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TEMPORAL DISTRIBUTION OF TOTAL NITROGEN CONCENTRATION IN ROOT ZONE OF MAIZE (*Zea mays L.*)

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KEYWORDS

Nitrogen

Pulling effect

N leaching

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Distribution patterns

ABSTRACT

Nitrogen (N) plays an important role in the production of maize. In the absence of N in soils plants shows stunted growth and yellowish leaves and result into reduced crop yield. The study was conducted during two irrigation seasons of 2012 at Nkango Irrigation Scheme, Malawi in a Randomised Complete Block Design (RCBD). The factors were water and nitrogen and both were at four levels. The study inferred that movement, direction and distribution patterns of nitrogen concentration is influenced by evaporation of water from the soil surfaces, pulling effects by plant roots, deep percolation through gravitational force, and ability of plant roots to create environment that is conducive to diffusion of nitrogen. To minimize losses of nitrogen through leaching and ensure that nitrogen is deposited within active root zone, plant should not receive water after physiological maturity.

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1 Introduction

Nitrogen (N) is considered as the second most important limiting resource after water in maize production Bronson et al. (2006). The nitrogen deficiency resulted poor plant growth and crop yield. However, poor N nutrition may be due to inadequate N fertilization or temporal mismatch between N availability in soil solution and crop uptake needs. Matching N availability in soil solution and crop uptake needs is critical factor to improving irrigated maize production in an irrigation field. Efficient use of Nutrient is an important issue in agriculture in many parts of the world (Sheldrake et al., 2002). According to Mosier et al. (2004) amongst all the reported crop nutrients, the fate of applied nitrogen in fields has received considerable attention because of its crucial role in crop production and its environmental concerns. Currently human activities around the world are producing about 120 million tones of reactive nitrogen every year for agriculture purposes, but only a third is used by the target crops (UNEP, 2010). A large amount of nitrogen is therefore lost to atmosphere, leached below root zone depths and/or run off the land to water bodies. With low inherent nitrogen content in most agricultural soils, application of nitrogen fertilizers in irrigation farming has become the single most important consideration for farmers. Mloza-Banda (1994) reported that it is only when application rates of nitrogen are increased three-to four-fold that the potentialities of high maize productivity are fully realized. Farmers are enticed to use high levels of nitrogen fertilizers because of high crop production associated with such nitrogen application (Zotarelli et al., 2007).

Environmental concerns such as surface and groundwater contamination, eutrophication, and air pollution have necessitated many scientists to put much effort on investigating the possible contribution of nitrogen pollution load from agricultural practices to environments, especially to surface and groundwater resources. Bauder et al. (2008) reported that good nitrogen and irrigation management practices can reduce the probability of nitrogen leaching into groundwater and maintain profitable yields. Understanding the movement of nitrogen through the soil profile is essential for decision making to improve efficiency of nitrogen use and avoiding nitrogen leaching (Pathak et al., 2003). Jansen (1999) studied the movement and leaching of residual nitrogen in the soil under lysimeter experiment and concluded that nitrogen is slowly translocated to greater soil profile depths partly by diffusion and partly by slow downward movement of soil water. Nitrogen concentration in the soil water decreases in the upper soil layers and increases in deeper soil layers, but does not precipitate in the soil profile.

Similarly, Saito (1990) reported that in moist climatic zones, nitrogen in the plowed layers easily moves downward and accumulates in layers beneath from which deep-rooted crops can efficiently absorb it. Magnitude of nitrogen leaching strongly varies and depending on the types of soil and water application regimes Verloop et al. (2006). Randall et al. (1997) quantified nitrogen leaching potential under different crops and they found highest nitrogen leaching levels under maize fields. To efficiently manage nitrogen and minimize environmental concerns, there is a need to understand the movement and direction of nitrogen through soil profile of maize fields. The aim of proposed study was therefore to understand the temporal distribution, establish the movement patterns and direction of nitrogen in maize field under irrigation.

2 Materials and Methods

2.1 Description of study site

Present study was carried out at Nkango Irrigation Scheme in Kasungu district of Tanzania. Data were collected at growing seasons of 1st June to 8th September, 2012; and 10st September to 5th December, 2012. Nkango Irrigation Scheme is an informal scheme which is owned and managed by the local communities and is situated at Latitude 12^{0}35' South and Longitudes 33^{0}31' East of Tanzania and is at 1186 m above sea level. The mean annual rainfall is about 800 mm. The site lies within maize production zone of Malawi and had dominant soil type of coarse sandy loam. Smallholder farmers in the area practise irrigation and are conversant with water application regimes.

The soil of the plots is sandy loam with a low soil organic matter and nutrient concentration as described in (Table 1).

Table 1 Characteristics of the soil at the research site Nkango, Malawi.

Depth of Sampling (cm)	pH	P (ppm)	K µeq g-1	Mg µeq g-1	Ca µeq g-1	Carbon (%)	C/N ratio	OM (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
0-20	5.2	33.206	1.215	28.964	19.254	0.599	13.011	1.0773	70	17	13	Sandy Loam
20-40	4.0	14.864	1.023	29.147	19.647	0.499	17.198	0.8977	67	17	17	Sandy Loam
40-60	4.0	11.648	0.854	26.470	16.540	0.319	9.673	0.5745	67	13	20	Sandy Loam
60-80	4.7	6.646	0.800	31.295	10.254	0.299	12.469	0.5386	60	13	27	Sandy Clay Loam
80-100	5.2	4.859	0.410	36.415	10.235	0.219	14.630	0.3950	67	7	27	Sandy Clay Loam

2.2

2.3 Experiemental design

The study plots were 5 X 5 m in size and ridges were spaced at 75 cm. The distance between plots to plot were 2 metre for avoiding 'sharing' of responses, water and nitrogen (edge effects). Three maize seeds of hybrid maize (SC 407) were planted per hole at spacing of 25 cm. They were later on thinned to one seed per station 7 days after germination.

The trials consisted of factorial arrangement in a Randomised Complete Block Design (RCBD). The factors were water and nitrogen and both at four levels. Water had four application regimes *viz* farmers' practice regime; full (100%) water requirement regime (FWRR) of maize plant; 60% of FWRR and 40% of FWRR.

A full maize water requirement was determined by the procudure described by Allen et al. (1998). Nitrogen also had four application regimes i.e. the typical nitrogen application rate in the area (TNPRA) of 92 kg N/ha was used as a basis to determine other dosage levels in the study (MoAFS, 2011). The nitrogen dosage levels were TNPRA, 92 kg N/ha; 125% of TNPRA, 115 kg N/ha; 75% of TNPRA, 69 kg N/ha and 50% of TNPRA, 46 kg N/ha.

The fertlizer was applied two times, basal and top dressings, 21 and 51 days after planting respectively. At each application time, the following methods were used to achieve the nitrogen dosage levels:

- To acheive 50% of TNPRA, 46 kg N/ha, 2.8g fertilizer scooped using one coke bottle top with inside lining was applied per station.
- To achieve 75% of TNPRA, 69 kg N/ha, 4.2g fertilizer scooped using one coke bottle top without inside lining was applied on each station.
- To achieve TNPRA, 92 kg N/ha: apply 5.6g fertilizer that is 2 coke bottle tops per station without inside lining.
- To achieve125% of TNPRA, 115 kg N/ha: apply 8.4g fertilizer using 3 coke bottle tops without inside lining.

2.4 Data collection

The triscan sensor (EnviroScan, Sentek Pty Ltd, Stepney, Australia), was used to measure total nitrogen concentration at lateral distances. The measurement of the sensor are in Volumetric ion concentration (VIC), by using standazation equation the concentration of total nitrogen on each point was known. The lateral distances were as follows: at point of application (represented by 0 cm), at 5 cm away from the plant (represented by -5 cm), at 5 cm towards the plant, 10 cm towards the plant (this point was maize planting station), and 15 cm after maize planting station.

The lateral distances were measured on the basis of spreading and elongation pattern in rhizospere of maize plants. The lateral reading of nitrogen were respecively taken at five soil depths of 20, 40, 60, 80, and 100 cm. The soil depths were selected based on maize roots growth habits which extend down to 100 cm (FOASTAT, 2000).

2.4 Data analysis

The GENSTAT software (VSNi, Hemel Hempstead, UK) was used for statistical analysis. The data are mean there of four replicates. The representation of collected data was in graphical form to indicate comparative change of N concentration and direction of flow.

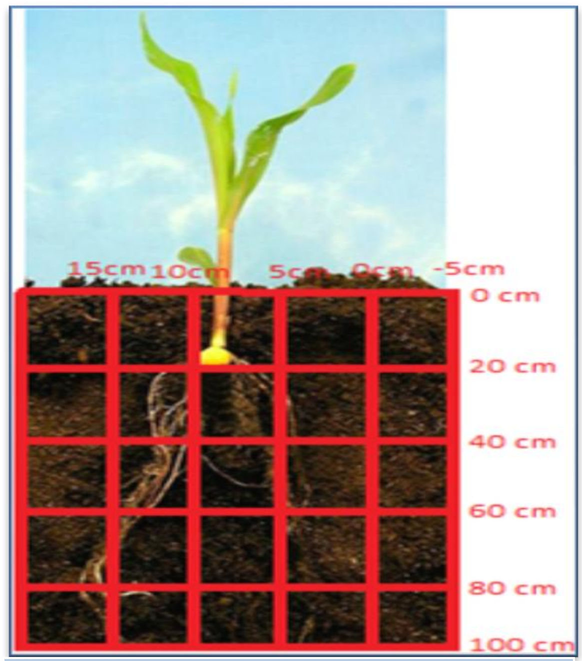

Figure 1 Showing measurement points.

3 Results and Discussion

3.1 Temporal distribution of Nitrogen at 20 cm below from the surface

The observation of temporal distribution of N concentration at 20 cm below soil surface in irrigated maize plot that received full crop water requirement are represented in Figure 2 A successive reduction (0.17-0.06%) in nitrogen concentration was reported with the increasing of distance (-5 to 15 cm) from the site of application. The maize was planted on 1st June and on 10th July was 40 days old, nitrogen was applied on 15th June and on 10th July was 25 days old.

The concentration of distribution on 10th June may therefore be due the fact that the plant demand of nitrogen has not yet increased. Less demand of nitrogen by maize meant that the potential of plant roots to absorb nitrogen is still low hence having high concentration at the point of application which is about 10 cm away from the point where maize seeds were planted (Hati et al., 2001). The other explanation can be that during this period the leaves have not yet developed hence loss of water is still greatly through evaporation from the soil surface hence leass amount of water is available in the soil that would otherwise redistribute the N concentration (Hati et al., 2001).

The trends of N distribution on 20th July were slightly difference with the observation made on 10th July. On 20th July also a gradual reduction in N concentration with the increasing of distance was observed except at -5 and +5 cm away from the site of application where a slight improvement was reported than the site of application (Figure 2), during this time maize was 50 days old and at reproductive stage of tasseling, the demand of N had increased. At 5cm the concentration is highest indicating that roots are actively pulling nitrogen towards its direction than opposite direction (Jones et al., 1986). The observation taken on 30th July were totally differ than the previous two observation and a significant improvement in N accumulation (0.16 – 0.25 %) was reported with the increasing of distance from – 5 to 15 cm (Figure 2), at this date the concentration of N distribution was reported highest than other dates, this was due to the fact that maize roots were in addition to pulling nitrogen through water flux created an environment which facilitated movement of nitrogen towards its roots through diffusion (Mthandi et al., 2013). The trends of N concentration distributions from 9th august 2012 to 8 September, 2012 had become flatter and showing less changes in the concentration from one point to the other (Figure 2), during this period the ability of roots to mobilize nitrogen is declined and hence is just absorbing nitrogen that is next to it and therefore depletion of nitrogen is happening which within its soil zone region. The other reason may be due to leaching of nitrogen down the soil depth. This period water losses are greatly lost through leaching than evaporation due to soil surface cover by plan leaves (Hammad et al., 2011).

3.2 Temporal distribution of N at 40 cm from the surface

The pattern of temporal distribution of N concentration at 40 cm below from soil surface in irrigated maize plot that received full crop water requirement were represented in figure 3. The trends of distribution on 10th July, started with 0.13% at -5 cm and it slightly decreased at 0 cm (0.11%), further an improvement was reported on all studied distance except for 10 cm where the concentration was reported 0.02% only.

The growth habits of maize roots start with main root growing vertically and nodes are developed which grow laterally with roots developing on the lateral roots. On 10th July, it's very unlikely that applied nitrogen has trekked to this depth due to water loss through evaporation and this might be the reason that explains slight changes on N concentrations from -5 cm through 0 cm to 5 cm the decline of N concentration at 10 cm may be due to the fact that it is next to main root and hence its inherent nitrogen has been observed by the root (Al-Kaisi & Yin, 2003).

On 20th July, the trend was relatively flatter for the distance of -5 cm to 5 cm but letter on a gradual improvement in N concentration was reported on 10 cm treatment. High N concentration at 10 cm may due to pulling effect by maize plants from surrounding regions and this might also explains why other points have less N concentrations (Oikeh et al., 2003). It's also very important to note that contribution of N at 40 cm is greatly due to down movement of water flux from upper layers.

On 30th July, successive improvements in N concentration were reported from the site of application to 10 cm away from the application, further a slight reduction was reported. This suggests that movement of N was towards plant roots but when it was next to maize roots, N was immediately be uptaken by the roots. Plant roots always absorb nutrients and water that are situated close to it and whereby in the process creating low concentration towards which other fluid will flow to.

On 9th August, the trend of N concentration is 0.09% at -5 cm to 0.19% at 0 cm, slightly declined to 0.16% at 5 cm, increased to 0.20% at 10 cm and declined to 0.15% at 15 cm. With low concentration created by maize roots absorption, more N will move towards it and this might explain why at 10 cm has high N concentration (Kamara et al., 2006). The other reason might be due to the fact that when N demand by plants is higher than n supply, roots will deliberately create a situation that will still trigger N to move towards it even though concentration in the soil might be low (Song et al., 2013).

On 19th August, N concentration has increased from 0.14% at -5 cm to 0.16% at 0 cm, and with no changes at 5 cm and 10 cm, the concentration has declined to 0.10% at 15 cm. The slight changes of N concentrations are observed on 29th August and on 8th September, with the latter having lower N concentrations than the other. The absorption capacity of N by maize roots might have decreased due to aging of the roots which lessen its ability to absorb nitrogen so the decrease of N concentrations during these three dates might be due to leaching by percolating water.

3.3 Temporal distribution of N at 60 cm from the surface

Figure 4 indicates temporal distribution of N concentration at 60 cm below soil surface in irrigated maize plot that received full crop water requirement. Very less concentration (0.04 - 0.09%) of N reported at this distance was reported on 10th July, 2013. The trend shows that the concentration is solely due to inherent nitrogen and there is no addition of nitrogen from inorganic N that was applied (Ma et al., 1999). Similarly very less N concentration was reported on 20th July, 2012 also. Later on the rate of N accumulation is gradually increased with the increasing of distance and time (Figure 4).

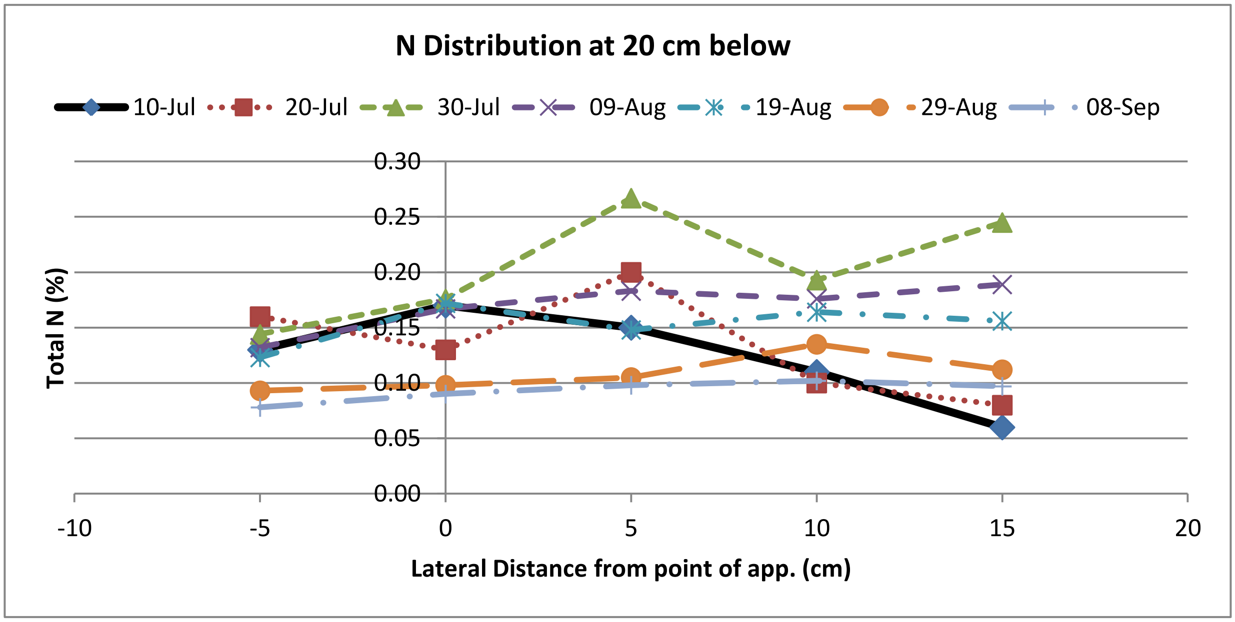

Figure 2 Temporal distribution of N concentration at 20 cm.

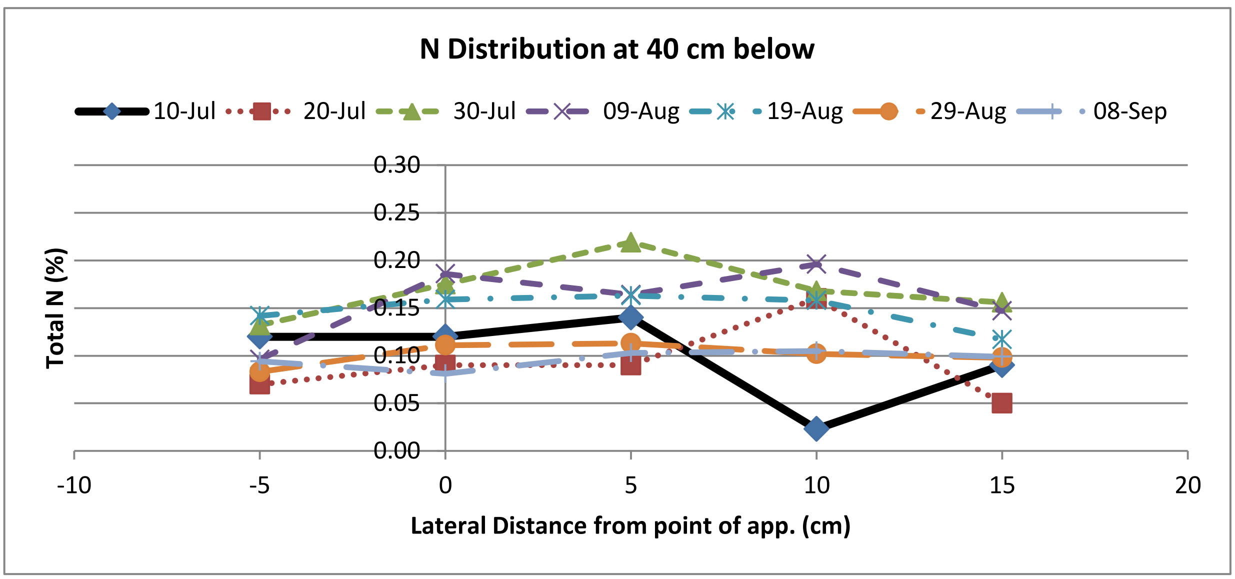

Figure 3 Temporal distribution of N concentration at 40 cm.

There was slight difference in N concentrations at various lateral points. This may be explained by accumulation of leached nitrogen from the top layers. The trend of N concentrations on 9th and 19th August suggest maize roots were absorbing the nitrogen and this absorption influenced behavior of N concentration across the points. However, the general distribution trend of N concentrations at the points of this graph line was much lower than that of 19th August. This observation may be due to leaching of nitrogen to underlying layers from 29th August. So even at 60 cm leaching of nutrients may occur especially when water applied is high.

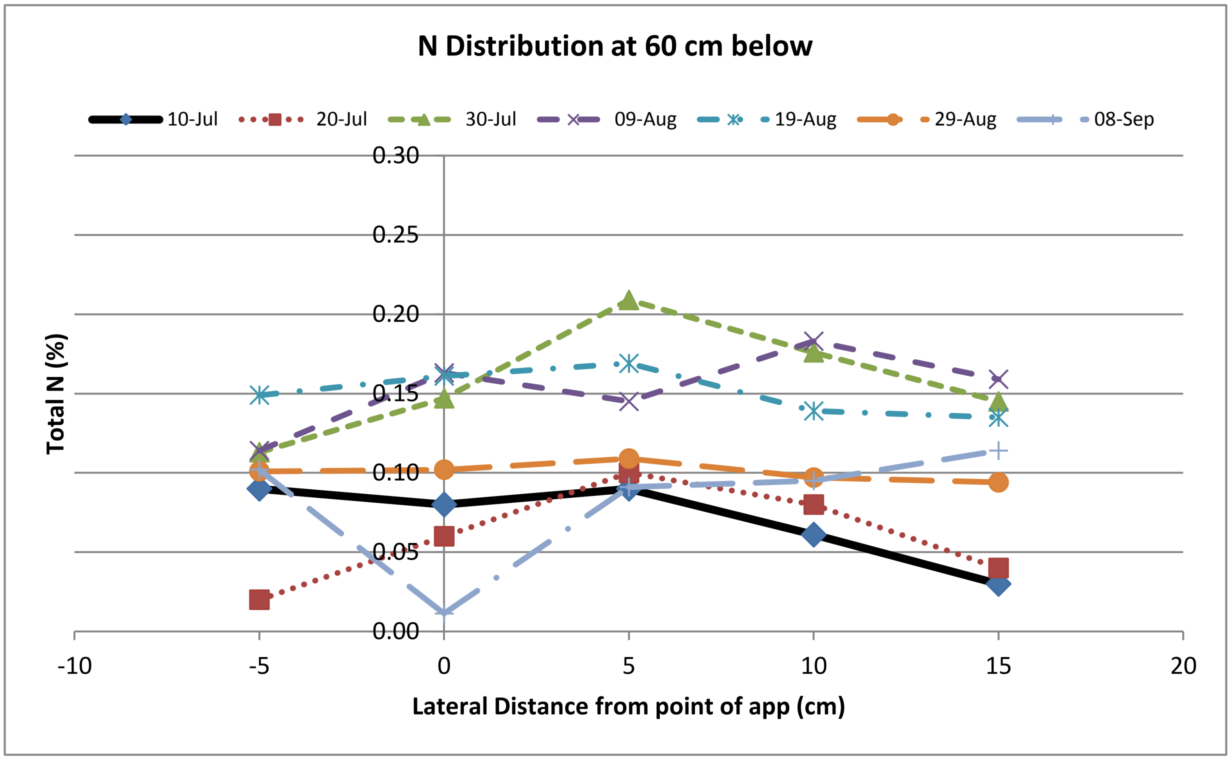

Figure 4 Temporal distribution of N concentration at 60 cm.

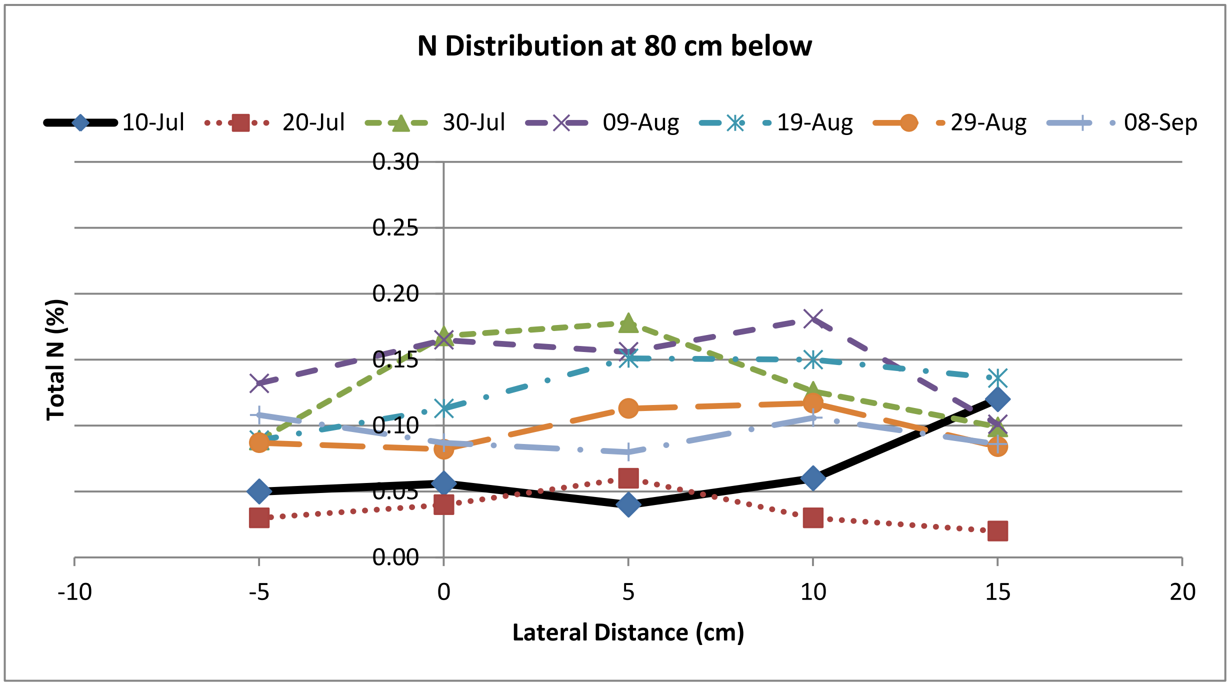

Figure 5 Temporal distribution of N concentration at 80 cm.

3.4 Temporal distribution of N at 80 cm from the surface

Temporal distribution of N concentration at 80 cm below soil surface in irrigated maize plot that received full crop water requirement had been represented in figure 5. On 10th July, the N concentration at -5 cm is 0.05% and concentration had not changed at 0 cm. There had been slight decline to 0.04% at 5 cm which has increased to 0.06% at 10 cm. The N concentration has greatly increased to 0.12% at 15 cm. The trend shows that on 10th July the N concentration was solely due to native nitrogen and there was no addition of applied nitrogen. The observation of 20th July, 2012 were not showing any similarities with the findings of previous observation and very less N concentration (0.02 – 0.06%) were reported at this time.

On 20th July about 50 days after maize emergence, the roots have fully developed and are able to pull nitrogen from the surrounding region while nitrogen near the roots are immediately absorbed. The decline of nitrogen at 10 cm indicates that it has been absorbed while high N concentration at 5 cm indicates that nitrogen is moving from -5 cm towards roots (Zhou et al., 2010). After this, till 9th August, 2012 all the trends of 80 cm are showing the similarity with the findings of the 60 cm and a significant improvement was reported with the increasing of time duration.

On 30th July, it is likely that downward movement of nitrogen through percolation water has reached at the depth. However, the downward movement is towards the active region of roots due to gradient being created by transpiration stream. The movement of nitrogen can be seen as totally influenced by pulling effect of roots.

On 19th August, at -5 cm the N concentration is 0.09% and has increased to 0.11% at 0 cm. At 5 cm the N concentration is 0.15% and has remained the same at 10 cm but slightly decreased to 0.14% at 15 cm. The concentrations of nitrogen have decreased as compared to those on 9th august indicating that ever demand has increased or leaching of nitrogen occurred. On 19th August, the crop 80 days after emergence and during this period the demand of nitrogen by maize has likely decreased because leaves have dried. The loss of nitrogen may therefore be due to leaching by deep percolating water. From 29th August, 2012 to 8th September, 2012 that rate of N accumulation is showing gradual reduction with the increase of distance.

3.5 Temporal distribution of N at 100 cm from the surface

The findings of temporal distribution of N concentration at 100 cm below soil surface in irrigated maize plot that received full crop water requirement are represented by figure 6. All the observation is clearly represented the very less amount of N accumulation. The maximum accumulation was 0.7% on the 10th July, 2012. The trend of N concentration changes throughout the measured points indicates negligible additions and this suggests that the concentrations were due to native N concentration with no addition from applied N. So too the trend observed on 20th July, it suggest that there was no additions from applied N.

On 30th July, at -5 cm N concentration is 0.08% and has slightly decreased to 0.07% at 0 cm. At 5 cm N concentration is 0.10% and has been the same at 10 cm. At 15 cm the concentration has decreased to 0.07%. The increase of N concentration across the measured points especially at 5 cm and 10 cm whose N concentrations have increased from 0.01% and 0.03% to 0.10% within 10 days respectively suggests the increase were due to applied N percolating down with water. The trend of increasing N concentration have continued to increase on points measured on 9th August suggesting that more water is percolating down with N. On 9th August, the improvement in N concentration was reported at all the distance. The increase in N concentration might be due to addition of N concentration from shallow depths to underlying layers. The similar trends were observed in later on observations also.

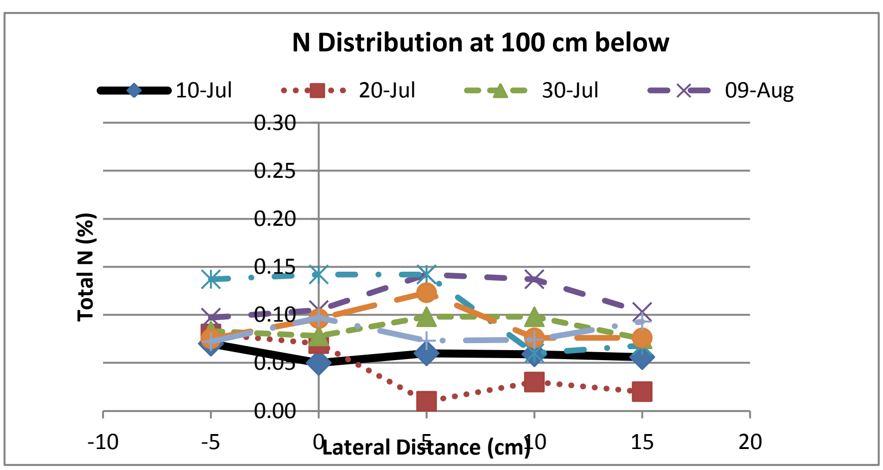

Figure 6 Temporal distribution of N concentration at 100 cm.

3 Conclusions

Present study showing the movement patterns, direction and distribution of nitrogen concentration and help in the establishment of the fact that N concentration is influenced by evaporation of water from the soil surfaces, pulling effects by plant roots, deep percolation through gravitational force, and ability of plant roots to create environment that is conducive to diffusion of nitrogen. To minimize losses of nitrogen through leaching and ensure that nitrogen is deposited within active root zone, plant should not receive water after physiological maturity.

The study established the fact that when the plant leaves are not fully developed water loss is greatly influenced by evaporation from the uncovered soil surfaces. This loss of water therefore reduces ability to dissolve and move nitrogen. When plant leaves are fully developed and soil surface is covered, an evaporation loss is minimized and high losses of N are through leaching.
The pulling effect by plant roots is created by negative gradient due to water uptake. Nitrogen therefore moves towards the plant roots through water flux. However, when the plant demand of nitrogen is surpassing availability of nitrogen in the soil, plant roots create an environment which facilitates movement of nitrogen through diffusion. In this case, nitrogen will still move towards plant roots even though the region next to roots has high concentration of nitrogen concentration.

Maize roots over time reduce their ability and capacity to absorb nitrogen from surrounding soil masses. The reduced capacity of roots to absorb nitrogen induces maize plant to start re-mobilizing nitrogen from old leaves to new leaves.

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