JA427 395

Plant and Soil 82, 193–203 (1984). Ms. 5847

Aob

Labeled nitrogen fertilizer research with urea in the semi-arid tropics

3. Field studies on alfisol

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Received 9 March 1984. Revised May 1984

Key words Alfisol Fertilizer application Leaching losses ^{15}N balance Nitrogen fertilizer recovery Nitrogen immobilization Nitrogen losses Nitrogen mineralization *Sorghum bicolor* L. Urea supergranule Vertisol

Summary Field studies with bordered microplots were conducted on an Alfisol in the semi-arid tropics of India to determine (1) the fate of ^{15}N-labeled urea applied to dryland sorghum in two successive rainy seasons and (2) the effect of method of application on N fertilizer efficiency. Recoveries of ^{15}N-labeled fertilizers by above-ground plant parts ranged from 46.7% to 63.6% in 1981 when the rainfall was above the average and from 54.4% to 66.9% in 1980 when the rainfall was near the average. Small (0.014 g) pellets of urea applied twice as post-emergent applications in separate 5 cm deep bands were more effective than single preemergent applications either surface applied or incorporated. Both banding and the split applications contributed to overall fertilizer efficiency. Large (1.0 g) pellets of urea (supergranules) placed at a depth of 5 cm were also superior to the incorporated, small-pellet treatment in 1981. The ^{15}N-balance data for the soil (0–90 cm in depth)-plant system in 1981 showed that the unaccounted-for fertilizer N ranged from 5.1% to 20.6%. An important finding was that high grain yields, in excess of 6,000 kg/ha, with N fertilizer losses of less than 10% could be obtained through fertilizer management during a very wet season. The data from the Alfisol experiments were compared with data from similar Vertisol experiments; N fertilizer losses resulting from incorporated and surface applications were greater for Vertisols than for Alfisols in the wetter year.

Introduction

In the previous paper[7] in this series, the fate of N fertilizer applied to rainy-season sorghum grown on a Vertisol in the semi-arid tropics of India was discussed. Alfisols are also widely distributed in the semi-arid tropics of India, as well as in eastern Africa, Australia, and South America[13]. However, few reports are available of research in which ^{15}N-labeled materials were used to determine the effectiveness of N fertilizers applied to such soils.

Alfisols have lower and more variable water-holding characteristics

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than do Vertisols[12]. Consequently, the potential for deep percolation of nitrate ions beyond the rooting zone is greater with Alfisols. These lower water-holding capacities of Alfisols greatly reduce the chances of successfully raising a post-rainy season crop without irrigation. Thus, the present study was confined to rainy-season sorghum.

Recovery of ^{15}N-labeled fertilizers by sorghum growing on a Paleustalf in the semi-arid gropics of northern Australia was poor[9,10]; N recoveries in above-ground plant parts at maturity were 12.6% to 30.0% in one study[9] and 23.7% in a second study[10]. In an earlier report[8], banded and split applications of N fertilizer at the same location were superior to a preplant application mixed with the topsoil.

Deep placement of large granules of urea, called supergranules, was recently reported to be an effective means of fertilizing lowland rice[4]. Although the use of this technique has not been as extensively tested for nonflooded crops, soil incorporation of urea either as small pellets in nests or as large pellets increased the efficacy of fall-applied N fertilizer in Canada[11]; these placement techniques were presumed to decrease nitrification and denitrification losses associated with nitrate accumulation. In a greenhouse study with sorghum[3], placement of urea as supergranules at a depth of 6 cm was superior to broadcasting small pellets.

The purpose of this study was to determine the following: (1) the fate of ^{15}N-labeled fertilizers applied to sorghum growing on an Indian Alfisol during the rainy season and (2) the influence of method of placement on N fertilizer efficiency.

Materials and methods

Soil and experimental sites

The experiments were conducted in 1980 and 1981 on adjacent areas of a Udic Rhodustalfs at ICRISAT Centre in India. Composite samples of soil from the 0–15 cm depth had the following selected properties: organic C = 0.46%; total N = 0.040%; pH (soil:H_2O = 1:5) = 6.4. No pre-rainy season estimates of soil nitrate levels were obtained because, near the end of the dry season, this Alfisol was impenetrable to a soil probe. The upper 99 cm of soil at the experimental site contained approximately 25 cm of soil water at the field capacity; approximately 11 cm was held at a tension of greater than 1.5 MPa.

The prior rainy-season crops for the 1980 and 1981 sites were sorghum intercropped with pigeonpea and maize, respectively. These crops were grown on broad beds with a spacing of 150 cm between centers of adjacent furrows.

All chemical analyses and calculations of fertilizer N recovery were performed as previously described[7]. CSH-6 sorghum (*Sorghum bicolor* (L.) Moench), with final populations of 130,000 and 100,000 plants/ha in 1981 and 1980, respectively, was planted in both experiments. The urea applied in the various treatments was labeled with approximately 5% excess ^{15}N.

Experiment 1

The 1981 experiment consisted of a completely randomized design with the following treatments: (a) check, (b) 40 kg urea-N/ha, incorporated (I), (c) 80 kg urea-N/ha, (I), (d)

120 kg urea-N/ha, (I), (e) 160 kg urea-N/ha, (I), (f) 80 kg urea-N/ha, split banded (SB), (g) 80 kg urea-N/ha, surface (S), (h) 80 kg urea-N/ha, banded (B) and (i) 80 kg urea-N/ha, ("supergranules"), banded (SG).

All treatments, except h, were replicated four times; the h treatment was replicated three times. Urea pellets, 2.38 mm in diameter and weighing approximately 0.014 g, were used for Treatments b through h; urea pellets 12.7 mm in diameter and weighing approximately 1 g (supergranules) were employed for Treatment i.

The basic experimental unit consisted of a rectangular microplot, 1 m in width and 2 m in length, which was placed across the bed used in the previous growing season. Each microplot was protected to a depth of 30 cm by a metal border and to a depth of approximately 135 cm by three layers of heavy plastic sheeting. The plastic material was placed in position during the preceding dry season after trenches were excavated to a depth of 150 cm around an isolated block of soil with a surface area of 2 m^2. The metal border, which protruded 2.5 cm above the soil surface, was placed in the soil with minimum disturbance prior to excavation. The metal border, in addition to providing stability to the isolated soil block during excavation, also prevented physical loss of ^{15}N from microplots due to runoff.

The experiment was commenced on June 23 after early-season rains had moistened the soil to a depth of approximately 60 cm. The urea for Treatments b, c, d and e was first spread uniformly on the surface of relevant plots. The upper 15 cm of soil of all plots was then mixed by use of a garden fork after the application of a basal dressing of ordinary superphosphate. Two furrows, 5 cm in depth and 25 cm from the long sides, were next dug within the microplots; sorghum was planted in these openings and subsequently covered with soil. Exterior border rows, 25 cm away from the microplots' long sides, and the continuation of the microplot rows outside of the enclosed areas were also planted with sorghum. The urea for Treatment g, involving surface placement without manual incorporation, was then spread uniformly on the soil surface and left undisturbed.

The split-band method of application for Treatment f consisted of splitting the 80 kg urea-N/ha treatment into two equal applications of 40 kg urea-N/ha on June 29 and July 13, 2 and 16 days after emergence, respectively. The split applications were applied in separate bands 5 cm deep at distances of 12 cm from opposite sides of both plant rows. In Treatment h and in Treatment i 80 kg of urea-N/ha was placed in a single band, 12 cm from each plant row at a depth of 5 cm, on June 29. Supergranules for Treatment i were spaced 11.8 cm apart.

All sorghum plants within microplots were harvested on September 24 and 25. Five soil cores, 5 cm in diameter and 90 cm in depth, were taken from each microplot. Composite samples were obtained from the 0–15, 15–30, 30–60, and 60–90 cm depth increments; they were air-dried and ground. To reduce heterogeneity problems resulting from banding of fertilizers in Treatments f, h, and i, a soil slab, 25 cm wide and 30 cm deep, across the width of the microplot and at right angles to the long sides, was isolated as earlier described[4]; soil from the 0–15 and the 15–30 cm depth increments was separated, thoroughly mixed, subsampled, and air-dried preparatory to analysis.

Experiment 2

The 1980 experiment was more limited in scope and was designed to compare the influence of method of placement of 80 kg urea-N/ha on fertilizer N recovery by sorghum. This experiment had a completely randomized design with four replications and the following treatments: (a) check, (b) 80 kg urea-N/ha, incorporated (I), (c) 80 kg urea-N/ha, surface (S) and (d) 80 kg urea-N/ha, split band (SB).

Microplots, similar in construction to those employed in 1981 except that the dimensions were 2.1 × 1.13 m, were used in this study. However, only three layers of heavy plastic sheeting, to a depth of 120 cm, were used to confine the fertilizer and the sorghum roots in the designated areas.

Sorghum was planted on June 18, and seedling emergence was essentially completed by June 26. The split applications of urea, 40 kg N/ha, for Treatment d were applied on July 4 and July 17. The sorghum plants from within the microplots were harvested on September 23.

Table 1. Influence of rate and method of application of urea-N on yield of dry matter and N of above-ground parts of rainy-season sorghum in 1981

Urea		Dry matter (kg/ha)			Plant N (kg/ha)			
N rate, (kg/ha)	Application method†	Grain	Stover	Chaff	Grain	Stover	Chaff	Total
0	—	1,590	3,650	420	17.9	12.0	2.0	31.9
40	I	3,650	4,930	870	41.1	16.9	3.9	61.9
80	I	4,660	6,080	1,060	56.7	21.6	5.3	83.6
120	I	5,720	6,700	1,270	76.7	28.1	6.5	111.4
160	I	5,720	6,680	1,320	76.9	32.1	7.3	116.3
80	SB	6,060	6,080	1,250	70.5	26.4	5.6	102.5
80	S	5,450	6,080	1,180	66.0	23.6	5.8	95.4
80	B	5,380	5,910	1,230	63.5	23.5	5.9	92.8
80	SG	5,170	5,940	1,250	63.6	24.4	6.7	94.7
$S\bar{x}$		320	259	56	4.6	1.7	0.4	6.2
F value		***	***	***	***	***	***	***

*** denotes significance at the $P = 0.001$ level. $S\bar{x}$ indicates the standard error of the particular mean value.

† I, SB, S, and B indicate application methods were incorporation, split band, surface application, and single band, respectively; SG refers to supergranules placed in a single band.

Results

Experiment 1

Growing season conditions. Total rainfall between planting and harvesting in 1981 was 827 mm. A rainfall of 16.6 mm commenced within 5 hours of planting and washed the surface-applied urea (Treatment g) into the soil. Rainfall between harvesting and the completion of soil sampling was 147 mm. The sorghum plants exhibited no signs of water stress throughout the growing season.

Yield and nitrogen uptake. As shown in Table 1, rate and method of application of urea greatly affected dry matter production and N uptake by sorghum. Grain yields increased from 1,590 to 5,720 kg/ha as the rate of soil-incorporated urea was increased from 0 to 120 kg N/ha. Of particular interest is the effect of method of application of 80 kg urea-N on grain yield. The split-band treatment was clearly superior to the treatment involving incorporation of urea into the upper 15 cm of soil on the day of planting. The application of supergranules or small pellets in a single band soon after planting and the day-of-planting surface application tended to be more efficacious than the corresponding incorporated, small-pellet treatment; however, the first mentioned treatments also tended to be inferior to the split-band treatment.

The superiority of a split-band application of urea over the

Table 2. Effect of rate and method of application on the fate of labeled urea fertilizer applied to rainy-season sorghum in 1981

Urea		^{15}N recovery (%)				
N rate, (kg/ha)	Application method[†]	Soil	Grain	Stover	Chaff	Total
40	I	46.9	28.9	14.7	3.1	93.6
80	I	33.0	32.1	14.6	3.3	83.0
120	I	31.1	36.3	14.7	3.2	85.4
160	I	27.8	33.7	14.6	3.2	79.4
80	SB	28.8	40.6	19.4	3.6	92.4
80	S	35.6	33.6	14.7	3.3	87.2
80	B	29.1	36.9	17.4	3.8	87.2
80	SG	33.3	38.2	19.0	4.5	94.9
$S\bar{x}$		2.4	1.4	0.9	0.3	2.8
F value		***	***	**	*	*

*, ** and *** denote significance at the $P = 0.05$, $P = 0.01$ and $P = 0.001$ levels, respectively. $S\bar{x}$ indicates the standard error of the particular mean value.

†I, SB, S, and B indicate application methods were incorporation, split band, surface application, and single band, respectively; SG refers to supergranules placed in a single band.

corresponding incorporated treatment is also evident when total N uptake data for above-ground plant parts are considered. Nitrogen accumulations were relatively similar for the supergranule, single band, and surface-applied urea treatments.

Fate of fertilizer nitrogen. A balance sheet showing how rate and method of application of urea influenced the distribution of labeled fertilizer N between above-ground plant parts and soil in the 0–90 cm depth is given in Table 2. The presence of rocks and stones prevented sampling to deeper depths. The quantity of labeled fertilizer N accounted for at the end of the rainy season ranged from 79.4% to 94.9%. The highest recovery was obtained by applying 80 kg N/ha in the form of urea supergranules. The split-band application resulted in the largest plant accumulation of fertilizer N. The magnitude of the fertilizer N remaining in the soil, 27.8% to 46.9%, was high. However, the quantity of this residual soil N from the incorporated treatments, expressed as a percentage of the amount applied, decreased with higher rates of fertilizer addition.

A comparison of percentage N fertilizer recovery estimated by direct (isotope) and indirect (difference) methods is given in Table 3. The indirect method in all cases resulted in a higher recovery value for a given treatment. Difference methods suffer from the disadvantage that the variance of a difference between two means is equal to the sum of the individual variances. This accounts at least partly for the poor

Table 3. Comparison of direct (isotope) and indirect (difference) methods for determining recovery of N-labeled urea fertilizer by above-ground parts of rainy-season sorghum in 1981

Urea		N recovery (%)	
N rate (kg/ha)	Application method†	Direct	Indirect
40	I	46.7	75.0
80	I	50.0	64.6
120	I	54.3	66.2
160	I	51.6	52.7
80	SB	63.6	88.2
80	S	51.6	79.4
80	B	58.1	76.1
80	SG	61.6	78.5
$S\bar{x}$		2.0	8.8
F value		***	NS

NS and *** denote no significance and significance at $P = 0.001$ level, respectively. $S\bar{x}$ indicates the standard error of the particular mean value.

†I, SB, S, and B indicate application methods were incorporation, split band, surface application, and single band, respetively; SG refers to supergranules placed in a single band.

Table 4. Recovery of labeled urea-N in selected soil depths at the end of the 1981 season

Urea		^{15}N recovery (%)/depth increment (cm)				
N rate (kg/ha)	Application method†	0–15	15–30	30–60	60–90	Total
40	I	29.5	9.5	5.4	2.5	46.9
80	I	20.0	7.3	3.6	2.0	33.0
120	I	19.1	6.9	3.4	1.8	31.1
160	I	12.3	8.4	4.7	2.4	27.8
80	SB	20.5	2.6	3.8	2.0	28.8
80	S	23.9	6.0	3.3	2.3	35.6
80	B	21.0	3.7	2.4	2.0	29.1
80	SG	24.0	3.5	3.7	2.0	33.3
$S\bar{x}$		1.9	2.0	0.6	0.4	2.4
F value		***	***	NS	NS	***

NS and *** denote no significance and significance at the $P = 0.001$ level, respectively. $S\bar{x}$ indicates the standard error of the particular mean value.

†I, SB, S, and B indicate application methods were incorporation, split band, surface application, and single band, respectively; SG refers to supergranules placed in a single band.

precision of the indirect estimates of N fertilizer recovery. Nevertheless, the highest N recovery among the 80 kg N/ha treatments, and in fact among all treatments, was obtained by use of the split-band application technique.

Most of the fertilizer N remaining in the soil after the maturity harvest was located in the top 15 cm of soil (Table 4). For example, the quantity of the residual fertilizer N in the upper 15 cm of soil

Table 5. Influence of method of application of urea-N on yield of dry matter and N of above-ground parts of rainy-season sorghum in 1980

Urea (kg N/ha)	Application method	Dry matter (kg/ha)			Plant N (kg/ha)			
		Grain	Stover	Chaff	Grain	Stover	Chaff	Total
0	–	5,230	4,250	1,290	63.9	17.2	8.3	89
80	Incorporation	6,120	4,530	1,210	91.1	25.5	7.7	124
80	Surface	6,140	4,380	1,190	89.6	23.7	9.0	122
80	Split	6,570	4,590	1,280	93.2	24.3	9.0	127
$S\bar{x}$		175	172	106	3.7	1.0	1.0	5
F value		***	NS	NS	***	***	NS	***

NS and *** denote no significance and significance at the $P = 0.001$ level, respectively. $S\bar{x}$ indicates the standard error of the particular mean value.

Table 6. Comparison of direct (isotope) and indirect (difference) methods for determining recovery by above-ground parts of rainy-season sorghum in 1980 of N-labeled urea fertilizer

Fertilizer application method	N recovery (%)	
	Direct	
Split band	66.9	46.5
Surface	55.0	41.2
Incorporation	54.4	43.7
$S\bar{x}$	1.1	5.4
F value	***	NS

NS and *** denote no significance and significance at the $P = 0.001$ level, respectively. $S\bar{x}$ indicates the standard error of the particular mean value.

Table 7. Influence of method of fertilizer application on recovery of N-labeled urea fertilizer (80 kg N/ha) by above-ground parts of sorghum growing on Alfisols and Vertisols in the 1980 and 1981 rainy seasons

Fertilizer application method	^{15}N recovery (%)			
	1980		1981	
	Vertisol†	Alfisol	Vertisol†	Alfisol
Split band	–	66.9	55.7	63.6
Surface	48.0	55.0	30.5	51.6
Incorporation	48.6	54.4	28.9	50.0
$S\bar{x}$	1.0	1.1	2.0	2.0
F value	***	***	***	***

*** denotes significance at the $P = 0.001$ level. $S\bar{x}$ indicates the standard error of the particular mean value.
†Data for the Vertisol experiment were reported in Part 2 of this series of articles.

expressed as a percentage of that in the top 90 cm, with one exception, exceeded 59%; the exception was the incorporated, 160 kg urea-N/ha treatment where only 44.2% was located in the surface layer. Most of the residue N in the upper 15 cm was presumably organic in nature, since the quantity of 2 *M* KCl extractable inorganic N in this zone was low. Small quantities of residue N, 1.8% to 2.5%, were found in the 60–90 cm depth increment.

Experiment 2

Growing season conditions. Total rainfall between planting on June 18 and harvesting on September 23, 1980, was 606 mm. The urea granules, albeit somewhat disintegrated as a result of moisture absorption, were visible on the soil surface until rain, 4.4 mm, fell on June 26. Rainfall during the 1980 growing season was appreciably less than that in 1981; however, the sorghum plants showed little evidence of water stress, apart from some slight wilting at the 8- to 10-leaf stage.

Yield and nitrogen uptake. The effect of method of application on yield and N uptake is illustrated in Table 5. Response to the application of 80 kg urea-N/ha was small. Consequently, the method of application of fertilizer was of little agronomic importance; nevertheless, grain production was highest with the split-band application. The yield of N, 89 kg N/ha, in the above-ground plant parts from microplots with the check N treatment was relatively high.

Fate of fertilizer nitrogen. When the isotope approach was used over 50% of the fertilizer N was found in the above-ground plant parts (Table 6). The recovery with the split-band application, 66.9%, was significantly greater than that from either the surface applied or incorporated treatments. Recoveries of urea applied with the last two techniques did not differ significantly. Also, recoveries of fertilizer N estimated by the difference technique were appreciably less than those obtained by use of the direct isotope method. However, the imprecision of the difference method prevented any firm conclusion regarding effects of fertilizer application methods.

Discussion

The 1980 and 1981 rainy season, with seasonal rainfall values of 753 and 1,049 mm, respectively, provided contrasting environments for recovery studies with ^{15}N-labeled fertilizers. Recoveries of ^{15}N-labeled fertilizers by above-ground plant parts, over a wide range of application methods and N fertilizer rates, were relatively high: they ranged from 46.7% to 63.6% and from 54.4% to 66.9% in 1981 and 1980, respectively. An important finding of this study was that high yields of sorghum with N fertilizer losses of less than 10% could be obtained with proper management. However, use of only two rows of sorghum within microplots could have restricted lateral proliferation of roots on the sides adjacent to the microplots long borders. This may have caused deeper root penetration which possibly reduced potential leaching losses of N.

Certain ^{15}N-labeled fertilizer treatments were common to the current study and the previously published Vertisol experiments[7]. As shown in Table 7, N recoveries by sorghum growing on Alfisols were higher than the corresponding values for Vertisols. These differences were particularly produced in the very wet 1981 season. Soil moisture contents at the field capacity are much higher for Vertisols than for Alfisols; for instance, the soils at the Alfisol and Vertisol experimental sites contained approximately 25 and 42 cm of water, respectively, in the upper 98 cm at their field capacities. Consequently, leaching losses of nitrate should be greater, for given rainfall amounts, from Alfisols than from Vertisols. The fact that the overall N recovery data showed the reverse trend strengthens the hypothesis that denitrification rather than leaching of nitrate is an important factor affecting N fertilizer efficiency on Vertisols, especially in wet years. Within-season drought is more likely to affect growth and N fertilizer efficiency of crops growing on Alfisols; however, such conditions were not encountered in the current study. Also, the type of microplots used in the Alfisol studies restricted N losses due to runoff.

Method of application influenced N fertilizer recovery. The agronomic and N recovery data demonstrated the superiority of banded applications of urea, applied in two split applications after sorghum emergence, over the corresponding soil-incorporated treatment. Although the data were not conclusive, a comparison of the agronomic and N recovery data for the incorporated, split band, and single band applications of 80 kg N/ha in 1981 suggests that banding and the time-delay factor increased the efficacy of urea fertilizer. There was little difference between the effectiveness of the incorporated and surface-applied urea treatments in either experiment. This result agrees with the findings from the Vertisol experiments[7].

Placement of supergranules in bands in the 1981 experiment resulted in higher fertilizer N recoveries than did the incorporated, small-pellet treatment. Superiority of large urea (+ thiourea) pellets over small pellets for fall applications of N in the Canadian Prairies was considered to be primarily a function of decreased nitrification and associated denitrification[11]. Moreover, banding urea and ammonium salts in soil reportedly creates a localized environment in which the soil solution has a high osmotic potential unfavorable to nitrifying bacteria[15]. Use of supergranules presumably would decrease the rate of nitrification and possible leaching losses of nitrate. Supergranules, deep placed in the soil, can also reduce ammonia volatilization losses[3].

Sorghum in our study recovered appreciably more fertilizer N than did sorghum growing on Alfisols in two ^{15}N-labeled fertilizer studies[9,10] in the semi-arid tropics of Australia. However, comparison of our work and the Australian studies is not generally valid since no agronomic and N uptake data for check (zero N) treatments were given for the latter investigations. Low recoveries of fertilizer N are frequently found when the levels of available N in the soil are high[2].

Interpretation of the data from labeled ^{15}N-fertilizer experiments would be affected if gaseous losses of N from plants occurred. Evidence is accumulating that under some conditions plant losses of gaseous N, particularly between anthesis and maturity, can be important[14]. However, the plant effect was probably of minor importance, at least in our 1981 study, since recovery of labeled fertilizer in soil and above-ground plant parts was as high as 94.9%. Little desiccation of stem and leaf tissue of N-fertilized plants had occurred by the final harvests in our study. Nevertheless, factors affecting gaseous losses from plants in the semi-arid tropics require additional study since such losses from sorghum were apparently significant in an Australian study[10].

Plant recoveries of fertilizer N measured by the direct isotope method in 1981 were lower than those measured by indirect estimates based on subtraction of total N taken up by plants growing on non-fertilized plots. This effect is commonly found in ^{15}N-labeled fertilizer studies[5,6]. The soil recovery data in Table 4 support the hypothesis[6] that the mineralization-immobilization turnover was at least partly responsible. Mineralization-immobilization phenomena, however, apparently do not account for the isotope recovery differences resulting from method of fertilizer application.

The plant recovery data for the 1980 experiment are anomalous in that the isotope technique yielded higher recoveries than did the indirect method. An important difference between the 1980 and 1981 sites was that the level of available N in the soil was much greater in 1980, as evidenced by quantity of N taken up by plants growing on the check plots and the small agronomic response to fertilizer. Efficiency of plant uptake of inorganic N sometimes decreases when levels of available N in the soil are greater than those required for maximum yield[2]. Also, high levels of available N in the soil restricted the uptake of deep soil nitrate by sugar beets[1]. If the labeled fertilizer was preferentially taken up early in the 1980 growing season because of positional or chronological factors, plant uptake of deep, residual nitrate or of N mineralized during the growing season may have been reduced. Such effects may reverse the usual bias in favor of the indirect approach.

Acknowledgements Appreciation is extended to Dr Paul Vlek for suggesting the study and for his sustained interest, to Dr. J. Burford for providing facilities at ICRISAT Centre, and to Mrs Seetha and Mr Pradhasaradhi for the laboratory analyses. The senior author expresses his thanks to Ms Teresa Papachek for secretarial help, to North Dakota State University for providing him with leave to participate in this study, and to IFDC and ICRISAT for the opportunity to work temporarily in international agricultural research.

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