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Using EU-Rotate_N Model to Determine Effects of Nitrogen Application Dosage on N Leaching

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***Abstract* – Nitrogen losses by leaching only occur when the capacity of the ecosystem to accumulate nitrogen has been saturated (which may take considerable time if the rate of nitrogen input is low). The research study was conducted at Nkango Irrigation Scheme in Kasungu district to determine the impact of nitrogen application regime on N leaching. Maize (SC 407) was a test crop. The planting and harvest were done on Julian day of 2012152 and 2012250 respectively. Water regime was kept constant at 100% of maize full water requirement regime (FWRR) while N application varied from 92 kg N/ha which represents Typical Nitrogen Placement Rate in the area (TNPRA), 125% of TNPRA (115 N kg/ha); 75% of TNPRA (69 N kg/ha); to 50% of TNPRA (46 N kg/ha). The EU-Rotate_N model was used to run the field data. The paper concluded that treatments that received high amount of inorganic N fertilizer lost more nitrogen through N leaching. Plant roots will only absorb nitrogen it requires leaving excess to be leached by water below the active rooting zone. The study also concluded that EU-Rotate_N model to perfectly predict N leaching from irrigated maize production. The study also found out that applying N fertilizers at once increase its susceptibility to leaching and therefore the study recommended that to apply N fertilizer in several small applications during the cropping season.**

***Keywords* – N fertilizer, Water Application Regime, N Leaching, EU-Rotate_N Model.**

I. Introduction

Nitrogen as a macronutrient has an eminent role in plant nutrition. Excessive use of nitrogen fertilizers in agriculture has resulted in leaching of fertilizers and their derivatives below the root zone, contaminating groundwater [1]. Some nitrogen fertilizers such as urea and ammonium nitrate have a high mobility and leaching potential. [2] reported that there is a direct relationship between nitrogen loading levels and nitrogen leaching. They reported that increasing the loading rate of urinary nitrogen significantly increased the cumulative N_2O emissions, NO_3^- leaching and pasture N uptake, due to an increasing supply of N. Leaching occurs from an ecosystem when the external nitrogen supply exceeds the demand by plants and soil micro-organisms, and when the soil chemical capacity to bind nitrogen has been reached, which means that a situation of nitrogen saturation has been entered [3, 4]. Nitrogen losses by leaching only occur when the capacity of the ecosystem to accumulate nitrogen has been saturated (which may take considerable time if the rate of nitrogen input is low). [5] simulated N leaching for different nitrogen fertilization rates using a GIS-GLEAMS system. They observed that a great reduction of N leaching (up to 68% for vegetables, and 75% for citrus) was observed under the most reduced fertilization rates and this reduction was greater in areas irrigated with surface water in comparison to those irrigated with groundwater. Since the value of the produce is high in comparison to the cost of additional fertiliser, the temptation to overfertilise is high, leading to greater risks of nitrate pollution [6].

The aim of this paper was determine the impact of nitrogen application regime on leaching of nitrogen through soil profile. EU-Rotate_N model was used to run the field data. EU-Rotate_N is a model that specifically simulates N response for vegetable and arable crops only [7]. The model consists of a number of subroutines that simulates the growth both below and above ground, nitrogen mineralisation from the soil and crop residues, subsequent N uptake, and balance between supply and demand to regulate growth. The sub-routines that define the fate of nitrogen in the soil are as follows: The soil N mineralization subroutine, which calculates soil N mineralization in the top 30 cm soil depth from soil organic matter, crop residues and organic and inorganic N fertilisers; The potential maximum increment in shoot dry weight subroutine calculated on the assumption of no restriction from N-deficiency and water stress; The potential maximum N-uptake subroutine calculated from the product of potential maximum dry weight and the critical %N for a crop of that size; The actual N uptake subroutine, which calculates the amount of N that the roots can take from the root zone; and The actual %N in the plant subroutine calculated from the N uptake, the amount of N in the plant on the previous day, and the dry weight of the plant calculated for the previous day. Movement of nitrogen from one layer to the other either upward or downward is defined by soil water balance module. The soil water balance module allows calculation of water use and water movement both vertically and horizontally [7]. The water module has different parts that calculate Crop evapotranspiration (soil evaporation and transpiration); Effective water infiltration (applied water minus runoff); Drainage; and Water redistribution in soil.

The properties of the soil layers are provided by the user of the model and include water content at permanent wilting point, field capacity and at saturated level. These properties control water availability to the plant and allow calculation of drainage. Mineralisation and losses of nitrogen by denitrification is adjusted for water content. Other inputs include pH, which allows for the simulation of N losses where urea fertilisers are used. The amount of organic matter levels affects the supply of N from mineralisation. Clay and sand contents are used to calculate urea solution and hydrolysis, ammonia volatilisation from top layer, decay rate coefficients, and denitrification.

II. Methods and Materials

2.1 Site description

The research study was conducted at Nkango Irrigation Scheme in Kasungu district. Data were taken in two irrigation growing seasons from 1st June to 8th September, 2012 during the first season, and from 10st September to 5th December, 2012 during the second season. Nkango Irrigation Scheme is situated at Latitude 12^{0}35' South and Longitudes 33^{0}31' East and is at 1186 m above mean sea level. The study area has a unimodal type of rainfall with rains between December and April. The mean annual rainfall is about 800 mm.

Soil samples were collected from the soil layers. There were 5 soil layers and each layer was 20cm thick. Table 1 shows the initial soil properties after analysis of the samples. The analysis of soil samples was done at Bunda College Soil Laboratory. The average C/N ratio of the site was 10.48.

Table 1: Soil Properties of the research site

Soil layers	FC	PWP	SAT	Clay content	Sand content	Bulk density	Soil pH	OM content	Soil moisture content	Mineral soil_N kg N/ha
1	0.21	0.12	0.43	0.17	0.68	1530	4.7	1.17	0.04	33
2	0.22	0.12	0.42	0.18	0.67	1490	4.4	0.95	0.07	26
3	0.23	0.14	0.44	0.20	0.60	1490	4.4	0.57	0.12	26
4	0.24	0.14	0.44	0.23	0.63	1450	4.5	0.45	0.15	24
5	0.25	0.14	0.42	0.24	0.63	1500	4.6	0.31	0.17	20

2.2 Experimental design

Maize was a test crop. Three maize seeds (SC 407) were planted per hole on Julian day of 2012152 at plant spacing of 25 cm and row spacing of 75 cm. They were later on thinned to one seed per station 7 days after germination. The harvest was done on Julian day of 2012250. The plot size was 5 m by 5 m and ridges were spaced at 75 cm.

The study investigated the impact of N application regimes on N leaching, as such water requirment regime was kept constant while N application varied. Maize received full water requirement regime (FWRR) denoted as 100% of FWRR. Nitrogen regimes used were 92 kg N/ha which represents Typical Nitrogen Placement Rate in the area (TNPRA), 125% of TNPRA (115 N kg/ha); 75% of TNPRA (69 N kg/ha); and 50% of TNPRA (46 N kg/ha).

The first fertilizer was applied on the Julian day of 2012159 and second fertilizer was applied on the Julian day of 2012195). Maize was irrigated on the following Julian days: 2012152, 2012160, 2012170, 2012180, 2012190, 2012200, 2012220, 2012230, and 2012240. The first 5 irrigation events, water was applied using watering cans (which is represented as sprinkler irrigation method), and the last 5 irrigation days, water was applied using treadle pump which delivered water through furrows (which is represented as furrow irrigation method). The EU-Rotate_N model was used to simulate N leaching below 90cm from the treatments.

III. Results and Discussion

The EU-Rotate_N model was used to simulate N leaching from the four treatments. This section presents the results of the simulation. The discussion on the results has also been done. The Figure 1 shows the N leaching trend in treatment that received full water requirement regime and 46 N kg/ha. Inorganic N fertilizer of 23 N kg/ha was applied on 7th June, 2012 and the same amount was applied o 16th July, 2012.

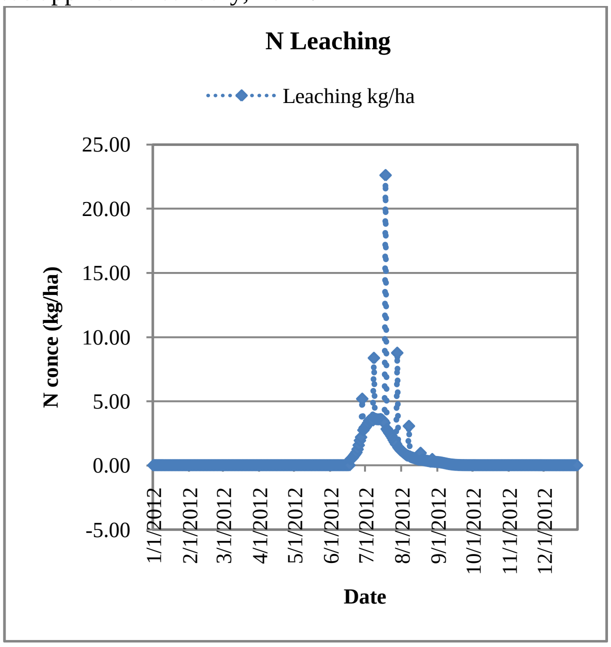

Fig.1. N leaching 100%FWRR with 50%TNPRA

The figure 1 shows that N leaching started to occur between late June (about 25th June) and increased to its highest level of about 23 N kg/ha in mid July (18 July). During this period, as shown in figure 2 below, total N leached moved from almost zero to about 150 N kg/ha and it remained there until harvest. This indicates soil become susceptible to leaching of nitrogen during the time when surface evaporation is minimised due to covering of soil surface by the leaves of the plant. Consequently this is during the same period when N uptake by the plant roots is at highest level because plant's leaves transpire more water.

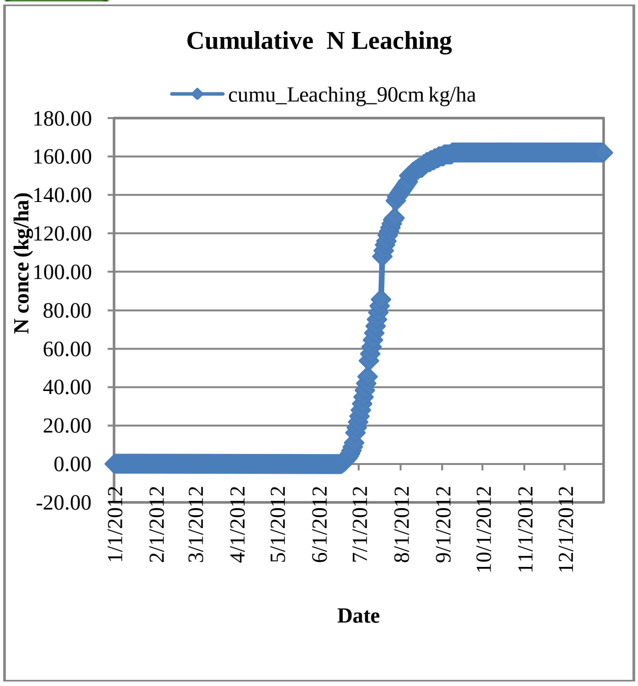

Fig.2. Cumulative N leaching 100%FWRR with 50%TNPRA

Cumulatively N leaching has moved from zero on 25th June, 2012 to about 150 N kg/ha on 28th July, 2012 as is shown in figure 2. Water moves down the soil profile only when it has satisfied the carrying capacity on the proceeding soil layers. It is therefore not surprising that N leaching is starting late June after 3 irrigation events (i.e. after 240 mm of water was applied). It might be during late June, carrying capacities of top soil layers were met and excess water was allowed to move down to the next soil layers, coincidently during the same period is when inorganic N fertilizer was applied.

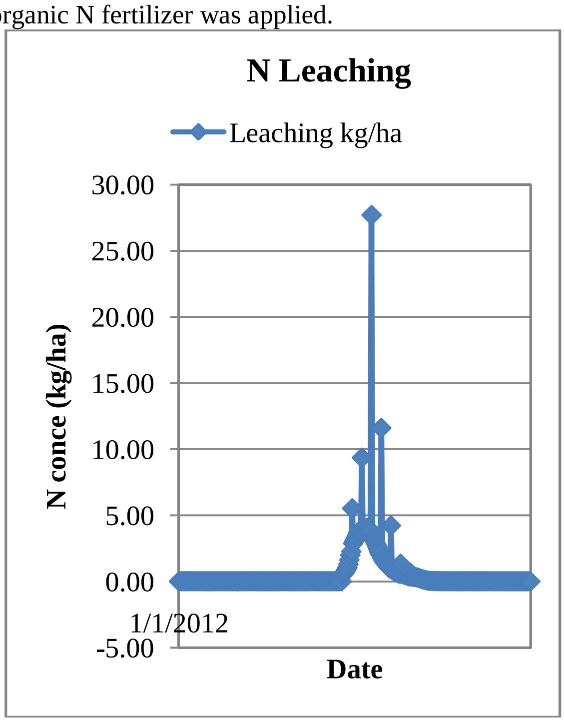

Fig.3. N leaching 100%FWRR with 75%TNPRA

Figure 3 indicates the N leaching trend in the plot that had received 100% of full water requirement regime and had Nitrogen application of 69 kg N/ha which is 75% of the Typical Nitrogen Application Rate in the Area (TNPRA). The highest N leaching was about 27.5 N kg/ha and was noted in the month of July. The trend of N leaching underscores the fact that with the same amount of water, high N leaching will occur in plots that have received high amount of nitrogen. While there shall still be N leaching in plots with less applied nitrogen but increase in N leaching will occur with happen with increase in nitrogen availability in the soil. There shall be no N leaching in plots that have no nitrogen. in figure 1 above, during the same date about 23 N kg/ha was through to leaching meaning that increasing of applied inorganic N fertilizer to 69 N kg/ha resulted into increase of about 4.5 N kg/ha lost through N leaching. With the same amount of applied water resulted into differences in nitrogen that was lost through leaching. it is therefore paramount important to apply nitrogen that will be used by plant roots than applying excess nitrogen that will not be used by plant only contributing to contamination of groundwater. Figure 4 below shows the cumulative nitrogen that was lost through leaching, as it can be shown from the figure that nitrogen lost through leaching increased exponentially from about 0 N kg/ha on 25th June, 2012 to about 190 N kg/ha on or about 28th July, 2012. If compared with that from figure 2 above, the difference of nitrogen lost through leaching during the same period was about 40 N kg/ha which is representing about 27% of nitrogen lost through N leaching. If compared with 25% increase of nitrogen applied in this treatment, one can note that the whole 25% increase was lost and in addition 2% was again lost from the treatment. This consequently means that even though applied nitrogen was increased it never benefitted the plant and it only contributed to N leaching.

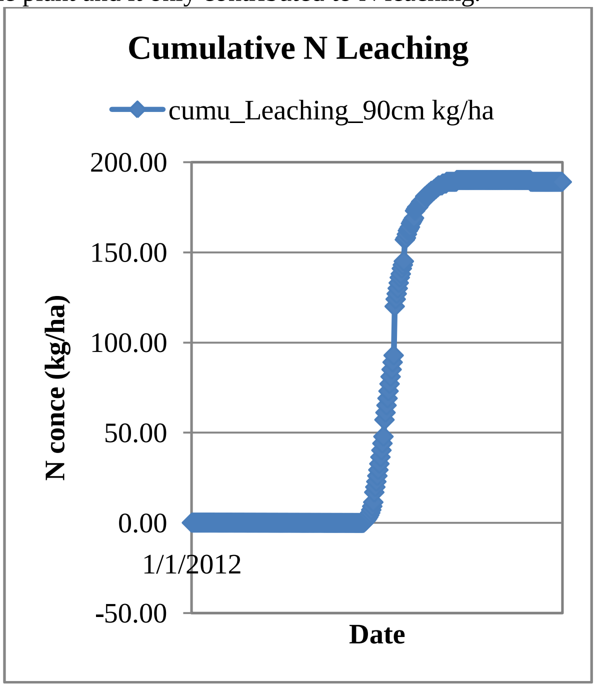

Fig.4. Cumulative leaching 100%FWRR with 75%TNPRA

Figure 4 shows that nitrogen lost through leaching increased a lot when compared to figure 2 above even though these treatments received the same amount of water. This difference is due to increase of applied inorganic nitrogen which increased by 25% from 50% of Typical Nitrogen Application Rate in the Area (TNPRA) to 75% of TNPRA. However, of great interest to note is that N leaching occurred during the same period between late June to late July. This indicates that it is possible to minimise N leaching in irrigated maize production by reducing amount of applied water.

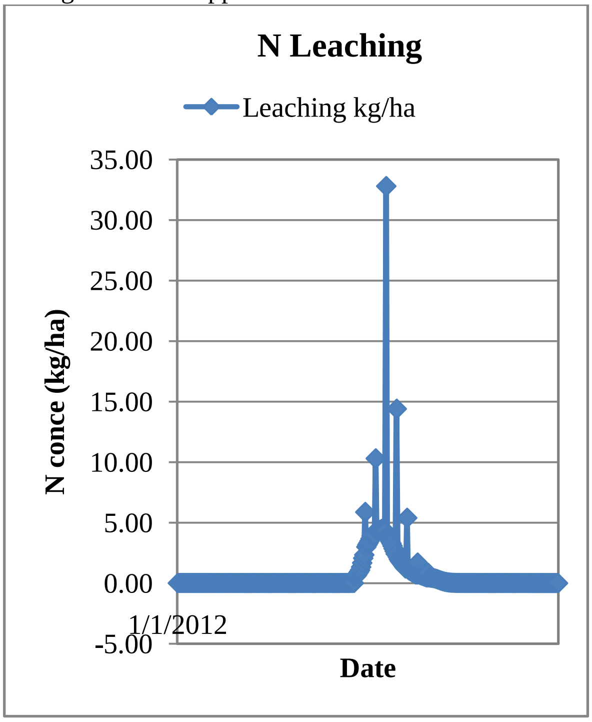

Fig.5. N leaching 100%FWRR with 100%TNPRA

Figure 5 indicates the N leaching trend in the plot that had received 100% of full water requirement regime and had Nitrogen application of 92 N kg /ha which represents 100% of the Typical Nitrogen Application Rate in the Area (TNPRA). In this figure, the highest N leaching was about 33 N kg/ha. Figure 1 indicates the N leaching trend in the plot that had received 100% of full water requirement regime and had Nitrogen application of 46 kg N/ha which is 50% of the Typical Nitrogen Application Rate in the Area (TNPRA). From the figure 1 it can be shown that between 1st June to 1st July, N leaching started to occur and increased to over 5 N kg/ha. It has to be noted that during the same period, inorganic N fertilizer of about 23 N kg/ha was applied. Between, 1st July to 1st August, N leaching was the highest of all growing season and at some point during the period; N leaching went above 20 N kg/ha. During the same period on 16 July, N fertilizer of 23 N kg/ha was applied. as already explained, its amount of water that influence level of N leaching, when applied water of less quantity, less or no nitrogen will occur but if applied water is of high quantity, regardless of how much nitrogen was in the soil, N leaching will still occur. N leaching has increased in the month of July because during this month, maize is at mid stage and there is high leaf area index, meaning that surface evaporation has been reduced. Reduction of surface evaporation increases infiltration of water in the surface hence high amount of water is contributing to down movement of nitrogen.

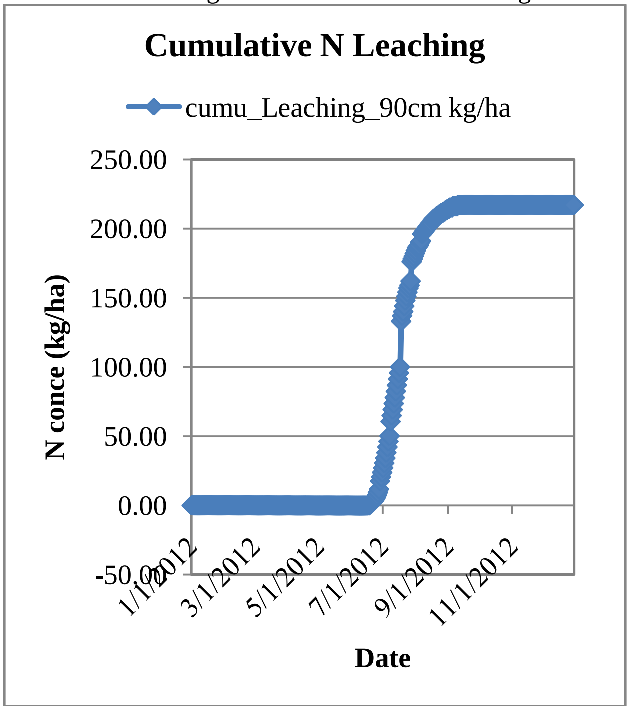

Fig.6. Cumulative N leaching 100%FWRR with 100%TNPRA

Figure 6 indicates the N leaching trend in the plot that had received full water requirement regime and had Nitrogen application of 92 N kg/ha which is the Typical Nitrogen Application Rate in the Area (TNPRA). Figure 7 indicates the N leaching trend in the plot that had received 100% of full water requirement regime and had Nitrogen application of 115 N kg/ha which is 115% of the Typical Nitrogen Application Rate in the Area (TNPRA). The plot has registered the highest noted N leaching of about 37 N kg/ha. The figure 7 shows that the total nitrogen that was leached below rooting zone can be well above half of the applied nitrogen, meaning that only less that 50% of the applied nitrogen stayed in active rooting depth. Leached N represents economic loss to a farmer in this case about 50% of the total cost was lost through N leaching. However, it has also to be noted that leached N contributes to the contamination of groundwater.

Figure 7 indicates the N leaching trend in the plot that had received full water requirement regime and had Nitrogen application of 115 N kg/ha which represents 115% of the Typical Nitrogen Application Rate in the Area (TNPRA). The plot has registered the highest noted N leaching of about 37 N kg/ha. The figure 7 shows that the total nitrogen that was leached below rooting zone can be well above half of the applied nitrogen, meaning that only less that 50% of the applied nitrogen stayed in active rooting depth. Leached N represents economic loss to a farmer in this case about 50% of the total cost was lost through N leaching. However, it has also to be noted that leached N contributes to the contamination of groundwater.

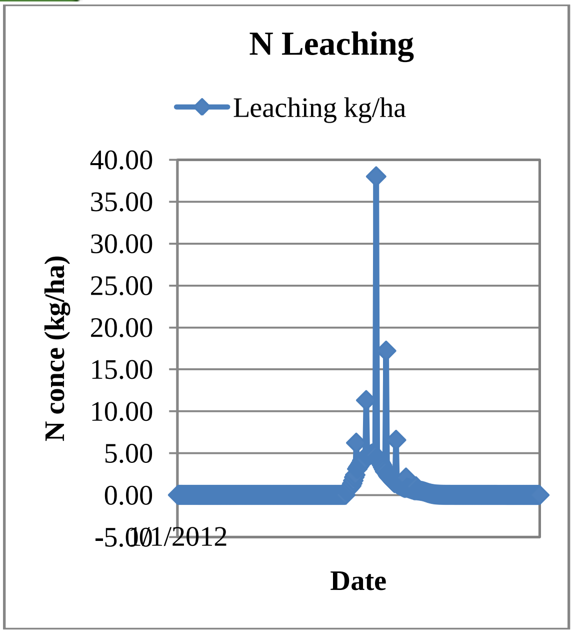

Fig.7: N leaching 100%FWRR with 125%TNPRA

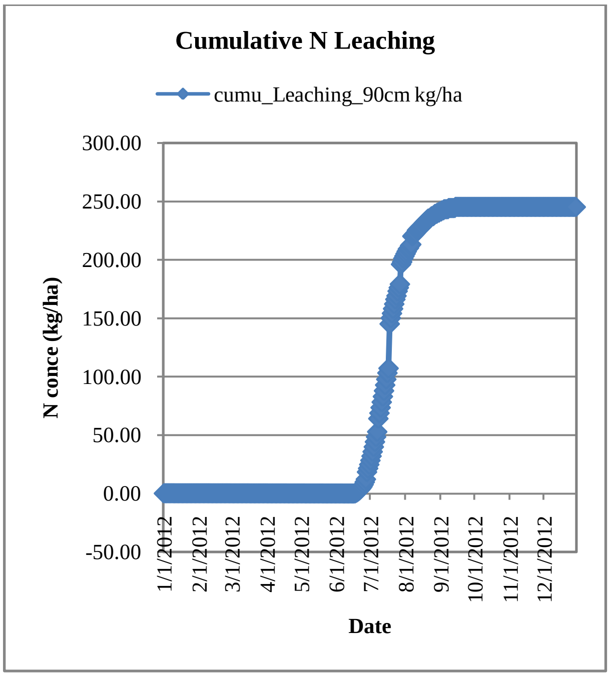

Fig.8. Cumulative N leaching 100%FWRR with 125%TNPRA

Figure 8 indicates the cumulative N leaching trend in the plot that had received 10% of full water requirement regime and had Nitrogen application of 115 kg N/ha which is 125% of the Typical Nitrogen Application Rate in the Area (TNPRA). The figure 8 shows that from about 15 June to about 1st August, cumulative N leaching jumped from zero to about 250 N kg/ha respectively. Within the space of about a month losing more 250 N kg/ha is very unacceptable. One of approaches to reduce N leaching during this period when leaf area index is 1 or nearly there is to reduce amount of applied water. This can ensure that water stays within the active rooting depth and less nitrogen is leached. This can be maximize economic returns on nitrogen and less nitrogen to contaminate groundwater.

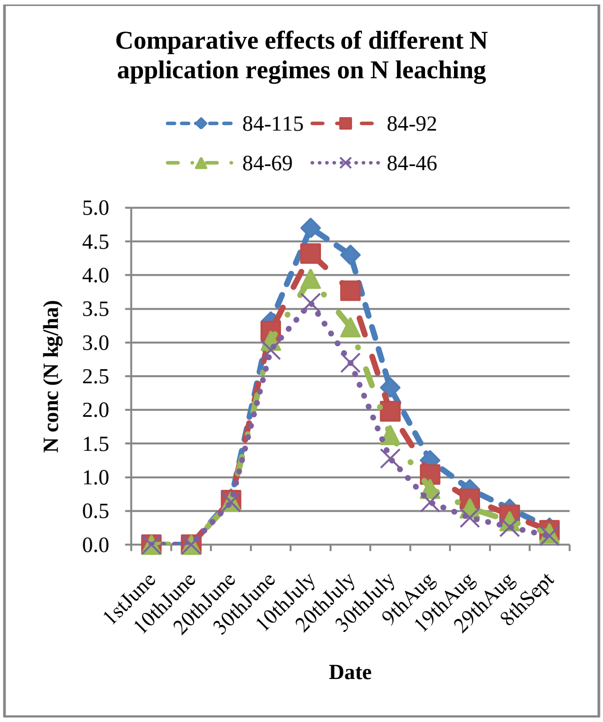

Fig.9. Comparative effects of N application regimes on N leaching

Figure 9 shows the effect of nitrogen application regime on N leaching. The treatments received equal amount of water (84 mm) which was applied on the irrigation days as indicated in the section of methods and materials above. The nitrogen application regimes varied and were 115 N kg/ha, 92 N kg/ha, 69 N kg/ha, and 46 N kg/ha. The figure 9 indicates that treatment that received highest amount of nitrogen experienced highest N leaching while treatment that received least nitrogen experienced lowest N leaching. However, of importance to note is the trend of N leaching, the figure 9 shows that all four treatments had similar trend of N leaching. N leaching started almost on the same time i.e. on 10th June, 2012 and reached on peak on the same day on 10th July, 2012.

Conclusion

This paper has presented findings on the impact of nitrogen application regimes on N leaching. Four nitrogen application regimes of 115, 92, 69 and 46 N kg/ha were applied to plots which received the same water application regime of 82 mm. The EU-Rotate_N model was used to simulate N leaching from the plots.

The paper has concluded that treatments that received high amount of inorganic N fertilizer lost more nitrogen through N leaching. Plant roots will only absorb nitrogen it requires leaving excess N to be leached by water below the active rooting zone. The study has also concluded that with the use EU-Rotate N model, it is possible to minimise N leaching by reducing amount of applied water during the time when leaf area index is 1 or nearly there. Applying nitrogen fertilizers at once increase its susceptibility to leaching and therefore applying the fertilizer in several small applications during the cropping season can reduce N leaching. Nitrogen losses by leaching only occur when the capacity of the ecosystem to accumulate nitrogen has been saturated (which may take considerable time if the rate of nitrogen input is low). Hence we are recommending that N should be applied in small doses during the cropping season to avoid N leaching away from the root zone.

REFERENCES

[1] Solhi, S., Solhi, M., sief, A., Aghakhani, A., Mousavi, F. S., and Abedi-Koupaii, J. 2012. Effect of nitrogen fertilizers on nitrate leaching from a saline soil profile under corn and barley cultivation. International Research Journal of Applied and Basic Sciences. Vol., 3 (3), 563-567, 2012. Available online at http://www. irjabs.com ISSN 2251-838X.

[2] Selbie, R. D., Cameron, C. K., Di, H. J., J. L. Moir, L. J., Lanigan, J. G., and Richards, G. K. 2014. The fate of Urine Nitrogen: A grassland Lysimeter study in Ireland. New Zealand Centre for Soil & Environmental Research, Lincoln University, Christchurch, New Zealand.

[3] Aber, J. .D., Nadelhoffer, K. Steudler, .J. P., Melillo, J. M. 1989. Nitrogen saturation in northern forest ecosystems. *BioScience* 39:378-386

[4] Aber, J.D., 1992. Nitrogen cycling and nitrogen saturation in temperate forest ecosystems. Trends Ecol. Evol. 7, 220–224.

[5] de Paz. M. J., Ramos, C. 2003. Simulation of nitrate leaching for different nitrogen fertilization rates in a region of Valencia (Spain) using a GIS–GLEAMS system. Agriculture, Ecosystems and Environment 103 (2004) 59–73. Received 14 January 2003; received in revised form 10 October 2003; accepted 27 October 2003.

[6] Neeteson, J. J. & Carton, O. T. 2001 The environmental impact of Nitrogen in Field Vegetable Production. In proceedings of ISHS/ENVEG conference 1999. *Acta Horticulturae* 563: 2128.

[7] Rahn, C. R., Zhang, K., Lillywhite, R., Ramos, C., Doltra, J., de Paz, J. M., Riley, H., Fink, M., Nendel, C., Thorup-Kristensen, K., Piro, F., Venezia, A., Firth, C., Schmutz, U., Raynes, F., Strohmeyer, K. 2007. Using the EU-Rotate_N model to forecast the effects of nitrate legislation on the economic output and environmental benefits on cropping rotations. Proc. of 16th 9 International CIEC Symposium, 16-19 September 2007, Gent, Belgium, 433-439.