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Original Research Paper

A Study of Fertilizer Application and Irrigation Effects on Nitrate-N Leaching in Paddy Crop Fields Near Cauvery River Basin - A Case Study

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ABSTRACT

Fertilizer leaching affects farm profitability and contributes to nonpoint source pollution of receiving waters. The objective of the study was to evaluate nitrate leaching, i.e., nitrogen export for six application rates of inorganic fertilizer and two applications of cattle manure (A-50, B-75, C-150 D- 200, E-225 and F-350 G_{CM} 150 and H_{CM} 200 Mg/ha) from the irrigated lands in Mandya district near Cauvery basin (65.51% ha). Nitrogen (N) fertilization/application in the district was determined through interviews with local farmers for the years 2006, and NO_3-N load in the plots was monitored during the irrigation period and non irrigation period. The most fertilized crop in the region was paddy. The moderate nitrogen fertilizer rates in fields A, B and C were able to completely cover the N needs of irrigated paddy. Low nitrogen fertilizer rate in field A with sufficient side dressing was best as it did not pollute the surroundings with nitrogen leachate and the crop yield was also good. In case of fields D and E, nitrogen fertilization was higher than N uptake for irrigated crops and indiscriminate use of fertilizer did not increase the paddy yield, in contrast the high fertilizer rate above the nitrogen crop need, produced highest risk of pollution to water resources due to higher nitrate concentrations in drainage. In the field F, the crop yield was not quite good as there was no side dressing which also produced risk to environment. In fields G and H, crop yield was good and also negligible pollution since only cattle manure was applied with sufficient side dressing.

INTRODUCTION

Fertilizers are compounds given to plants to promote growth. They are usually applied either via the soil for uptake by plant roots, or by foliar feeding for uptake through leaves. Fertilizers can be organic (composed of organic matter), or inorganic (made of simple, inorganic chemicals or minerals). They can be naturally occurring compounds or manufactured through natural processes (such as composting) or chemical processes (such as the Haber process). Fertilizers typically provide, in varying proportions, the three major plant nutrients (nitrogen, phosphorus, potassium), the secondary plant nutrients (calcium, sulphur, magnesium), and sometimes trace elements or micronutrients with a role in plant nutrition (boron, chlorine, manganese, iron, zinc, copper, molybdenum).

Some 10 million tons of N-fertilizer are applied to crops every year to sustain high crop production. In fact N-fertilizer has played a primary role together with hybrid seeds in ushering in and sustaining green revolution in India. Usually 10 to 20 kg of N are added to the soil with the rainwater. The amount of mineralized N added to soils is a function of the soil organic matter content. Some 10 to 40 kg N is supplied by this process in most arable mineral soils. Additionally 20-40 kg N is added when farmers apply compost or farm yard manure to their fields. But, the largest N additions to the soils are made by the application of N-fertilizers particularly in the 'green revolution' areas and in regions producing commercial crops. Commonly used fertilizers are urea, cal-amm-nitrate, di-amm-phosphate and others. The annual N-fertilizer use in some land use systems like rice-wheat (RW cropping system) in intensively cultivated areas may be as high 300 kg N/ha annually. During the hot dry months, when the soil is bare, soil N is mineralized from the organic matter. Some of it is lost as NH_4^+, NO and NO_2 into the atmosphere. With the onset of rains, some soil N is lost with surface runoff water. It is estimated that applied fertilizer nitrogen is rarely used beyond 60-70% by the wheat crop and 30-40% by the rice crop. The nitrogen loss, thus, averages about 50% for the rice-wheat system, a cropping system which is popular in NW India. The soil N is lost to the atmosphere, it drains with surface runoff water into the lakes and ponds; and percolates into the soil to join with the groundwater. When high N-concentration water is used for drinking, it causes diseases like meth-aemoglobinaemia (commonly known as blue baby syndrome) in bottle-fed babies and also causes cancer. World Health Organisation has prescribed the safe drinking water limit for nitrate-N as 45 mg/L. Generally, the surface and ground potable waters in India have a nitrate content of 5 mg/L. In some small areas, where N-bearing rocks are present in geological formation, the ground waters may have high N content (http:// www.devalt.org./water/waterinIndia/swm.htm, http://www.devalt.org/water/WaterinIndia/issues.htm, Ministry of Water Resources 1991**).**

The addition of an organic fertilizer provides carbon that can serve as an energy source for most soil microorganisms. The residue not only will increase microbial activity but also nitrogen needs of the organisms. The microbes use the carbon to build cells and the nitrogen to synthesize proteins. If the organic residue has a C:N ratio less than 20:1 (high nitrogen content), then the microorganisms will obtain adequate nitrogen for their needs and will convert the excess organic nitrogen to ammonium (NH_4^+). This conversion is called mineralization.

Ammonium ion is a form of nitrogen that plants can absorb; organic nitrogen cannot be used by plants. If the organic material has a C:N ratio greater than 20:1 (low nitrogen content), then the microorganisms, whose activity increases because of the addition of the carbon, will not obtain enough nitrogen from the residue. Consequently, the microbes absorb the plant-available sources of nitrogen in the soil. This process probably would cause a nitrogen deficiency in plants where a high C:N ratio compounds have been added to the soil. The loss of plant-available nitrogen is called immobilization. Immobilization could tie up the nitrate (NO_3^-) and ammonium (NH_4^+) for several months. After this time, the nitrogen will be released by mineralization of the organic nitrogen found in the residue and microbial tissue (Table 1).

The influence of land-use patterns and agricultural activities on pesticide and nutrient (particularly N) pollution of ground and surface waters has been a major research activity in the last several decades. Nitrogen fertilization is known to increase nitrate (NO_3) concentration of aquifers receiving leachates from agricultural lands. Nitrate concentration in aquifers is related to the fraction of the area dedicated to heavily fertilized or irrigated crops and fertilizers used as well as to physiographic and soil properties. The contribution of N fertilization to NO_3 concentration and fluxes in surface waters has also been extensively investigated. In a long-term study it was found that as much as 30% of the N fertilizer applied in an agricultural basin was exported through its drainage outlet. The seasonal patterns of N fluxes in surface waters have been related to land use and management, flow regimes, or catchment characteristics.

Concerns about nitrate contamination in the surface waters of the Cauvery river basin near Mandya district, where the study area is located, are based on the prevalence of irrigated agriculture in the basin. 783 900 ha or 9.2% of the total surface within the Cauvery river basin and irrigation area found a N export of 65.8 kg N/ha/yr and a net nitrate export between 35.5 and 59 kg N/ha/yr (16-30% of the N applied as fertilizer) in the drainage waters of the 25000 hectares of Mandya Irrigation District.

MATERIALS AND METHODS

Study Area

Mandya district, popularly known as 'land of sugar', is one of the districts with fertile land in south Karnataka. Main crops grown are paddy and cane sugar. The district is located in the southeast of Karnataka state and shares its borders with the districts of Mysore, Hassan, Tumkur and Bangalore. Most of the land is flat, interspersed with hilly region and sparsely vegetated by thorns and bushes. The district is situated at the height of 762 to 914 meters from the sea level. The prominent rivers that influence the life of people of Mandya district are Cauvery, Hemavathi, Lokapavani, Simsha and Veera Vaishnavi. Soil of the district can be classified into three groups, such as red sandy loam, red clayey loam and clayey loam **(**Alfoldi 1983**)**.

Geographical area of Mandya district is 498244 ha of which 326383 ha is under operational holdings and 65.51 % is available for cultivation**.** Source-wise irrigated area in Mandya (area in hectares) is as follows **(**Ministry of Water Resources 1991**).**

Canals		Tanks		Wells		Tube/ Bore wells		Lift Irrigation		Other Sources		Total	
Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net	Gross	Net
107627	88241	8879	7591	13197	10524	4496	3353	584	468	12220	956	136003	111133

Majority of the land in Mandya district is surface irrigated with good irrigation efficiency, but there are many pot holes and ditches which collect drainage water from irrigated lands, the spill-overs of the irrigation ditches, and the leakages and occasional releases from the main canals. The open ditches flow into some wells and also the main collectors which join some streams of the river.

Determination Nitrogen Balance

The main N inputs and outputs were estimated during the irrigation and non-irrigation periods. The N balance equation is written as **(**Alfoldi 1983):

$$\Delta N = (N_{drain} + N_{upt} + N_{fs}) - (N_{fert} + N_{is})$$

Where N_{fert} is the nitrogen applied as fertilizer, N_{is} is the initial soil nitrate, N_{drain} is the mass of nitrate in drainage, N_{upt} is nitrogen uptake by the crop and N_{fs} is the final soil nitrate. ΔN is the difference between outputs and inputs.

Sampling and Analytical Procedures

All containers used for collection of samples were soaked in nitric acid and rinsed with de-ionized water prior to use. Samples were preserved by acidifying with concentrated ultra pure nitric acid having pH< 2, and stored at 4°C in polyethylene bottles. All glassware was thoroughly cleaned by soaking first in detergent and then in nitric acid for 24 hours and finally rinsed with de-ionized water several times. Ultra pure quality chemicals were used and all samples were analysed by using standard methods (Page et al. 1982**)**. The soil was sampled before and after irrigation period (after harvesting). Two samples per lysimeter (with a 5 cm diameter manual auger) were taken at 0 to 0.4, 0.4 to 0.6, and 0.6 to 0.75m depth increments. The holes created were backfilled with original soil and compacted properly to avoid posterior preferential flows. Nitrate concentrations were determined in 1:5 soil to saturated calcium sulphate solution extracts. Soil water content was measured by drying a part of the samples at 110°C for 45 h. The rest of the samples were air-dried, ground and sieved to 2 mm.

Leachate was collected and measured three times during the fertilizer cycle, at 2, 4 and 8 weeks after the fertilizer application. Leachate was filtered through Whatman qualitative filter papers and collected in 20 mL aliquots. Samples were acidified with concentration sulphuric acid to lower pH and frozen. Samples were analysed for NO_3-N. Results have been presented based on both nutrient concentration in leached water (mg/L) and total nutrient content (TNC) leached (ppm). Total nutrient content (TNC) was calculated by multiplying nutrient concentration by the corresponding leachate volume.

TNC = Nutrient concentration × Leached water volume

Grain yield of the harvested plants and above-ground dry biomass were measured (Tables 3 and 4). Moisture content and specific weight of grain were measured using an Aquasearch 600 grain moisture meter. Matured leaf tissue samples were collected, dried, ground, and analysed for nutrient concentration (N, P, K, Ca, Mg, Fe, Zn, Cu and Mn). Analysis of N was done by total Kjeldahl nitrogen (TKN) procedure and the remaining elements were analysed with Spectro Ciros ICP. After overall fertilizer treatments, shoots and roots from each pot were harvested and dried for 24 hours at 75ºC. Drainage was collected in graduated 50-L plastic containers. The volume of drainage was measured after each irrigation and precipitation event, and drainage water samples were taken for analysis of nitrate concentration. Data for some other forms of nitrogen in the drainage water were not reported because they are generally negligible compared with nitrate (Csaki & Endredi 1981, Goldberg 1989**)**. Experimental design was a randomized complete block with four replications. Data were analysed with the SAS analytical program. Unaccounted N was obtained as the difference between outputs and inputs and included the net mineralization of organic matter, gaseous losses by volatilization and denitrification, immobilization or fixation of the applied N, and inorganic N forms different than nitrate in the soil and in the irrigation and drainage water.

RESULTS AND DISCUSSION

Six application rates of inorganic fertilizer and two applications of cattle manure (plot A-50, B-75, C-150, D-200, E-225 and F-350, G_{CM} 150 and H_{CM} 200 Mg/ha) from the irrigated lands in Mandya district near Cauvery basin (65.51% ha) were observed. The moderate nitrogen fertilizers rates in plots A-50, B-75 and C-150 Mg of N/ha with 14.5, 14.6 and 15.7 kg/ha crop yield. In case of plots D-200 and E-225 the crop yield was 17.8 and 17.1 kg/ha and in plots G_{CM} 150 and H_{CM} 200 mg/ha, the paddy yield was 14.7 kg/ha. The maximum nitrate-N observed in drainage was in plots D, E and F (298, 334 and 320 mg/ha) and minimum nitrate-N observed in drainage was in plots G_{CM} and H_{CM} (24 and 25 mg/ha). In plot C, D and E nitrogen fertilization was higher than N uptake for irrigated crops and indiscriminate use of fertilizer did not increase the paddy yield; in contrast, the high fertilizer rate above the N crop need produced highest risk of environmental pollution to water resources

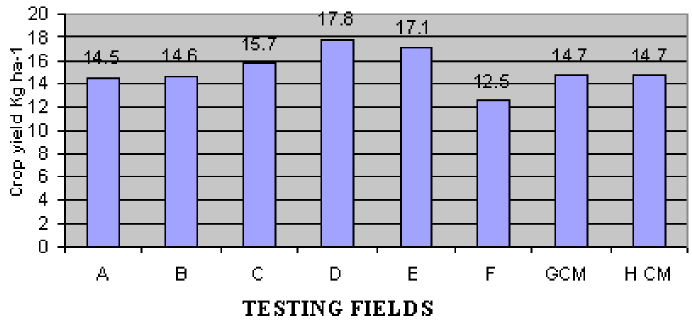

Figure-1 Paddy crop yield obtained in various testing areas as result of the application of Inorganic fertilizer and Cattle Manure.

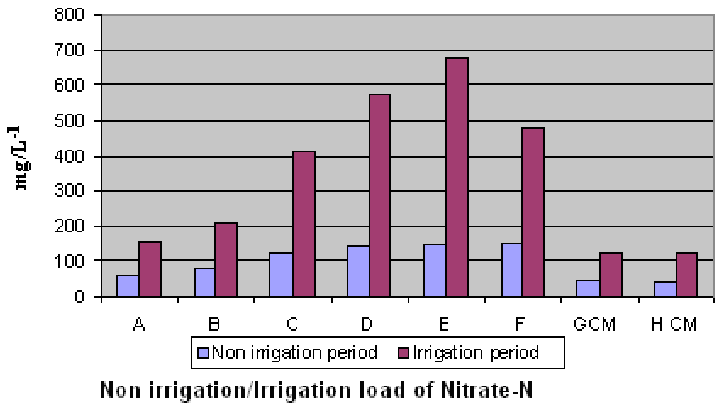

Figure-2 Nitrate load (N_L) measure during non- irrigation and irrigation period in the testing fields showing maximum Nitrate –N in testing fields D,E and F during irrigation period

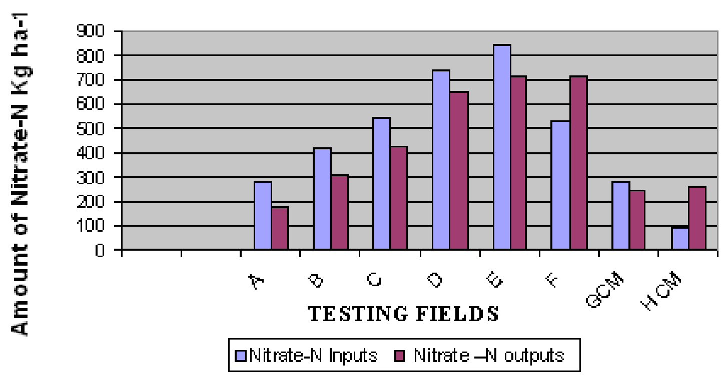

Figure- 3 Nitrogen balance components for testing fields showing indiscriminate use of fertilizer is not required to maximise the crop yield and also **Organic manure** with sufficient side dressing is most suitable and beneficial.

Table 1: Physico-chemical characteristic of the cattle manure (dry powdered matter).

Physico-chemical characteristic	Value
Specific weight, g/L	0.980
pH	7.26
Dry matter, kg DM/Mg	46.23
Organic matter, kg DM/Mg	15.67
Ammonium N, kg N/Mg	3.46
Total N, kg N/Mg	4.43
Potassium, kg/Mg	1.1
C:N ratio	17:1

Table 2: Paddy leaf tissue nutrient concentration (ppm) in response to fertilizer treatments.

Paddy fields	Treatment kg N/ha	TKN	P	K	Ca	Mg	Zn	Mn	Cu	Fe
A	205	640	34.64	162.70	24.50	24.61	0.24	0.36	0.0012	0.19
B	309	840	34.64	162.55	24.64	21.65	0.24	0.36	0.0012	0.19
C	409	1010	33.46	149.45	26.47	20.15	0.196	0.26	0.0004	0.13
D	573	1120	29.10	154.65	26.77	17.63	0.16	0.20	0.0	0.14
E	674	1120	29.10	134.65	26.42	17.85	0.16	0.20	0.0	0.14
F	350	870	34.64	162.70	24.94	21.61	0.24	0.36	0.0012	0.19
G_{CM}	220	540	23.45	145.65	24.35	20.22	0.24	0.42	0.0	0.21
H_{CM}	230	560	25.34	140.50	24.22	20.25	0.24	0.39	0.0	0.21

Means are averaged from paddy leaf tissue collections taken after plant harvest.

Table 3: Amount of available nitrogen applied and yield in different quantities of ammonium nitrate fertilizer.

Treatment kg N/ha	Pre plant kg N/ha	Side dress kg N/ha			Total N applied	Crop Yield kg/ha
		Feb 2006	March 2006	April 2006		
A	50	40	50	65	205	14.5
B	75	79	89	75	309	14.6
C	150	109	101	99	409	15.7
D	200	123	140	122	573	17.8
E	225	160	149	140	674	17.1
F	350	-	-	-	350	12.5
G_{CM}	150	20	20	30	220	14.7
H_{CM}	200	10	10	10	230	14.7

Less crop may be attributed to the application of fertilizer at the beginning is more but no sidedressing.

due to higher nitrate concentrations and loads in drainage. In plot F, the crop yield was not quite good as there was no side dressing, which also produced risk to environment (Goldberg 1982, 1989). Inputs of N to the site comes from fertilizer, precipitation, irrigation water and soils. Outputs of N from the site were leached to groundwater, harvested crops, in surface runoff, soils and loss from the field. Leaching loss was calculated from daily fluxes of water percolation and soil. Based on six months observation, it is inferred that the best source of fertilizer application was cattle manure with sufficient side dressing as it is seen from the results of G_{CM} and H_{CM} (Tables 3 and 4).

Table 4: Nitrogen balance components for paddy observation plots.

Testing field	Nitrate-N Inputs kg N/ha			Nitrate-N Outputs kg N/ha			Unaccounted Nitrate-N
	N_{irr}	N_{fert}	N_{is}	N_{drain}	N_{upt}	N_{fs}	
A	18	160	78	33	127	7.6	-88.4
B	20	309	112	76	132	9.2	-233.8
C	29	409	138	120	199	12.5	-244.5
D	31	573	166	298	234	15.7	-222.3
E	31	674	177	334	244	31.6	-272.4
F	33	680	178	320	255	35.5	-268.5
G_{CM}	18	250	62	24	147	12	-147
H_{CM}	18	245	62	25	145	12	-143

N_{irr} - mass of nitrate in irrigation and rain water; N_{fert} - nitrogen applied as fertilizer; N_{is} - initial soil nitrate; N_{drain} - mass of nitrate in drainage; N_{upt} - nitrogen uptake by the crop; N_{fs} - final soil nitrate. Difference between outputs and inputs.

Paddy leaf tissue nutrient analysis showed maximum differences in total Kjeldahl nitrogen (TKN) between different fertilizer treatments (Table 2). This was probably due to the application of nitrogen at different rates. There was almost no difference in results for all other nutrients.

CONCLUSIONS

For the application rates of inorganic fertilizer and two applications of cattle manure (A-50, B-75, C-150, D- 200, E-225 and F-350, G_{CM} 150 and H_{CM} 200 Mg/ha) from the irrigated lands in Mandya district near Cauvery basin, the lower fertilizer doses before sowing complemented with sufficient side dressing, reduced nitrate losses in the first stage of crop development. Improvement of fertilizer application did not affect crop yield but increased the amount of nitrate leached. The inappropriate use of nitrogenous fertilizers can further aggravate the problem to the environment. To improve nitrogen-use efficiency and to diminish nitrate contamination in these areas, an urgent need for good irrigation management, proper education to the farmers, and scientific approach is key factors. Nitrogen compounds, apart from causing global warming, contaminate water table and cause biological dead zones at the mouth of river. It is important in an irrigated environment to adapt N applications to crop extractions. The main source of nitrate pollution in groundwater results mostly from the action of farmers. The farmers first deplete the soil by excessive, repeat planting and then try to replenish the resulting less-productive soil by putting more and more nitrogen-based fertilizers on the land in an attempt to keep crop yields constant.

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