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Recovery of Fertilizer Nitrogen by Maize Grown with Nutriseed Pack and Soil Nitrogen Retention Using ^{15}N Tracer

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In a cropped land plant and soil utilizes nitrogen (N) mainly from fertilizer. Deep placement of fertilizer N enhances added N use efficiency. Nutriseed Pack technique is a way of deep placing fertilizer in the root zone simultaneously when sowing the seed. A Green house experiment with ^{15}N tracer technique was conducted during 2009 at open premises of green house in the Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore to evaluate the effect of application of fertilizers in maize by surface broadcast and Nutriseed Pack. Each Nutriseed Pack was assembled by stacking of seed, manure and fertilizer pellets and then wound in newspaper as a roll. On placement in soil, supply of nutrients is expected from Nutriseed pack throughout the crop period. Column study on ^{15}N recovery of added fertilizer by maize resulted in high recovery (NUE) for horizontal placement of Nutriseed Pack (36.17%) followed by placement of vertical Nutriseed Pack with Furadan (33.62%), and moderate recovery for surface broadcast (30.45%). The applied labelled N retained in surface layer was high in horizontal placement of Nutriseed Pack which ranged from 8.0 to 18.1 per cent in surface layer (0-15 cm), 4.9 to 10.8 per cent in sub-surface layer (15-30 cm), and 2.8 to 6.0 per cent the lower layer (30-45cm) respectively. In case of surface application of fertilizers, N retained was 5.5 per cent in surface layer (0-15 cm), 3.2 per cent in sub-surface layer (15-30 cm), and 11.1 per cent in lower layer (30-45 cm) respectively.

Key words: Nutriseed Pack technique, Deep placing fertilizer, ^{15}N Tracer, Maize, Nitrogen use efficiency

Maize (*Zea mays* L.) is emerging as third most important crop after rice and wheat with adaptability to diverse agro-climatic conditions around the World. Maize is one of the World's leading crops cultivated over an area of about 148.5 million hectares with a production of about 699.3 million tonnes and productivity of 4.71 tonnes ha^{-1} (USDA, 2007). In India, it occupies third place among the cereals after rice and wheat, grown in an area of 7.9 million hectares with the production of 14.71 million tonnes with an average productivity of 1938 kg ha^{-1} (AGRISTAT, 2007).

Optimum nutrient management has long been acknowledged as being critical for producing high yield in maize. However, there are multiple factors that cause decision making on fertilizer application to be a complex process. Unless the supply of fertilizer nutrients to the crop is increased, low soil nutrient availability will remain as a serious constraint to increase maize production. One means of increasing the nutrient supply without increasing the fertilizer amount is to improve the efficiency of fertilizer, which can be achieved through deep placement of the fertilizers.

Nitrogen tracer (^{15}N) technique is an accurate tool to assess the N use efficiency and retention of added N in soil under different N management practices. Assaying on ^{15}N tracer added as labelled urea made in the present study in different plant parts of maize, brought out the superiority of particular treatments based on the derivation of fertilizer N from soil and its accumulation in plant parts, total N and retention of labelled N in soil layers, total uptake of N, quantity and per cent recovery of labelled N in plant parts and N use efficiency.

Materials and Methods

The ^{15}N recovery experiment was conducted in the green house (up to flowering) and in open premises of green house in the Department of Soil Science and Agricultural Chemistry, TNAU, Coimbatore. The experimental soil was brought from the eastern block of central farm, which belongs to **Vertic Ustropept** of Periyanaickanpalayam series.

Construction of soil column in rigid tube

Rigid PVC tubes were used to construct soil column. Tubes (22.5 cm diameter) cut into pieces of 60 cm length were made as a tubular pot to house soil column, by closing the bottom end tightly with end cap. This tubular pot was uniformly filled with 12 kg of soil to occupy up to 55 cm height by adding about 2 kg soil at a time and tapping gently on a gunny cushion. At 10, 20 and 30 cm level from the

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soil surface, a pair of small holes (3 mm diameter) were provided for aeration.

Nutriseed Pack Preparation

Nutriseed Pack was assembled by stacking of seed, manure and fertilizer pellets and then wound in newspaper as a roll.

Treatments

^{15}N labelled urea (5.474 % atom ^{15}N excess) was used for the preparation of fertilizer pellet of Nutriseed Pack and for surface broadcast.

Tr.No.	Treatment	Details
T_1	Manure Pellet + Fertilizer Pellet (Vertical)	Vertical placement in soil
T_2	Manure Pellet with Neem + Fertilizer Pellet (Vertical)	Vertical placement in soil
T_3	Manure Pellet + Fertilizer Pellet (Horizontal)	Horizontal placement in soil
T_4	[Manure + Neem + Fertilizer] Pellet (Vertical)	Manure + Neem + Fertilizer mixture within encapsulation
T_5	Manure Pellet with Furadan + Fertilizer Pellet (Vertical)	1 g Furadan mixed to 100g Vermicompost
T_6	Conventional surface broadcast fertilizers	Broadcasted 50% of N at basal, 25% N at 25 DAS, and 25% N at 45 days after sowing

Details of Experiment

Weight per Soil column	: 12 kg
Plants per tube	: 1
Crop and Variety	: Maize,CoH(M)5 Hybrid
Duration (days)	: 105 – 110 days
N, P_2O_5, K_2O kg ha^{-1}	: 150:75:75
Season	: Kharif 2009
Replication	: 2

Observations recorded

At harvest stage, the total N was estimated in soil layers of 0–15 cm (surface layer), 15–30 cm (sub surface layer), and 30–45 cm (lower layer). Plant samples collected at harvest stage were separated into leaves, stem, tassel, earleaf, pith and grain. Plant and soil samples were subjected to ^{15}N assay.

Measurement of ^{15}N assay

The plant and soil samples were digested by adopting regular kjeldahl digestion procedure to convert N in to ammonia form (Bremner, 1965). The digested samples were distilled in to 2 per cent boric acid solution containing double indicator (Bromo cresol green and Methyl red) and titrated with 0.1N H_2SO_4 to obtain ammonium sulphate, a suitable material for ^{15}N analysis (Buresh *et al.,* 1982). The acidified boric acid solution containing ^{15}N as ammonium sulphate was evaporated at 90°C on a sand bath to reduce the volume to about 3 ml. The contents were then evaporated at room temperature until it dried to flakes. The boric acid flakes were transferred to a small polythene bag, stored and used for ^{15}N assay.

^{15}N/^{14}N ratio analysis

The ammonium sulphate samples were allowed to react with sodium hypobromite solution to evolve N_2 in the inlet system of mass spectrometer (model micromass 622 VG ISOGAS) Inside the mass spectrometer, N_2 was ionized for ^{15}N/^{14}N ratio measurement. Ratio analysis was performed as per the procedure outlined by Buresh *et al.,* (1982) and Pruden *et al.,*(1985).

Calculation of results

Isotopic abundance was expressed in terms of ^{15}N atom per cent and calculated using the following relationship.

$$^{15}\text{N atom \%} = \frac{R}{R+2} \times 100$$

Where,

R = Measured ratio between the ion currents corresponding to the mass 28 (^{14}N^{14}N) and mass 29 (^{14}N^{15}N)

$$\text{Further,} \quad R = \frac{m}{(M+1)\,100}$$

Where,

m = current of minor ion beam (^{14}N ^{15}N).

M = current of major ion beam (^{14}N ^{14}N)

The labeled ^{15}N recovered by crop as well as retained in soil were calculated as detailed in the technical document IAEA (1983).

The fraction of N derived from ^{15}N fertilizer (fNdff) in the plant or soil was calculated using the following equation.

$$\text{fNdff} = \frac{\%\text{ atom }^{15}\text{N excess in plant or soil}}{\%\text{ atom }^{15}\text{N excess in fertilizer}}$$

$$\%\text{Ndff} = \text{fNdff} \times 100$$

Accounting for ^{15}N recovery in plant and ^{15}N retained in soil were made with the following formulae:

$$\text{mg Ndff Column}^{-1} = \frac{\%\text{ Ndff}}{100} \times \text{(N uptake / plant) (mg)}$$

$$\text{Total \% Ndff} = \frac{\text{mgNdff (leaves) + mgNdff (stem) + mgNdff (tassel) + (mgNdff (sheath) + mgNdff (pith) + mgNdff (grain) + mgNdff (root)}}{\text{Total N uptake (mg pot}^{-1}\text{)}} \times 100$$

Total mgNdff = Total %Ndff X Total N uptake

Total N uptake (mg Column^{-1}) = dry matter (mg pot^{-1}) X N content (%)

$$\text{Crop recovery of fertilizers N (N use efficiency) (\%)} = \frac{\text{Total N uptake (mg pot}^{-1}\text{) X \%Ndff}}{\text{Fertilizer N applied (mg pot}^{-1}\text{)}} \text{ X } 100$$

$$\text{Retention of fertilizer N in soil (\%)} = \frac{\text{Total N in soil (mg Column}^{-1}\text{) X \%Ndff}}{\text{Fertilizer N applied (mg pot}^{-1}\text{)}} \text{ X } 100$$

$$\text{Partitioning efficiency (\%)} = \frac{\text{mg Ndff of plant part}}{\text{Total mg Ndff of whole plant}} \text{ X } 100$$

Results and Discussion

Tracer studies with labelled N conducted in soil column brought out clear cut information on the extent of distribution of applied N in different plant parts of maize plant, N use efficiency and retention in soil layers.

Total N and Retention of Labelled N in Soil Layers

Among the treatments, horizontal placement of Nutriseed Pack (T_3) registered the highest total N (6350 mg) in 0-15 cm layer, whereas the other Nutriseed Pack treatments recorded relatively high total N ranging from 6044 to 6350 mg. Surface broadcast of fertilizers resulted in low status of total N (6118 mg).

With respect to retention of applied labelled N, the highest value was found in horizontal placement of Nutriseed Pack (T_3) registering 326 in the 0-15 cm soil layer. In general Nutriseed pack treatments retained more labelled N on surface layer (0-15 cm) than the underlying layers. In contrast surface application of fertilizers retained very high labelled N (200 mgNdff) in the lower layer (30- 45 cm) (Table 1).

Over all, the applied labelled N retained in surface layer was highest (18.1%) in horizontal placement of Nutriseed Pack (T_3). By placing Nutriseed packs retention of applied N ranged from 8.0 to 18.1 per cent in surface layer (0-15 cm), from 4.9 to 10.8 per cent in sub-surface layer (15-30 cm), and from 2.8 to 6.0 per cent the underlying lower layer (30-45cm). In case of surface application of fertilizers, N retained was 5.5 per cent in surface layer (0-15 cm), 3.2 per cent in sub-surface layer (15-30 cm), and 11.1 per cent in lower layer (30-45cm).

Due to application of fertilizers by surface broadcast and by deep placed Nutriseed Pack total N of soil layers did not vary much in the underlying layers, however variation was noted in the surface layer (0-15 cm). Horizontal placement of Nutriseed Pack registered the highest total N followed by vertical placement, and then surface application.

Table 1. Total N and Retention of Labelled N in Soil Layers

Treatment	Layer (Depth in cm)	Total N (mg)	Labelled N		
			% Ndff	mg Ndff	%N retained
T_1	0-15	5641	3.27	184	10.2
	15-30	4656	4.18	195	10.8
	30-45	3758	2.87	108	6.0
T_2	0-15	6227	3.76	234	13.0
	15-30	5005	3.13	156	8.7
	30-45	3747	2.63	99	5.5
T_3	0-15	6350	5.13	326	18.1
	15-30	4865	3.24	158	8.8
	30-45	3665	2.14	79	4.4
T_4	0-15	6218	2.33	145	8.0
	15-30	5048	1.74	88	4.9
	30-45	3682	1.53	56	3.1
T_5	0-15	6044	2.53	153	8.5
	15-30	5012	3.75	188	10.5
	30-45	3650	1.37	50	2.8
T_6	0-15	6118	1.63	100	5.5
	15-30	4911	1.16	57	3.2
	30-45	3665	5.46	200	11.1

Similarly very high retention of labelled N to the tune of 11.1 per cent found in 30-45 cm layer also strongly substantiates the result.

Placement of N with Nutriseed Pack could have released N steadily when placed within 2 cm from surface under horizontal placement and at 5 cm under vertical placement. Steady release of N in small amounts might have remained around the point of release thereby would not have been lost or leached.

Drymatter and Yield

The drymatter of plant parts and grain of maize grown in soil column showed remarkable variation with the methods of ^{15}N application. Among the treatments, vertical and horizontal alignments as well as mixture Nutriseed Pack produced the very high drymatter of stem (26.3 to 27.3 g plant^{-1}). The leaf weight of tassel was high under Neem, Furadan and mixture Nutriseed packs (20.1 to 22.3 g plant^{-1}). In case of dry matter production the root, tassel and ear leaf showed no specific variation among treatments (Table 2).

Table 2. Drymatter of plant parts and Grain weight of Maize

Treatment	Drymatter and Grain Yield (mg plant^{-1})						
	Root	Leaf	Stem	Tassel	Ear leaf	Pith	Grain
T_1	6.9	17.5	27.3	2.8	10.9	16.7	61.0
T_2	5.9	20.1	23.6	2.9	9.6	16.6	60.1
T_3	7.4	18.4	26.4	2.3	10.3	16.2	63.1
T_4	6.7	22.3	26.3	3.1	9.9	17.4	56.3
T_5	6.7	20.1	25.8	3.2	10.7	15.3	59.1
T_6	6.6	18.1	21.7	4.2	9.3	16.9	58.2

The grain weight was highest under horizontal placement followed by vertical placement with plain and Neem based Nutriseed Packs (60.1 to 63.1 g plant^{-1}). In other treatments the yield was relatively high ranging from 56.3 to 59.1 g plant-1.When the same amount of NPK fertilizers (N as ^{15}N urea) were applied, the effect on drymatter of plant parts seemingly varied only in stem and leaf of maize due to the effect of surface broadcast and Nutriseed Pack treatments. Stem weight was high under Nutriseed Pack under horizontal / vertical orientation. On the other hand, more leaf production might have occurred due to Neem and Furadan which were known to enhance the growth by nitrification inhibition and hormonal function respectively

Uptake of N in plant parts

The amount of N utilized for the development of root was meager whether the fertilizer was surface broad cast or deep placed using Nutriseed Pack.Very high N uptake in stem was obtained due to Nutriseed pack under vertical and horizontal alignment (286 mg plant-1) while uptake of N in stem due to broadcasted fertilizers (T_6) was low (220 mg plant-1).

Noticeably horizontal placement of Nutriseed pack showed very high N uptake in grain (886 mg plant-1), followed by vertical placement of Nutriseed Pack Plain (T_1) and with Neem in manure Pellet (T_2). Surface Broadcast (T_6), Nutriseed Pack with Fertilizer + Neem + Manure as mixture (T_4) or with Furadan (T_5) registered lower N uptake in grain ranging from 744 to 794 mg plant-1 (Table 3).

Table 3. Uptake of N in plant parts of Maize

Treatment	N uptake (mg plant-1)						
	Root	Leaf	Stem	Tassel	Ear leaf	Pith	Grain
T_1	17	223	286	29	116	84	859
T_2	14	244	245	31	103	79	831
T_3	19	239	286	24	112	85	886
T_4	16	262	254	31	102	75	744
T_5	16	250	260	32	115	73	794
T_6	16	317	220	43	98	79	784

The estimated uptake of N in roots was small, because roots of maize are fibrous and do not contain pigments or compounds in tissues that are plenty with N. Uptake of N in leaves was enhanced by surface broadcast of fertilizers, whereas Nutriseed Pack treatments influenced moderately. Controversially, very high N uptake in stem occurred due to Nutriseed Pack under both vertical and horizontal alignment. Rees *et al.* (1997) found that the crop recovery of fertilizer N following point placement was 25 per cent of that applied, which was higher than that of surface application and also increased the grain yield, total N uptake, and dry matter yield as well as grain N contents in maize and wheat.

Quantity of labeled N in plant parts (mgNdff)

The Horizontal placement of Nutriseed Pack (T_3) registered high quantity of labeled N in root (1.0 mgNdff). The surface broadcasting fertilizers (T_6) enhanced very high quantity of labeled N in leaf (138.7 mgNdff), whereas Nutriseed Pack with Furadan treatments influenced high concentration labeled N 120 mgNdff. Very high quantity of labeled N in stem (188.8 mgNdff) was obtained due to Nutriseed Pack with Furadan (T_5). For tassel development the quantity of labeled N noted was high (15.3 mg Ndff) under surface broadcast of fertilizers (T_5). Nutriseed Pack with Furadan influenced high support for the development of Ear leaf with quantity of labeled N (83.5 mgNdff). Remarkably horizontal placement of Nutriseed pack showed very high quantity of labeled N of 31.6 and 308.7 mgNdff in pith and grain respectively (Table 4).

Table 4. Quantity of labeled N in plant parts of maize (mgNdff)

Treatment	mgNdff						
	Root	Leaf	Stem	Tassel	Ear leaf	Pith	Grain
T_1	0.5	84.0	136.0	11.2	49.6	22.0	239.7
T_2	0.5	99.8	128.5	7.7	58.6	23.0	225.2
T_3	1.0	100.9	137.3	6.4	65.1	31.6	308.7
T_4	0.5	92.8	114.4	11.2	55.1	19.5	140.7
T_5	0.5	120.5	188.8	12.0	83.5	22.2	177.7
T_6	0.6	138.7	168.9	15.3	76.0	17.9	130.7

The function of fertilizer N in contributing the development of different plant parts and resulting in grain yield has been distinctly brought out by mgNdff values. Even though mgNdff values were very high in leaf, stem and ear leaf, ultimately it did not escalate mgNdff of grain and yield.

In the case of Nutriseed Pack treatments other than fertilizer + manure mixture, there were moderate mgNdff values in all plant parts. Appreciably, horizontal placement of Nutriseed Pack recorded very high mgNdff of grain that could have been the responsible factor for high grain yield. These results clearly reflect the continuous contribution of fertilizer N throughout the crop period when fertilizer N was placed at different depth, and its release was regulated.

Recovery of labeled N in plant parts and N use efficiency (%)

The placement of Nutriseed Pack as well as surface broadcast showed very low recovery of labeled N in root ranging from 0.03 to 0.06 per cent. High recovery of labeled N measuring 7.70 and 6.69 per cent in leaf occurred due to surface broadcast of fertilizers (T_6) and Nutriseed Pack with Furadan (T_5) respectively. Similarly the same T_5 and T_6 treatments registered high recovery in stem with 10.49 and 9.38 per cent respectively (Table 5).

Table 5. Recovery of labeled N in plant parts of maize and N use efficiency (%)

Treatment	Recovery%							
	Root	Leaf	Stem	Tassel	Ear leaf	Pith	Grain	NUE
T_1	0.03	4.67	7.56	0.62	2.75	1.22	13.32	30.17
T_2	0.03	5.55	7.14	0.43	3.26	1.28	12.51	30.19
T_3	0.06	5.61	7.63	0.36	3.62	1.76	17.15	36.17
T_4	0.03	5.15	6.35	0.62	3.06	1.08	7.82	24.12
T_5	0.03	6.69	10.49	0.67	4.64	1.23	9.87	33.62
T_6	0.03	7.70	9.38	0.85	4.22	0.99	7.26	30.45

The recovery noted was meagre for all treatments ranging from 0.36 to 0.85 per cent for tassel development and from 0.99 to 1.76 per cent in pith. Nutriseed Pack with Furadan (T_5) and surface broadcast (T_6) influenced high support for the development of Ear leaf with recovery of labeled N of 4.64 and 4.22 per cent respectively. Horizontal placement of Nutriseed pack showed very high recovery of labeled N in grain (17.15 %). Overall the total recovery (NUE) was highest for horizontal placement (T_3) of Nutriseed Pack (36.17%) followed by vertical placement of Nutriseed Pack with Furadan (T_5) with 33.62 per cent. The performance of Nutriseed Pack plain (T_1), Nutriseed Pack with Neem (T_2) and surface broadcast (T_6) are similar with NUE ranging from 30.17 to 30.45 per cent. The true efficiency of added N fertilizer measured as total % $_{15}$N recovery (NUE) ranged from 30.17 to 36.17 per cent. Placement of Nutriseed Pack horizontally registered the highest N use efficiency (36.17%), followed by vertical placement (30.17%). Close placement of nutrients in the pellets of Nutriseed Pack near the surface where roots proliferate caused very high mgNdff that has been reflected in $_{15}$N recovery under horizontal placement, followed by vertical placement.

Greater increase in NUE has resulted in these treatments particularly due to translocation of fertilizer N accumulated in stover to grain. Even though surface broadcast caused higher recovery of fertilizer N in leaves and stem, it was not translocated to grain as that of Nutriseed Pack and hence only 30.45 per cent NUE was achieved. As expected, due to added N interaction more utilization of soil N by stover might have been favoured at every time of urea application under surface broadcast.

The study revealed that for achieving high NUE steady release of N was necessary when compared to surface application where N losses, induced soil N mineralization and immobilization would be high. These results correspond to the findings of Van Dijk and Brouwer (1998) who reported that placement of fertilizers close to the roots improved nutrient recovery by the maize crop. Dotson *et al.* (2007) reported that deep placement of N fertilizer has the potential to increase N use efficiency in maize. Noellsch *et al.* (2009) found that pre -plant incorporated polymer coated urea increased N fertilizer recovery efficiency and grain yield compared to control in the clay pan landscapes.

Conclusion

Study on $_{15}$N recovery by maize from surface broadcast and deep placed $_{15}$N labelled urea brought out the account of fertilizer N in soil layers and in plant parts. The applied labelled N retained in surface layer was high in horizontal placement of Nutriseed Pack ranged from 8.0 to 18.1 per cent in surface layer (0-15 cm), from 4.9 to 10.8 per cent in sub-surface layer (15-30 cm), and from 2.8 to 6.0 per cent the underlying lower layer (30-45cm). In case of surface application of fertilizers, N retained was 5.5 per cent in surface layer (0-15 cm), 3.2 per cent in sub-surface layer (15-30 cm), and 11.1 per cent in lower layer (30-45cm). Nutriseed Pack under Vertical and horizontal placements as well as with fertilizer + manure mixture produced very high dry matter of stem (26.3 to 27.3 g plant$_{-1}$), whereas Nutriseed Pack with Neem, Furadan and fertilizer mixture produced high dry matter of leaf (20.1 to 22.3 g plant$_{-1}$). The high grain weight of 60.1 to 63.1 g plant$_{-1}$ was recorded under horizontal and vertical placement in plain and Neem based Nutriseed Packs.

High recovery of labelled N measuring 7.70 and 6.69 per cent in leaf and 10.49 and 9.38 per cent in stem due to surface broadcast of fertilizers and Nutriseed Pack with Furadan respectively. Horizontal placement of Nutriseed pack showed very high recovery of labeled N in grain (17.15 %). Overall total recovery (NUE) was highest for horizontal placement of Nutriseed Pack (36.17%) followed by vertical placement of Nutriseed Pack with Furadan (33.62 per cent). The performance of Nutriseed Pack (plain/ Neem) and surface broadcast are similar with NUE ranging from 30.17 to 30.45 per cent.

References

AGRISTAT, 2007. Agricultural Statistics at a Glance. Directorate of Economics and Statistics, New Delhi.

Bremner, J.M. 1965. In: Methods of Soil Analysis. Ed. C. A. Black. Part 2, *American Soc. Agron.* Madison, Wisconsin.

Buresh, R.J., Austin, E.R. and Craswell, E. T.1982. Analytical methods in $_{15}$N research. *Fert. Res.,* 37-62.

Dotson, C.R., Brian Arnall, D., Tubana, B., Girma, K., Daft, M.C.,England, B.B., Edmonds, D.E., Holtz, S. L., Turner, P. L. and Raun, W. 2007. Nitrogen Rate and Placement in Corn Production 298-5 Oklahoma State University, 051 Ag Hall, Stillwater, OK 74078.

IAEA. 1983. A guide to the use of Nitrogen-15 and Radio Isotope in studies of plant nutrition: Calculation and interpretation of data. Tech. document, IAEA, Verma, 63.

Noellsch, A.J., Motavalli, P.P., Nelson, K. A. and Kitchen, N. R. 2009. Corn Response to Conventional and Slow-Release Nitrogen Fertilizers across a Claypan Landscape. *Ameri. Soc. Agron. J.,* **101**: 607-614.

Pruden, G., Powlson, D.S. and Jenkinson, D.S. 1985. The measurement of $_{15}$N in soil and plant material*. Fert. Res.,* **6**: 205-218.

Rees, R.M., Ruelcke, M., Li, S.X., Wang, X.Q., Li, S.Q., Stockdale, E.A., Mctaggart, T.P., Smith, K.A. and Richter, J. 1997. The effect of fertilizer placement on nitrogen uptake and yield of wheat and maize in Chinese loess soil. *Nutrient Cycling in Agroecosystems,* **47**: 81-91.

Thamir, A. and MacKenzie, A.F. 1996. Banding urea and lignosulfonate in corn (*Zea mays* L.) production and $_{15}$N recovery. *Can. J. Soil Sci.,* **76**: 365–371.

USDA. 2007. United States Department of Agriculture. Crop Production Statistics.

Van Dijk, W. and Brouwer, G. 1998. Nitrogen recovery and dry matter production of silage maize as affected by subsurface band application of mineral fertilizer. *Neth. J. Agric. Sci.,* **46**: 139-155.

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