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Initial and residual effects of nitrogen fertilizers on grain yield of a maize/bean intercrop grown on a Humic Nitosol and the fate and efficiency of the applied nitrogen

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Abstract

Initial and residual effects of nitrogen (N) fertilizers on grain yield of a maize/bean intercrop grown on a deep, well-drained Humic Nitosol (66% clay, 3% organic carbon) were evaluated. Enriched (^{15}N) N fertilizer was used to study the fate of applied N in two seasons: using urea (banded) at 50 kg N ha^{-1} in one season, and ^{15}N-enriched urea (banded), calcium ammonium nitrate (CAN, banded), and urea supergranules (USG, point placement) were applied in the other season (different field) at 100 kg N ha^{-1}. Nitrogen fertilizer significantly ($P = 0.05$) increased equivalent maize grain yield in each season of application with no significant differences between N sources, i.e., urea, CAN, and USG. Profit-maximizing rates ranged from 75 to 97 kg N ha^{-1} and value: cost ratios ranged from 3.0 to 4.8. Urea gave the highest value: cost ratio in each season. Most (lowest measurement 81%) of the applied N was accounted for by analyzing the soil (to 150 cm depth) and plant material. Measurements for urea, CAN, and USG were not significantly different. The high N measurements suggest low losses of applied N fertilizer under the conditions of the study. Maize plant recovery ranged from 35 to 55%; most of this N (51–65%) was in the grain. Bean plant recovery ranged from 8 to 20%. About 34–43% of the applied N fertilizer remained in the soil, and most of it (about 70%) was within the top soil layer (0–30 cm). However, there were no significant equivalent maize grain increases in seasons following N application indicating no beneficial residual effect of the applied fertilizers.

Introduction

Studies of fertilizer use on maize in Kenya have mainly focused on pure maize stands used on large-scale farms [4, 10]. The bulk of maize in Kenya, however, is produced by smallholder farmers [4] who invariably intercrop maize with legumes like beans, cowpeas, and pigeon peas. Appropriate fertilizer response functions are required to determine optimum fertilizer levels in intercrop systems.

Because fertilizer research in Kenya has not included N balance studies, little is known about the fate and efficiency of N fertilizers applied to Kenyan soils. Problems associated with estimating N fertilizer recovery include the priming effect (or simple mineralization-immobilization turnover) as well as increased plant growth and root proliferation following fertilizer application. Because of these problems, ^{15}N tracer techniques have an advantage over the traditional 'difference' (or apparent recovery) method [7], which estimates fertilizer recovery as the difference in N uptake between the fertilized and nonfertilized crop per quantity of N applied.

The objective of this study was to evaluate the performance of available N fertilizer sources when used on the most common cropping system on smallholder farms for food crops in Kenya, i.e., maize/bean intercrop. The study also evaluated an experimental urea product, the urea supergranules (USG), which allows N fertilizer to be placed next to each hill (point placement); USG has performed well under paddy conditions. Concomitantly, ^{15}N-enriched N fertilizer was used to obtain data about the efficiency and fate of the applied N fertilizers.

Materials and methods

The study was conducted at the University of Nairobi (Faculty of Agriculture) Field Station, Kabete Campus, Kenya. The altitude of the site is 1,941 m, and the mean annual bimodal rainfall is 1,018 mm. The soils of the site are Humic Nitosols (FAO/UNESCO, 1975 classification), or Oxic Paleustult as the Soil Taxonomy (USDA, SCS, 1975) equivalent [9]. Characteristics of the soil in Field 14 where the studies were conducted are presented in Table 1. The Nitosols are widespread in the zones of high agricultural potential in Kenya, and they are some of the most productive soils of the high-plateau zones of the East and Southeast African region.

The field had been under napiergrass (*Pennisetum purpureum*) for 7 years. The last fertilizer application (N and P, rates unknown) was in 1979. In February 1983, the napiergrass, which had been periodically cut for fodder during the 7 years, was removed by cutting. The field was divided into two sections. One section (A) was used for the 1983 study, and the other section (B) was planted with maize, without fertilization, to reserve it for use in the 1984 study. Soil samples (0–15 cm) were taken in March 1983 just before fertilizer was applied (Section A) and in March 1984 following the unfertilized maize crop (Section B). Analytical data are presented in Table 2.

The plot size was 6.0×4.5 m. Interrow spacing was 75 cm for maize and 25 cm for beans; intrarow spacing was 30 cm for maize and 15 cm for beans. Thus, there were 8 maize rows (each 4.5 m long) and 14 bean rows (two bean rows between two maize rows). Plots were laid out in a randomized complete block design with five replications. Triple superphosphate (65.5 kg P ha^{-1}) and K_2SO_4 (30 kg S ha^{-1}) were incorporated into the plow layer of all plots before planting.

Two N sources were used: urea and calcium ammonium nitrate (CAN). In addition, point placement of urea, using USG, was compared with banding of urea and CAN. Nitrogen was applied at three levels (25, 50, and 100 kg N ha^{-}0^{1}) with an additional level (150 kg N ha^{-1}) for banded urea in 1983. For the 1984 study, the urea, CAN, and USG were applied at four levels (25, 50, 100, and 150 kg N ha^{-1}). Nitrogen fertilizer was applied in two splits: one-third at planting or soon after establishment, the remainder when the maize crop was about 50 cm tall. Urea and CAN fertilizers were applied in a band (8 cm deep) parallel to and 10 cm from the maize row and covered with soil. For point placement, the urea supergranules were placed 10 cm to the side of each maize hill at a depth of 8 cm and covered with soil.

Maize and beans were planted at the same time. Planting of the maize/bean intercrops in the 1983 and 1984 long rainy seasons (March–July) was followed by the application of N fertilizers. A maize/bean intercrop was also planted without fertilization during subsequent seasons – i.e., 1983 short rains (SR) and 1985 long rains (LR) – so that residual effects could be studied. Hybrid 512 maize seed was used during the long rainy seasons and Katumani composite maize seed during the 1983 short rainy season (October–December). The bean cultivars were Canadian wonder (NB26) during the 1983 LR, Mwezi moja (NB518) during the 1983 SR, and Rosecoco (NB510) during the 1984 LR and 1985 LR.

Ten bean rows, each 4.05 m, were harvested in each plot at maturity. For maize, five plants were taken from each of the inner six rows. Stover/leaf, cobs/husks, and maize and bean grain samples were dried (70°C to constant weight) for moisture determination and ground for nutrient uptake estimation. Grain yield was adjusted to

Table 1. Some soil characteristics of field 14 (University Field Station, Kabete, Kenya)

Horizon (thickness)		pH (1:2)		Organic matter (%)	Mechanical analysis (%)			Exchangeable cations[a] (meq 100 g^{-1})				CEC[a] (meq 100 g^{-1})	Base saturation (%)
		H_2O	$CaCl_2$ 0.01 *M*		Clay	Silt	Sand	Ca	Mg	K	Na		
Ap (all)	0–10	5.4	5.2	5.55	64.1	31.2	4.7	13.2	2.8	2.8	1.0	26.8	73.9
A12	10–20	5.5	5.2	4.47	67.3	26.2	6.5	11.2	3.8	3.0	1.1	26.4	72.3
(10–24 cm)													
B21	20–30	5.1	5.0	2.69	67.2	26.8	5.9	11.2	1.2	2.5	0.8	22.8	69.1
(27–71 cm)	30–50	6.5	5.5	1.84	72.5	22.6	4.9	11.4	1.0	2.5	1.0	22.0	72.5
	50–70	6.4	5.8	1.29	74.7	20.7	4.6	8.4	3.2	2.7	0.9	21.6	70.4
B22	70–90	6.8	5.6	1.19	77.4	18.6	4.0	8.0	3.2	2.7	1.0	21.2	70.5
(71–150 cm)	90–120	6.5	5.1	0.55	79.6	16.0	4.4	5.0	3.4	4.0	1.0	19.6	68.4
	120–150	6.7	5.7	0.41	76.0	20.5	3.5	2.8	1.3	5.7	0.8	17.6	60.4
B23	150–180	6.8	5.8	0.38	79.4	17.5	3.1	4.0	0.8	6.2	0.8	17.6	67.3
(150+ +)	180+ +	5.9	5.3	0.38	73.6	24.6	1.8	3.6	1.6	4.2	0.8	17.6	58.2

[a] Neutral ammonium acetate extract (1 *N*)

Adapted from: Lenga FK [6]

Table 2. Some characteristics of the experiment field soils at the beginning of each season before nitrogen fertilizers were applied[a]

Site[b]	Depth (cm)	Texture	pH (1:2) H_2O	pH (1:2) 0.01 *M* $CaCl_2$	C (%)	P (Olsen) (ppm)	meq/100 g Ca[c]	Mg[c]	K[c]	Na[c]	CEC[c]
1983	0–15	Clay (66%)	6.3	5.7	3.00	4.5	13.2	1.6	3.17	0.13	26.0
1984	0–15	Clay (67%)	6.2	5.5	3.70	6.1	7.3	2.4	3.32	0.27	24.8

[a] Plow layer (0–15 cm) soil samples taken before application of fertilizers.
[b] Both experiments in Field 14, University of Nairobi Field Station, Kabete; year indicates when experiment was established.
[c] Extracted with neutral ammonium acetate solution (1 *N*).

14% moisture. Grain yield for the mixed plots was expressed and subsequently analyzed as equivalent maize yield (EQMAIZE) obtained as follows:

$$\text{EQMAIZE} = \text{Ym} + \frac{[Y_B \times P_B]}{P_M}$$

Where Y_M = yield of maize (kg ha^{-1})
Y_B = yield of beans (kg ha^{-1})
P_B = price of beans per kg
P_M = price of maize per kg.

^{15}N studies

In order to minimize costs, ^{15}N-enriched fertilizer was applied in microplots at only one level of N. The microplots (3.0 × 3.0 m) were enclosed in 30 cm deep galvanized metal sheet borders to minimize cross-contamination through runoff. The microplots were in the center of a larger plot (4.5 × 6.0 m), and the area outside the microplot borders received unlabeled N fertilizer. With interrow spacing of 75 cm for maize and 25 cm for beans and intrarow spacing of 30 cm for maize and 15 cm for beans, there were 40 maize plants (4 rows) and 152 bean plants (8 rows) in each microplot. For details of microplot designs for ^{15}N-labeled fertilizer studies, see Mughogho et al. [7]. For the 1983 LR, ^{15}N-enriched urea was used at a rate of 50 kg N ha^{-1}. For the 1984 LR, ^{15}N-enriched urea, calcium ammonium nitrate (CAN), and urea supergranules (USG) were used at 100 kg N ha^{-1}. There were five replicates for each season. The ^{15}N-labeled fertilizer was applied in the same manner and at the same time as the unlabeled N fertilizers. Since N fertilizer was not equally split, one-half of the bean rows (A) were close to the one-third N application band, and the other half (B) were adjacent to the two-thirds N application band.

Bean plants were harvested at maturity but before leaf drop. The center eight bean plants in each of the central bean rows (A and B) of the microplot were harvested and handled separately. Pods and haulms were separated, dried (at 60°C to constant weight), weighed, and ground for ^{15}N assay. Eight maize plants in the center of the microplot (four plants from two central maize rows) were harvested and separated into four components (stem, leaf, cobs/husks, and grain), dried (60°C), weighed, and ground for ^{15}N assay.

Soil samples were taken from the center of the microplot (0.6 × 1.5 m). The four maize crown roots of this area were removed, washed, dried (60°C) weighed, and ground. The entire top layer (0–15 cm) of the soil was removed and mixed, and a composite sample (3 kg) was taken for ^{15}N assay. Another sample was similarly taken from the 15–30 cm soil layer. Samples were taken from the 30–60 cm, 60–90 cm, 90–120 cm, and 120–150 cm soil layers by augering (five cores for each layer). Soil bulk density was determined for each of the soil layers. In order to determine the background level of ^{15}N in the soil, soil samples were taken from control plots (no N applied) at 0–15 cm and 30–60 cm depth. Soil samples were air-dried and ground to pass a 2-mm screen. Soil and plant ^{15}N was determined at the International Fertilizer Development Center (IFDC) laboratories at Muscle Shoals, Alabama, U.S.A., according to procedures developed by Buresh et al. [2]. The amount of ^{15}N in the plant and soil samples was used to estimate plant uptake of N fertilizer, N fertilizer remaining in the soil at harvest, and, by difference, N fertilizer loss.

Results and discussion

Initial effects of applied N fertilizer

Site records (Table 3) indicate that rainfall was below average for both 1983 LR and 1984 LR; thus, supplementary irrigation was necessary, particularly in 1984. Equivalent maize yield curves for 1983 LR and 1984 LR are presented in Figs. 1 and 2, respectively. For both years there was a significant ($P = 0.05$) response to applied N (Table 4) and no significant interaction between N source and rate of application. Profit-maximizing rates ranged from 75 to 86 kg N ha^{-1} for 1983 and from 78 to 97 kg N ha^{-1} for 1984 (Table 5).

There was no response to applied N by the intercropped legume (beans) in either season of application. Value:cost ratios ranged from 3.6 to 4.8 in 1983 and from 3.0 to 3.6 in 1984 (Table 5). The lower V:C in 1984 was due to lower maize yields in this season and suggests that profitable returns in mixed cropping systems may vary depending on the weather. In 1983 LR the mean maize grain yield was 6,170 kg ha^{-1} while that of the intercropped beans was 714 kg ha^{-1}. The bean yield was equivalent to a maize yield of 1,412 kg ha^{-1} (18.6% of total EQMAIZE yield). In 1984 LR the mean maize grain yield was 4,786 kg ha^{-1} while that of beans was 3,429 kg ha^{-1} (42% of total EQMAIZE yield). Thus, although the calculated EQMAIZE yield for 1984 LR is high relative to that of 1983 LR, a large proportion of it (42%) is due to beans, which used only about 11% of the applied fertilizer (N fertilizer recovery, Table 6).

The lower maize grain yield in 1984 LR was probably a result of competition for available

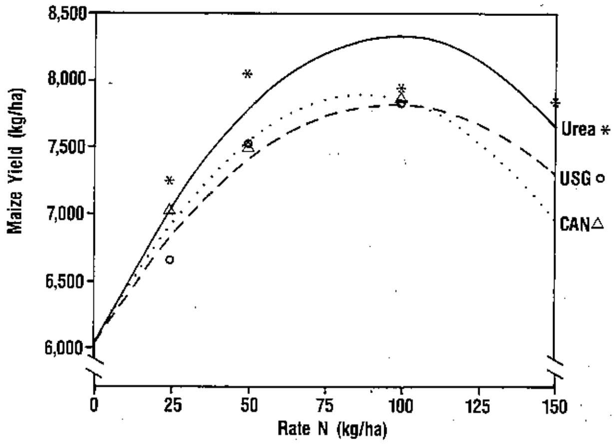

Fig. 1. Effect of nitrogen source (Urea, Urea Supergranules [USG], and Calcium Ammonium Nitrate [CAN]) and rates on equivalent maize grain yield in a maize/bean intercrop system (Initial Effects, 1983 Long Rains).

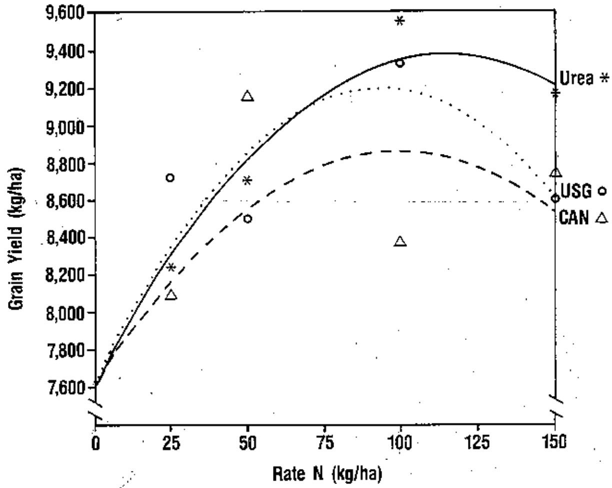

Fig. 2. Effect of nitrogen source (Urea, Urea Supergranules (USG), and Calcium Ammonium Nitrate (CAN)) and rates on equivalent maize grain yield in a maize/bean intercrop system (Initial Effects, 1984 Long Rains).

Table 3. Distribution of rainfall (mm, 15/16 day totals) during the long rainy seasons of 1983 and 1984

Year	March		April		May		June		July		August		Total[a]
	1–15	16–31	1–15	16–30	1–15	16–31	1–15	16–31	1–15	16–31	1–15	16–31	
1983	0.0	55.0	6.0[b]	226.4	27.6	18.2	37.3	14.4[b]	12.7	5.0[b]	13.3	25.5	441.4 (90)
1984	0.3	16.6	11.5	46.3	4.2[b]	5.5[b]	5.7[b]	0.2[b]	0.9[b]	23.4[b]	38.0	62.3[b]	214.9 (210)
9-year mean[c]	93.0		241.5		183.1		39.1		17.0		16.4		590.1

[a] Figures in parentheses indicate estimated total water applied through irrigation.
[b] Supplementary sprinkler irrigation (30 mm water/run), during the 15/16 day period.
[c] Long-term monthly means for Kabete.

Table 4. Effect of nitrogen source and level on equivalent maize grain yield of a maize/bean intercrop (main effect means)[a]

Season[b]	N sources				
	Control	Urea	CAN	USG	
1983LR (initial)	5,930a	7,752b	7,482b	7,368b	
1983SR (residual)	6,171a	5,650a	5,660a	6,084a	
1984LR (initial)	7,563a	8,930b	8,567b	8,782b	
1985LR (residual)	8,157a	8,313a	8,341a	8,266a	
	kg N/ha				
	0	25	50	100	150
1983LR (initial)	5,930a	6,979b	7,695bc	7,866c	7,010b[c]
1983SR (residual)	6,171a	5,912a	5,350b	6,110a	5,822a
1984LR (initial)	7,563a	8,337b	8,782b	9,069b	8,856b
1985LR (residual)	8,157a	8,639a	8,272a	7,963a	8,389a

[a] Yield in kg/ha.
[b] 1983 and 1984 indicate year when experiment was established. Initial refers to effects in the season of application. Residual refers to effects in the subsequent season; LR – long rains (March–July), SR – short rains (October–December).
[c] Only urea was applied at 150 kg N/ha in 1983.

For a given row, means followed by the same letter are not significantly different at P = 0.05 using the Duncan multiple range test.

water during the early stages of growth. Observations on a mono crop of maize on an adjacent plot (irrigated along with the trial plot) indicated much faster development for the mono maize crop. Development of the intercropped maize was retarded until the beans matured. The mean grain yield was 6,150 kg ha^{-1} for the sole maize compared with 4,786 kg ha^{-1} for the intercropped maize.

Results indicated no significant difference (P = 0.05) in performance between the two N sources (urea and CAN) in either season of application nor between point-placed USG and banded urea or CAN (Table 4). This would imply that farmers can use either urea or CAN satisfactorily and profitably on a maize/bean intercrop. In general, however, urea tended to perform better than CAN in the two seasons of application. Thus, when transport costs are considered, the high-analysis urea (46% N) may, in the long run, be a better source of N than CAN (26% N), provided Ca is not limiting crop growth. The effects of using a combination of the two sources (e.g., the widespread current practice in Kenya of applying urea or diammonium phosphate at planting, followed by topdressing with CAN) and different modes of N application on a maize/bean intercrop need to be further investigated. Studies in West Africa indicated that broadcasting (plus incorporation) urea and CAN was superior to banding, particularly in the humid and subhumid tropics [7]. Point place-

Table 5. Economic values and cost of using nitrogen fertilizer on a maize/bean intercrop at profit-maximizing rates of application

Year	N source	N cost (Kshs[b]/kg)	Maize price (Kshs[b]/kg)	N rate[a] (kg/ha)	Yield increment (kg/ha)	Gross benefit (V) (Kshs[b])	Fertilizer cost (C) (Kshs[b])	V:C ratio
1983	Urea	9.57	1.76	86.1	2,273.7	3,991.66	823.99	4.84
	CAN	10.61	1.76	75.2	1,836.4	3,223.91	798.23	4.04
	USG	10.53[c]	1.76	82.2	1,776.4	3,119.40	865.54	3.60
1984	Urea	9.57	1.99	96.6	1,730.8	3,364.74	924.37	3.64
	CAN	9.66	1.94	78.0	1,191.5	2,316.25	771.02	3.00
	USG	10.53[c]	1.94	78.9	1,548.8	3,010.80	831.18	3.62

[a] Profit-maximizing rate.
[b] US $1 = 18.00 Kenya Shillings (Kshs).
[c] Assuming USG cost to be 10% above that of urea.

Table 6. Nitrogen balance (% recovery) during the 1983 and 1984 long rains for a maize/bean intercrop (means of five replicates)

	Urea, 1983[a]	Urea, 1984[b]	CAN, 1984[b]	USG, 1984[b]
Maize plant recovery				
Plant component				
Crown roots	0.31 ± 0.05	0.68 ± 0.17	0.84 ± 0.12	0.68 ± 0.06
Stem	4.54 ± 0.55	3.98 ± 0.58	5.34 ± 0.82	6.35 ± 1.26
Leaf	7.79 ± 0.35	5.76 ± 1.06	6.08 ± 0.96	6.85 ± 0.33
Cob/husk	6.93 ± 0.96	4.32 ± 0.87	3.04 ± 0.45	4.32 ± 1.21
Grain	35.31 ± 2.69	23.26 ± 4.76	19.82 ± 3.48	18.60 ± 0.95
Total (LSD = 13.47)[c]	54.87 ± 4.06	38.00 ± 6.51	35.12 ± 4.31	36.80 ± 5.11
Bean plant recovery[d]				
A (LSD = 4.11)	16.45 ± 1.44	12.32 ± 2.02	14.88 ± 2.97	8.56 ± 1.22
B (LSD = 6.47)	22.16 ± 2.33	10.08 ± 2.98	9.88 ± 2.99	8.18 ± 1.62
Mean (LSD = 4.54)	19.30 ± 1.35	11.20 ± 2.35	12.38 ± 2.57	8.37 ± 0.58
Total plant recovery (LSD = 14.20)	74.17 ± 4.51	49.20 ± 5.35	47.50 ± 6.36	45.17 ± 3.0
Soil recovery				
Soil layer (cm)				
0–15	21.02 ± 2.07	20.95 ± 2.43	18.00 ± 1.99	16.46 ± 0.33
15–30	5.00 ± 0.30	9.45 ± 0.49	7.84 ± 0.63	8.26 ± 0.95
30–60	2.78 ± 0.74	4.45 ± 0.85	4.70 ± 0.84	5.62 ± 0.44
60–90	2.01 ± 0.31	4.42 ± 1.45	3.36 ± 0.87	2.83 ± 0.86
90–120	1.54 ± 0.37	1.53 ± 0.43	2.24 ± 0.72	0.78 ± 0.21
120/150	1.74 ± 0.80	2.50 ± 0.93	1.70 ± 0.26	1.46 ± 0.31
Total (LSD = 7.41)	34.09 ± 1.65	43.30 ± 4.34	37.84 ± 3.18	35.40 ± 1.07
TOTAL RECOVERY (LSD = 17.39)	108.26 ± 7.11	92.5 ± 6.6	85.3 ± 6.2	80.6 ± 3.8

[a] N applied at 50 kg N ha^{-1}.
[b] N applied at 100 kg N ha^{-1}.
[c] LSD at P = 0.05.
[d] A-bean row adjacent to first N split (one-third).
B-bean row adjacent to second N split (two-thirds).

ment of urea, despite the additional costs of making supergranules, had no advantages over banding urea or CAN and may not warrant further studies for similar conditions and cropping systems. Mughogho et al. [7] also found no significant differences between banding and point placement in the humid and subhumid tropics of West Africa; however, point placement significantly diminished the performance of urea in the semi-arid tropics, which suggests losses through ammonia volatilization.

^{15}N studies

Plant and soil recovery data are presented in Table 6. Distribution of ^{15}N is presented in Fig. 3 for the maize plant and Fig. 4 for the soil.

In 1983 (^{15}N-enriched urea banded at a rate of 50 kg N ha^{-1}), virtually all the N fertilizer was accounted for. Plant uptake accounted for about 70% of the N fertilizer (54% taken up by maize plants and 19% by beans), and the remainder was recovered from the soil. Most of the N fertilizer uptake (Fig. 3) was found in the grain (64%). The N fertilizer remaining in the soil (Fig. 4) was largely found in the top layer (0–15 cm, 62%) and decreased sharply down the soil profile.

Although the soils on which these trials were conducted are deep (ground water table believed to be below 15 m [5]) and well drained, the data do not suggest losses through leaching. The rainfall during the cropping period, however, was about 150 mm lower than the site mean. The low

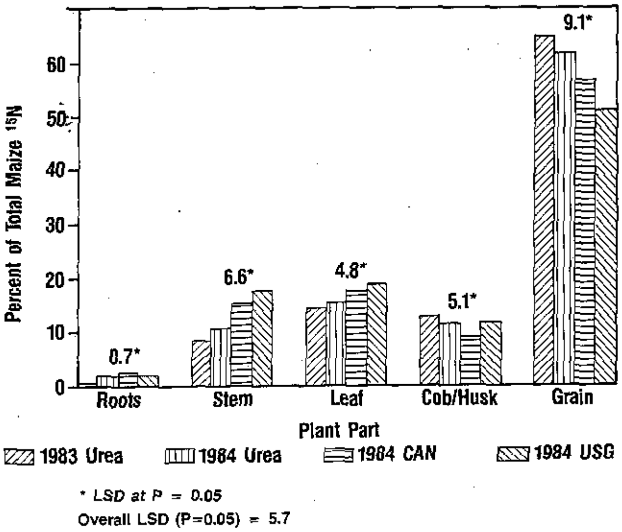

Fig. 3. Distribution of maize ^{15}N taken from applied urea, Calcium Ammonium Nitrate (CAN), and Urea Supergranules (USG) Fertilizers (1983 and 1984 Long Rains).

rainfall may have minimized losses through leaching despite the additional irrigation (about 90 mm) during the growth period. Because much of the soil N fertilizer remained in the top soil layer and no losses are indicated, it is assumed that there were virtually no losses of the split-banded urea through volatilization. The high clay content (64–74%) and high organic matter content (3% carbon) may also have contributed to the low N losses.

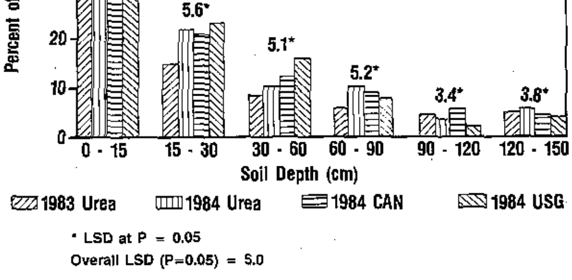

Fig. 4. Distribution of ^{15}N remaining in the soil at the end of 1983 and 1984 long rains where urea, Calcium Ammonium Nitrate (CAN), and Urea Supergranules (USG) have been applied.

Research at IFDC Headquarters indicated that N fertilizer losses via ammonia volatilization were negligible with the heavier textured soils [7]. Besides the higher cation exchange capacity (due to higher clay and organic matter content), which would minimize leaching losses, the additional buffering capacity limits pH rise during urea hydrolysis and results in low losses through volatilization. The relatively high crop densities of the intercropping system also help to minimize losses through an increase of the fertilizer N uptake by the plants (74% versus 55% in this case). The relatively high evapotranspiration of such a system may also help to limit N fertilizer losses through leaching [8].

In the following year (1984 LR), a higher rate of N was used (100 kg N ha^{-1}). A lower percentage of urea was taken up by the plants (49 versus 74%), and a higher percentage remained in the soil (43 versus 34%). The total recovery was again high (92.5%), indicating low losses of the split-banded urea N. The low rainfall during the cropping season (215 mm plus 210 mm through irrigation, compared with the long-term mean of 590 mm at the site), the high clay and organic matter contents in the soil, and the high crop uptake combine to reduce N fertilizer loss as discussed above. The distribution of N fertilizer in the plant (Fig. 3) and soil (Fig. 4) was similar to that of 1983 except that the recovery of N fertilizer by beans was lower (11.2 versus 19.6%). This may be due to cultivar differences. An earlier maturing bean cultivar was used in 1984, and recovery data indicate less uptake from the second split application. It is probable that, besides taking less of the first split N application (adjacent to row A), the early-maturing bean cultivar used in 1984 LR did not take much of the second (adjacent to row B) because the bean plants were approaching maturity at the time of the second split application. In 1983, where a medium-maturing cultivar was used, recovery from row B (where the second split was applied) was higher than that of row A (Table 6).

There were no significant differences ($P = 0.05$) in total N recovery (Table 6) between banded urea, banded CAN, and point-placed urea (USG) in 1984 LR. Data (Table 6) for the two urea sources in 1984 (urea and USG) indicate that concentrating urea by point placement at the maize hill does not necessarily increase N uptake by maize. The relatively low recovery by beans for USG would be expected in that the fertilizer was placed close to the maize hills. Soil ^{15}N recovery for USG was significantly lower than that for urea, and the main difference (20.95% for urea versus 16.46% for USG) occurred in the top soil layer (0–15 cm). The comparatively lower USG recovery in the top soil layer may indicate that N was lost through ammonia volatilization. Similar trends have been observed under low soil moisture conditions [1, 3, 7].

Results of the trials in 1983 LR and in 1984 LR indicate relatively low losses of N fertilizers applied to a maize/bean intercrop. Although rainfall was below average in both seasons, irrigation in 1983 LR increased the total to around the long-term mean and increased crop N uptake without indication of major losses through leaching. The urea supergranule did not improve N fertilizer recovery by the crop.

Residual effects of applied N fertilizer

Data on N fertilizer recovery (Table 6, Figs. 3 and 4) indicated that 34% to 43% of the applied N fertilizer remained in the soil at the end of the season, most of which remained in the top soil layer (70% within the 0–30 cm depth); however, EQMAIZE yield data (Tables 4 and 7) for the subsequent seasons indicated no significant ($P = 0.05$) increases. In some cases, particularly for CAN and urea in 1983 short rains (Table 7). There were significant ($P = 0.05$) reductions in yield compared with the no-nitrogen control. Examination of individual crop yield data indicated that, where significant reductions in EQ-MAIZE yield occurred, significant reductions in maize grain yields were also recorded with no corresponding significant reductions in the yield of the accompanying bean crop. Hence, this trend primarily reflects maize yields. The magnitude of the yield decrease for the residual trials tended to correspond with the magnitude of yield increase during the season of N application (Table 4); thus, nutrient depletion and/or nutrient imbalances following a good crop may be the main reason for the reductions in yield. The results suggest that (1) although some of the applied N fertilizer remains in the soil, it does not significantly benefit the subsequent crop and (2) if N fertilizer is not reapplied in the subsequent season, there might be a reduction in yields relative to crops that had never received N fertilizers.

Interpretative summary

Results of these investigations indicate a profitable response to N fertilizers in the season of application. Although 34–43% of applied N re-

Table 7. Residual effects of applied N on equivalent maize grain yield (kg/ha) of a maize bean intercrop

N source	kg N/ha				
	0	25	50	100	150
1983 short rains					
Control	6,171				
Urea		6,090	4,927	5,760	5,822
CAN		5,890	5,039	6,206	–
USG		5,711	6,085	6,382	–
		LSD ($P = 0.05$) = 939			
1985 long rains					
Control	8,157				
Urea		8,796	8,360	7,830	8,477
CAN		8,563	7,966	8,444	8,373
USC		8,605	8,511	7,542	8,310
		LSD ($P = 0.05$) = 1,007			

CAN – calcium ammonium nitrate, USG – urea supergranules.

mained in the soil at the end of the growing season, there were no beneficial residual effects on the subsequent crop in terms of equivalent maize grain yield of a maize/bean intercrop. Banded urea had a slight edge over banded CAN, but point-placed urea (USG) appears to offer no added economic advantage compared with banded urea and CAN. This is because of the higher cost of USG. High ^{15}N recovery indicated very low N fertilizer losses under the conditions of the study. Point placement of urea did not improve N fertilizer efficiency.

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