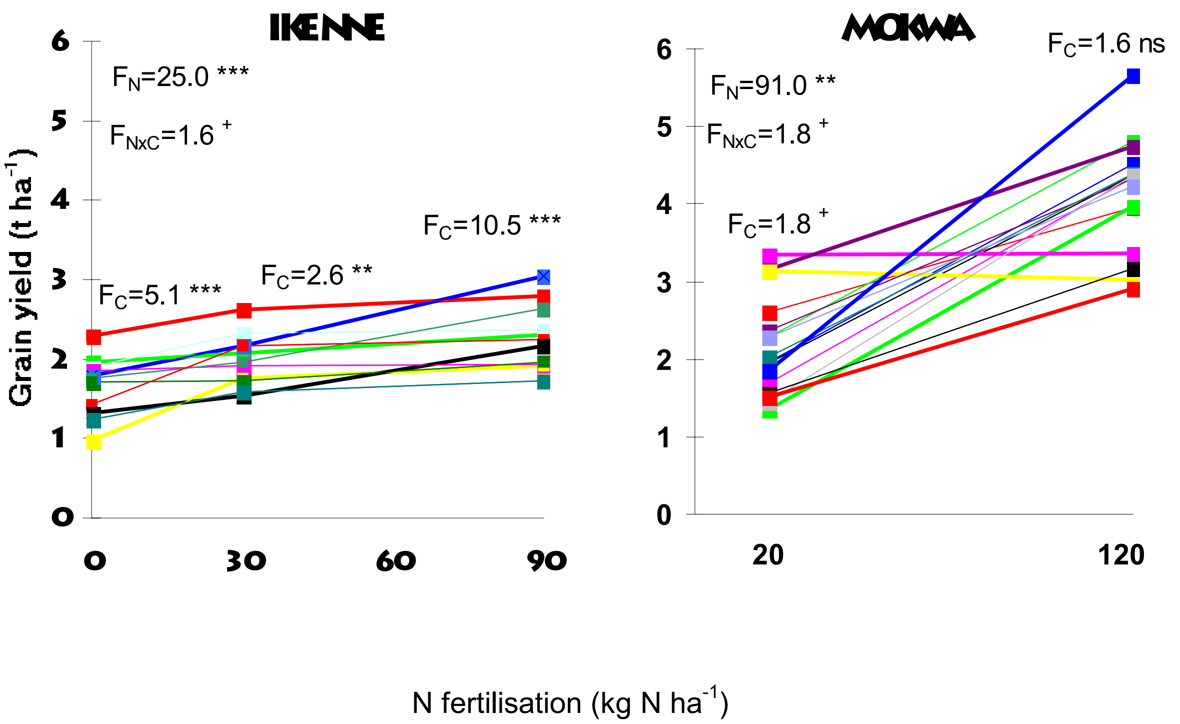

Figure 1: Maize grain yield of cultivars as affected by N fertilisation in 1993 (Ikenne, 11 cultivars) and in 1995 (Mokwa, 16 cultivars). F_C, FN, F_{NxC} denote F-values of cultivar and nitrogen effect and cultivar x nitrogen interaction; $^+$, **, *** denote *P*< 0.1, 0.01 and 0.001, respectively, ns denotes *P*>0.1

The traits contributing to such adaptation can be related to N uptake or N utilisation efficiency. The cultivars differed in N uptake at the beginning of stem elongation, at silking and at maturity (not shown). The importance of N uptake for N efficiency was indicated at several growth stages (Table 1). N uptake at stem elongation was related to grain yield at low but not at high N supply in 1993. N uptake at silking was correlated with N efficiency in all years. At maturity, grain yield at low N supply was related to both N uptake at maturity and N utilisation efficiency (Table 1) with a higher correlation coefficient for N uptake. At high N supply utilisation efficiency was more closely related to grain yield. A positive relationship between N efficiency and N uptake and N utilisation efficiency was also reported by Moll *et al*. (1982), Kamprath *et al.* (1982), and Akintoye *et al.* (1999). However, the relative relevance of the two traits for N efficiency varied among the studies. Akintoye *et al*. (1999) observed the same relevance and Moll *et al*. (1982) higher relevance of N utilisation efficiency. In the present study, N taken up at the beginning of stem elongation was 10-20% of N uptake at silking which was approximately 100 % of total N uptake. Therefore, about 80 % of N uptake occurred in the 4-5 weeks period from stem elongation until silking which required high nitrate concentrations in the rooting zone and a highly efficient uptake system during that period.

Table 1: Coefficients of correlation (r) between grain yield and N uptake at different stages of plant development and N utilisation efficiency as affected by N supply in 1993 and 1995

	Grain yield	
	1993	**1995**
Low N supply		
N uptake at beginning of stem elongation	0.60*	
N uptake at silking	0.74**	0.83***
N uptake at maturity	0.91***	0.91***
N utilisation efficiency	0.53^{+}	0.64**
High N supply		
N uptake at beginning of stem elongation	-0.07 ns	
N uptake at silking	0.66*	0.12 ns
N uptake at maturity	0.92***	0.64**
N utilisation efficiency	0.77**	0.83***

$^{+}$, *, **, *** denote P< 0.1, 0.05, 0.01 and 0.001, respectively, ns denotes P>0.1

In 1993, root-length densities increased approximately by 100 % from stem elongation until silking with exploration of deeper soil layers at the same time (Figure 2). In 1995, root-length densities measured at low and high N supply at silking were higher at high than at low N supply (not shown). Great genotypic variation in root-length density existed. However, differences between cultivars were not significant in either

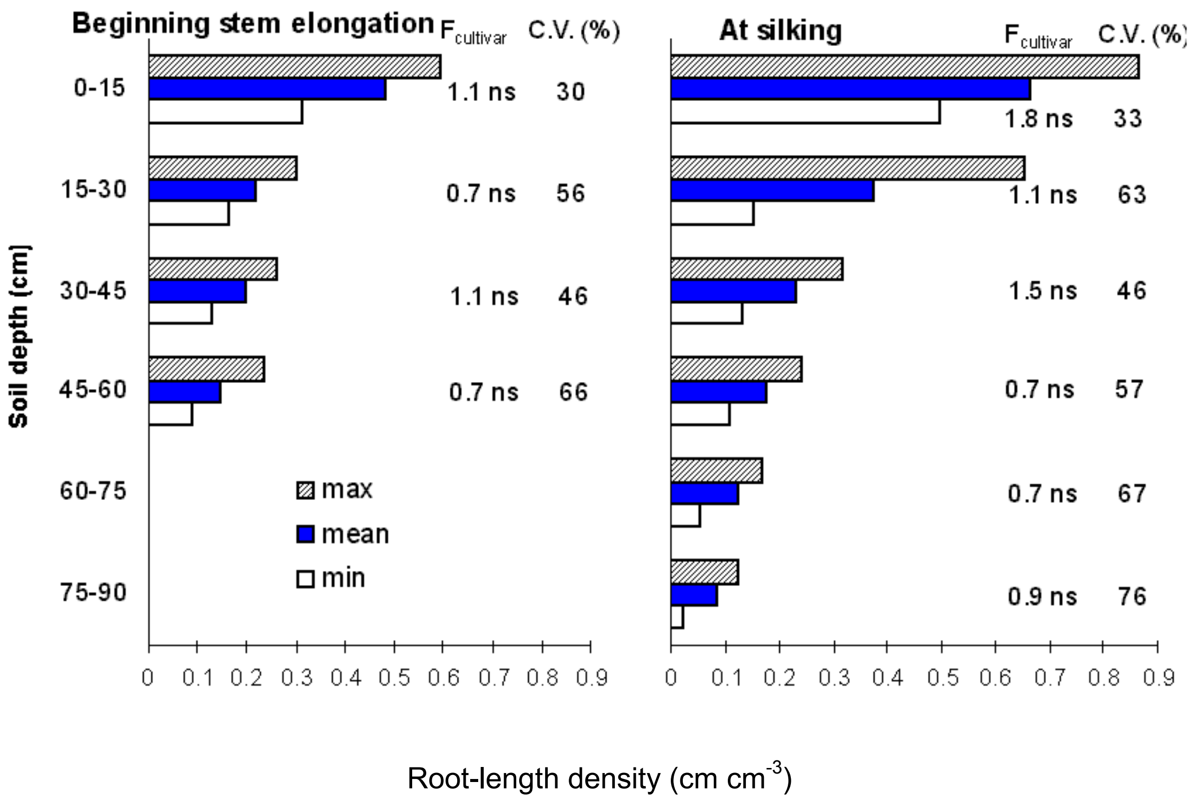

Figure 2: Root-length densities (cm cm^{-3}) at different profile depths at the beginning of stem elongation and at silking at medium N supply in Ikenne 1993. Means across cultivars and range of cultivar performance, F-values for cultivar effects ($F_{cultivar}$) and coefficients of variation (C.V.). ns denotes P>0.1

Table 2: Coefficients of correlation (r) between root-length densities (RLD) in different layers in the soil profile and N uptake at the respective sampling date at the beginning of stem elongation and at silking in 1993 at medium N supply, and at low and high N supply at silking in 1995. All coefficients are not significant (P>0.1)

N uptake	1993		1995	
vs. RLD in soil depth	Beginning stem elongation	At silking	Low N supply	High N supply
0 – 15 cm	-0.34	-0.21	0.23	-0.26
15 – 30 cm	-0.52	-0.56	0.02	0.37
30 – 45 cm	-0.06	-0.07	0.25	0.30
45 – 60 cm	0.11	-0.15	0.34	-0.02
60 – 75 cm		0.08	0.39	-0.38
75 – 90 cm		0.21	0.30	-0.32

year. This was possibly due to the inhomogeneity of the soil structure and the error attached to the method of root-auger sampling and root washing. Consequently, no relationship was found between root-length density at any depth and neither N accumulated by the plants at the respective sampling time and level of N supply (Table 2) nor residual nitrate in the soil in the respective soil layer (not shown).

The fate of nitrate in the soil profile followed a typical pattern as is shown in Figure 3 for 1993 as an example. At planting, the highest nitrate content was found at 0-30 cm soil depth. Four weeks later, at the beginning of stem elongation, the soil-born and fertiliser nitrate was leached to 30-90 cm soil depth. At silking, most of the nitrate has been taken up and only a small quantity of nitrate remained at 60-90 cm soil depth.

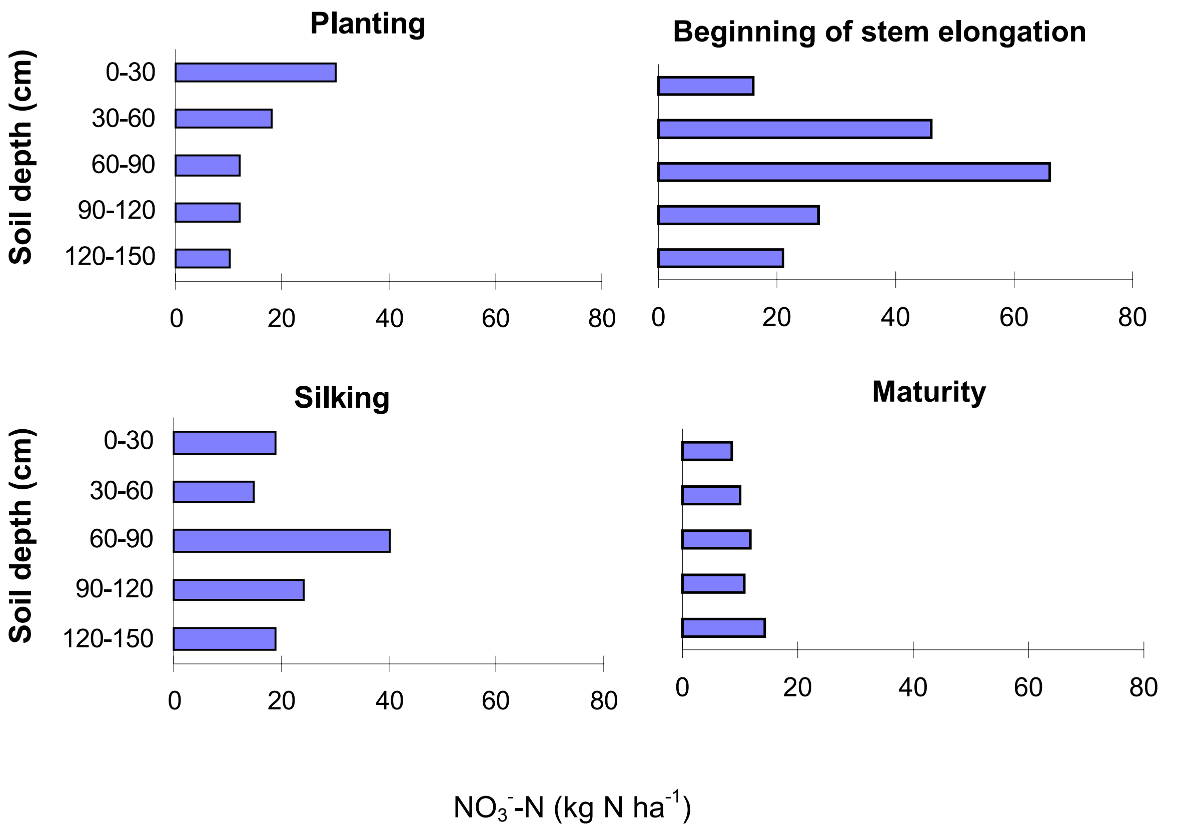

Figure 3: Nitrate distribution (kg N ha^{-1}) in different layers of the soil profile at different stages of plant development in 1993 at medium N supply with 30 kg N ha^{-1} at planting.

At maturity, the whole soil profile has been depleted from nitrate. The concentration of available nitrogen in soil layers below 30 cm soil depth during periods of intensive plant growth and N uptake stresses the importance of root growth and activity in the subsoil down to 90 cm depth.

High variability of root growth in the field, high error attached to the sampling method and labor-intensiv root-length estimation indicate that root-length density is not a suitable selection criteria in the breeding for N efficiency in spite of its important contribution to N uptake efficiency (Horst and Haerdter, 1994) and the positive reports by Wiesler and Horst (1994).

Therefore a technique was developed for the screening of maize cultivars for rooting characteristics at the seedling stage under semi-controlled conditions in the screenhouse. This technique was able to differentiate maize cultivars for root-growth characteristics (Table. 3). The seedlings of the different cultivars grown in compacted soil in tubes differed in root length, number of seminal and adventitous roots, and vertical growth rate (Table 3). However, the correlations between these root parameters in the pot and in the field and thus N uptake efficiency were not consistent (not shown). Feil *et al.* (1990) reported that low-input cultivars of maize developed more and longer seminal roots than the high-input types. Similarly, the number of seminal roots of spring barley was correlated with grain yield in the field (El Bassam, 1983). Since the seminal roots grow in more downward direction than adventitous roots (Gorny and Larsson 1989) they may particularly contribute to the exploration of the subsoil during early stages of development. The length of seminal roots of oats was correlated with the tolerance of juvenile plants to intermittend drought in the field (Larsson and Gorny 1988) which the authors attributed to a deep rooting system.

Table 3: Means and F-test for cultivar effect on root parameters of seedlings grown in subdivided tubes as affected by different soil bulk densities (g cm^{-3}); parameters determined 13 days after planting.

	Soil bulk density (g cm^{-3})		
	1.40	1.55	1.70
Root length (m) in			
Upper compartment	1.12 ns	1.20*	1.03***
Lower compartment	1.75 ns	0.19 ns	0[1]
Vertical growth rate (cm h^{-1})	0.080*	0.048 ns	0[1]
No. of **seminal roots** $plant^{-1}$	9.7*	9.1**	9.0*
No. of **adventitous roots** $plant^{-1}$	15.0	16.9***	15.9**

*, **, and *** denote P<0.05, 0.01, and 0.001, resp.; ns denotes P>0.1

[1] no roots reached the lower compartments, therefore vertical growth rate could not be calculated

In conclusion, differences in N efficiency in tropical maize germplasm do exist and can be exploited for the development of N-efficient cultivars. N uptake efficiency rather than utilisation efficiency appears to be a major factor contributing to overall N efficiency at stongly limiting N supply. Although of major importance, root characteristics in the field or at seedling stage under semi-controlled conditions did not prove to be reliable selection criteria for the breeding of N-efficient maize cultivars.

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