AMMONIUM LOSSES THROUGH SUBSURFACE DRAINAGE EFFLUENT FROM RICE FIELDS OF COASTAL SALINE SODIC CLAY SOILS

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Abstract. Subsurface tile drainage systems with drain spacings of 15 m in 0.4 ha and 25 m in 3.2 ha were installed at the farmers' field in 1986 and 1987, respectively, to study their effect on the reclamation of the coastal saline sodic clay soils. The system's performance in terms of the changing physical and chemical properties of the soil and rice yield was continuously monitored for a decade. Field data suggested the possibility of adopting wider drain spacings and thus, drainage system with 35 and 55 m spacings was laid in 1997 in a 4 ha area. On these installations the losses of NH_4^+-N through sub-surface drainage effluent were estimated. The area under 25 m drain spacing was the control with no crops, fertilization and irrigation. Analysis of water samples collected daily for 10 days starting from 40 DAT from the drain laterals revealed that there were no trace of NH_4^+-N in the effluent from 15 and 25 m drain spacings. However, the effluent from 35 and 55 m spacings contained an average of 6.704 mg L^{-1} and 4.205 mg L^{-1} of NH_4^+-N, respectively, before irrigation and 2.438 and 1.650 mg L^{-1} after irrigation. The magnitudes of the losses of NH_4^+-N during the crop season were 6.43 kg ha^{-1} in 35 m spacing with a drainage rate of 5.6 mm d^{-1} and 2.14 kg ha^{-1} in 55 m spacing with a drainage rate of 3.5 mm d^{-1}. The rice yield was 6.5 Mg ha^{-1} in 15 m drain spacing where no ammonium losses through subsurface drainage effluent occurred. The rice yields under 35 and 55 m drain spacings were 1.9 and 1.8 Mg ha^{-1}, respectively. The poor yield was due to significant loss of ammonium form of nitrogen through the drainage effluent and lesser availability of total nitrogen to the plants. The plant uptake of nitrogen in the unreclaimed area with 55 m spacing was half of that in the reclaimed area with 15 m spacing.

Keywords: ammonium losses, coastal clay, drain spacing, rice, saline sodic, subsurface drainage

1. Introduction

More than 90% of the rice (*Oryza Sativa* L.) in the world is produced in Asia (IRRI, 1986) and the production has been increasing at an average rate of 2.7% annually, slightly faster than the rate of population growth. The increased production is primarily due to higher productivity rather than increased area under cultivation. In the South and South-East Asia, there are 49 million ha salt affected area of which 27 million ha are coastal saline soils. India has about 3.1 million ha of coastal saline land stretching over nearly 7000 km along the coast of Bay of Bengal in the east and Arabian sea in the west (Sen, 2000). Asia consumed 58%

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of the World's N fertilizer in 1996/97 (FAO, 1998) as compared to only 24% in 1973 (FAO, 1974). Nitrogen represents approximately 70% of the total nutrient consumption in Asia and almost 60% of the N fertilizer is used on rice (Stangel and De Datta, 1985). Research over the past 20 to 30 yr has shown that N fertilizer is generally inefficient, with less that 40% of the applied N normally used by low land rice. Alternative management practices to improve N fertilizer use efficiency in flooded rice were suggested by De Datta and Patrick (1986).

Greater pay-offs from increased fertilizer use efficiency and integrated N management in rice is anticipated from Asia because of its dominance in the irrigated rice cultivation. More than 70% of irrigated rice is grown in this part of the world. Increased crop utilization and reduced losses of chemical N fertilizer will remain an important goal of effective N-management for the sustainability of high yields of irrigated rice. The reduction of N losses may gain importance as concerns over the eutrophication of surface and ground water and environmental pollution are on the increase.

Saline sodic clay soils occur in coastal low lands, irrigated, arid and semi arid areas. Excess accumulation of salts in the soil profile occurs due to tidal back water flow from the sea, evaporation from shallow water table or insufficient leaching of salts during the crop season. A subsurface drainage system controls the water table, restricts salinization caused by capillary flux from saline ground water and facilitates leaching of salts from the root zone soil profile. It is, however, apprehended that some amount of nutrients may also be lost from the cropped land via sub-surface drainage effluent. Besides, knowledge of the chemical composition of drainage effluent is necessary to understand the long term environmental impact of subsurface drainage works.

In clay soils, the negatively charged clay particles offer a base for the positively charged stronger cations to get adsorbed. Ammonium cations being weaker, remain loosely bound to the water molecules and their concentration increases if the pH of their environment is above 7.2. With increasing hydroxyl-ion concentrations in water, ionized NH_4^+ gets converted to nonionized NH_3, which escapes as a gas. Substantial losses of surface applied N fertilizer from flooded rice fields through volatilization of ammonia have been reported (Mikkelson *et al*., 1978; Vlek and Craswell, 1979). Placement of N fertilizer in soil at depths of 10 to 12 cm could reduce NH_3 volatilization losses to less than 1% of the applied N (Mikkelson *et al*., 1978). The first direct measurement of ammonia loss with micrometeorological technique in tropical irrigated rice fields were made by Freney *et al*. (1981). Their study was conducted with ammonium sulphate applied to a puddled lowland rice field in Philippines. The volatilisation loss of ammonia accounted for 5% of the ammonium sulphate which was broadcast before transplanting and 11% of the ammonium sulphate through surface run-off from the flooded rice fields at panicle initiation. Subsequent field measurements of ammonia loss have focused primarily on urea. Volatilisation loss of ammonia from urea broadcast before transplanting was 9% and total N loss by other mechanisms such as nitrification, denitrification, leaching and artificial drainage etc. were much higher (Cai *et al.*, 1986). Ammonia volatilization losses in flooded soils range from negligible to almost 60% of applied N (Savant and De Datta, 1982).

Generally, leaching losses of N occur in the form of NO_3^--N and not in the form of NH_4^+-N (Rossi *et al.*, 1991). Field experiment on non-rice crops (Juhasz *et al.*, 1997) showed that only 5% of the total inorganic nitrogen found in the sub surface drainage water was in the form of NH_4^+-N. No measured data from the salt affected rice fields on NH_4^+-N losses via sub surface drainage systems, are available. As such, the recovery of nitrogen by plant and soil are 47 and 60%, respectively, in wetland rice without subsurface drainage system (Reddy and Patrick, 1978).

Besides volatilisation losses, and if the water is mobile as in a subsurface drained field, the unadsorbed or weakly adsorbed ammonium may also get transported with the drainage water. Information on this aspect may be useful in formulating operational policies of the sub surface drainage system and nitrogen fertilizer application schedule (timing, rate and form of placement) and ultimately managing the nutrient losses via sub surface drainage system. In view of the steadily increasing cost of fertilizer, its further loss due to reclamation efforts is undesirable.

Smedema (2000) suggested that a medium term program of improved agricultural land drainage may increase the food production by 1% globally. And without drainage approximately 30 to 40 million ha of total world crop land would not be sustainable for crop production and is likely to degrade into waterlogged and/or saline waste lands.

The present study was undertaken to investigate the extent of losses of the NH_4^+-N form of nitrogen from the highly saline sodic rice fields which are being reclaimed by sub surface drainage technology in the coastal region of Andhra Pradesh in India.

2. Materials and Methods

2.1. Study Area

The experimental site is located at Endakuduru village in Krishna district of Andhra Pradesh in India. It lies between 15°43′ and 17°0′N latitude and 80°0′ and 81°33’E longitude; situated 18 km to the west of Bay of Bengal and the elevation is 1.5 m above the mean sea level. The land is flat and is dyked in small units for rice cultivation. The monthly data of the selected climatological parameters for the experimental site are presented in Table I. The soil is saline to saline sodic with high (avg. 58%) clay content. The soil is deep with no rock formations. A sandy layer exists at depths varying between 1 to 2 m from the surface.

TABLE I

Selected climatological parameters of experimental site

Year	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997[a]	Max Temp (°C)	27.9	31.3	33.5	34.5	38.3	39.2	34.9	34.2	32.7	31.6	30.2	29.2
	Min Temp (°C)	19.7	20.8	22.9	25.2	27.8	28.6	26.6	26.6	26.0	24.9	24.3	23.5
	Rainfall (mm)	9.4	0.0	9.6	7.7	1.2	56.9	247.9	135.0	491.6	125.1	194.1	87.1
1998[a]	Max Temp (°C)	29.8	31.5	33.1	35.1	39.0	38.6	33.4	32.6	32.6	31.3	31.0	29.4
	Min Temp (°C)	22.6	23.3	25.0	26.4	28.9	28.9	26.6	26.4	26.4	25.3	23.7	19.4
	Rainfall (mm)	19.6	0.0	0.4	19.8	0.2	78.2	162.5	181.5	216.5	311.1	57.5	0.0
Normal	Rainfall[b] (mm)	7.9	8.3	7.6	4.2	28.1	86.8	169.7	182.0	166.6	153.9	140.7	19.2
	PET[c] (mm)	109	122	166	176	193	167	134	136	123	118	108	102

[a,c] India Meteorological Department (IMD, 1999).
[b] Devadattam and Ramesh Chandra (1995).
PET: Potential Evapotranspiration.

2.2. SUBSURFACE DRAINAGE INSTALLATION

Sub-surface tile drains were installed in farmers' fields for a pilot study. The objectives were to reclaim the chemically degraded soil and to intercept the capillary flux towards the root zone from the brackish ground water below. Initially, tile drains were laid at a narrow spacing of 15 m in the summer of 1986 in 0.4 ha at an average depth of 1.0 m. Another 3.2 ha adjacent area was put under sub-surface drainage in the summer of 1987 with a wider lateral spacing of 25 m and at the same depth. The performance evaluation in terms of physical and chemical properties of the soil and rice yield was continuously monitored for over a decade (Devadattam *et al*., 1995; Bhattcharaya, 1996; AICRPAD, 1986–1997). Field data suggested the possibility of adopting even wider spacing of tile drains and thus, two more spacings of 35 and 55 m at 1.0 m depth were laid in the summer of 1997 in a 4.0 ha area. The discharge from the laterals of 15 and 25 m spacings were collected through two independent collector pipes in a sump and the discharge from the laterals of 35 and 55 m spacings were collected in another sump through one collector pipe and subsequently, the leachate was pumped out into an open drain which ultimately discharges in to the sea.

2.3. FIELD EXPERIMENTS

Field experiments were conducted for measuring ammonium losses through subsurface drainage effluent in four drain spacing areas, namely 15 and 25 m commissioned earlier, and 35 and 55 m, newly commissioned in 1997. One month old rice (Variety: MTU 1010) seedlings were transplanted on 2nd February 1999 on 15, 35 and 55 m spacing plots whereas, the 25 m spacing plot was left fallow for reference/control. The density of transplantations was 33 hills in one square metre. Urea was applied to supply 120 kg -N ha^{-1} in three splits; i.e. 60 kg basal broadcast, incorporated just before transplanting, 30 kg 15 days after transplanting (DAT) and the remaining 30 kg on 35 DAT. Soil samples for the determination of salinity and pH of soil profile were collected on 50 DAT. The duration of the crop is 85 days after transplanting.

For finding other soil properties viz. bulk density, cation exchange capacity (CEC) and exchangeable sodium percentage (ESP), soil samples were collected when the soil surface was dry. The physical and chemical properties of the soil profiles; 0–15, 15–30, 30–60 and 60–90 cm for all the 4 spacings are presented in Table II.

For estimating ammonium in the effluent, after the last dose of N fertilizer has been applied and the drainage system was operational, sampling was done from the drainage effluent of the central lateral in each of the four spacings. Sampling began on 40 DAT and continued for 10 days during which two irrigations were applied.

The plant/hill samples were collected from 3 places i.e. just at the lateral, at 1/4 spacing away from the lateral and at mid-spacing, on 45 DAT when the plant uptake of N is supposedly at its peak. The grain yield data were recorded from 1 m

TABLE II
Basic physical and chemical properties of the soils

Sampling (1) location and depth (cm)	Bulk density Mg m^{-3}	Texture Sand %	Silt %	Clay %	Salinity (2) dS m^{-1}	pH	CEC c.mol (p^{+}) kg^{-1}	ESP %
15 m drain spacing								
0–15	1.25	32	8	60	3.8	7.98	50.0	25.0
15–30	1.06	12	18	70	4.0	7.81	57.5	34.8
30–60	1.06	12	14	74	4.1	8.20	56.3	37.8
60–90	1.11	24	23	53	4.1	8.30	61.3	44.9
25 m drain spacing								
0–15	1.23	16	18	66	6.1	7.50	51.3	43.9
15–30	1.11	18	16	66	6.2	7.60	43.8	62.9
30–60	1.04	14	14	72	4.7	7.20	56.3	46.7
60-90	1.00	24	11	65	3.9	7.14	50.0	57.5
35 m drain spacing								
0–15	1.25	22	18	60	9.2	7.15	48.8	48.7
15–30	1.24	26	15	59	10.5	7.20	52.5	50.0
30–60	1.31	22	33	45	17.1	7.18	47.5	57.9
60–90	1.34	32	27	41	20.1	7.25	52.5	54.8
55 m drain spacing								
0–15	1.17	36	14	50	16.5	7.24	40.0	62.5
15–30	1.00	20	15	65	21.0	7.25	53.8	48.8
30–60	1.23	38	18	44	25.2	7.25	45.0	66.7
60–90	1.18	56	14	30	28.9	7.28	31.3	68.0

Note: Values given in the table for various parameters are mean of the triplicates.
(1) Sampling location is at the intersection of the mid-spacing and mid-lateral length lines.
(2) ECe of 1:1 soil:water suspension.

square plots of each spacings. Canal irrigation water of 125–130 cm was applied during the crop season in 20 irrigations.

2.4. Laboratory Analysis

The soil and water samples were analysed immediately after collection from the field and when storage was required for more than 24 hr, the samples were frozen to prevent microbial activity during storage. NH_4^+ extraction from the field saturated soil samples were done with water in 1:1 ratio. NH_4^+-N both in soil extracts and drainage water was determined colorimetrically using the modified indophenol blue method (Novozomsky *et al.*, 1974). The amount of ammonium removed via drainage water was calculated from the volume of the drainage water and its ammonium concentration. The average value obtained during the sampling period was then integrated over the whole crop season to get an approximate value of loss per hectare over the season. The total N in plant was determined using an autoanalyser following the procedure outlined in Technicon Monograph I, 1971. The CEC and ESP of the soil profile were determined by the procedure adopted from Richards (1954).

3. Results and Discussion

3.1. Soil characteristics vis-a-vis subsurface drainage

Laboratory test revealed that the soil of the study area was of highly swelling and shrinking type and *in situ* saturated hydraulic conductivity ranged between 0.02 to 0.90 m d^{-1} with a geometric mean of 0.144 m d^{-1} (Devadattam and Ramesh Chandra, 1995). The areas with 15 and 25 m drain spacings had been under the reclamation influence of subsurface drainage for the last one decade and their soil profile salinity was similar (Ramana Rao, 1998) until the dry season of 1997. During the experiment, the area with 15 m drain spacing was under rice cultivation whereas the area with 25 m drain spacing was left fallow with no crop, no irrigation and only restricted sub surface drainage. The average bulk density of soil profiles (0–90 cm) were 1.12 and 1.10 Mg m^{-3} (Table II) for the 15 and 25 m drain spacing areas, respectively. The salinity of the four selected profiles was almost uniform (3.8 to 4.1 dS m^{-1}) in the area with 15 m drain spacing and it ranged from 3.9 to 6.2 dS m^{-1} in the area with 25 m drain spacing (Table II). During the experimental period (March-May 1999) the mean EC of the effluent from 15 m drain spacing area was 4.35 dS m^{-1} and from the 25 m drain spacing area was 9.83 dS m^{-1}. Prior to the dry season of 1998 the EC of drainage water remained in the range of 4–5 dS m^{-1} in under both 15 and 25 m spacing (Devadattam and Ramesh Chandra, 1995). During 1998 and 1999, the area with 25 m spacing was left natural fallow and this led to the build up of root zone salinity in the absence of crop, irrigation, leaching and drainage etc. Apart from this, the PET always exceeds the rainfall in the dry months from January through May of any year. This climatic factor does aggravate the chemical degradation of the root zone soil profile (Table I). Because of all these factors, the soil salinities in the 0–15 and 15–30 cm soil layer of 25 m drain spacing were 6.1 and 6.2 dS m^{-1}, respectively. Under this situation when the drainage system was operated in March 1999 it was found that the EC of the drainage effluent from 25 m spacing had increased by more than two folds as compared to 15 m spacing (Table VI). This finding suggests that such lands are prone to quick secondary salinization in the absence of adequate leaching by

TABLE III

Ammonium-N concentration (mg L^{-1}) in sub-surface drainage effluent

Drain spacing (m)	Before irrigation	After irrigation	Losses (kg ha^{-1})
15	N.D.	N.D.	Nil
25	N.D.	N.D.	Nil
35	6.704	2.438	6.43
55	4.205	1.65	2.14

N.D.: Not detected.

drainage. The data on bulk density and soil salinity of the similar profiles from the new experimental area with 35 and 55 m drain spacings are also presented in Table II. The average bulk density of soil of the 35 m spacing area was 1.28 Mg m^{-3} as compared to 1.15 Mg m^{-3} of the 55 m spacing area. This was due to higher sand content in the soil as compared to the old reclaimed area (Table II).

The electrical conductivity (EC) of the drainage effluent samples, collected daily from March 12 to 22, and May 16 to 23, 1999 were 44.89 and 36.31 dS m^{-1}, respectively, with respect to 35 and 55 m drain spacing areas (Table VI). The corresponding drain discharges were, respectively, 5.6 and 3.5 mm d^{-1}. This resulted in 32.8 and 10.5 Mg ha^{-1} yr^{-1} salt removal from the 35 and 55 m spacing areas, respectively. This indicates that the drains with 35 m spacing were more efficient as compared to 55 m spacing, the probable reasons being higher leaching efficiency, lighter soil texture and higher drainage rate of the area corresponding to the former as compared to that of the latter (Tables II and VI). The mean salinity of the soil extracts above the drainage base were 14.2 and 22.9 dS m^{-1} in 35 and 55 m drain spacing areas, respectively (Table VI). Such a root zone salt balance in the new area under reclamation was found after one year of operation of subsurface drainage system. These values are approximately 4 to 6 fold of the salinity of the reclaimed land with 15 m drain spacing (Table II).

Data on CEC and ESP of the sixteen profiles are also presented in Table II. The average CEC of the soil above the drainage base was maximum at 56.3 c.mol (p+) kg^{-1} in the 15 m spacing area and was minimum at 42.5 c.mol (p+) kg^{-1} in the 55 m spacing area. These are compatible with the corresponding soil textures (Table VI). Average ESP of the soil profile of the 15 m spacing area was the lowest of 35.6 while the highest value of 61.5 was found in the soil profile of 55 m spacing. The ESP of the soil profile of 25 and 35 m spacing was similar with an average value of 52.8 (Table VI). Such variations were related to the direct effect of drainage density and long term operation of sub surface drainage system.

TABLE IV

Ammonium-N concentration (mg L^{-1}) in 1:1 soil water suspension from soil samples of different layers

Depth	Subsurface drain spacing (m)			
	Old and reclaimed area		New area under reclamation	
(cm)	15	25	35	55
0–15	N.D.	N.D.	1.987	1.788
15–30	-do-	-do-	1.687	1.056
30–60	-do-	-do-	1.433	0.839
60–90	-do-	-do-	1.298	0.717

N.D.: Not detected.

3.2. Ammonium losses through subsurface drainage effluent

The average concentrations of NH_4^+-N in drainage effluent are given in Table III and the statistical parameters of a number of soil, water and plant properties of the study area are presented in Table VI. Sampling began on 40 DAT and continued for 10 days during which two irrigations were applied following the local practice. Effluent from the 15 m drain spacing area did not contain any NH_4^+-N, either before or after the irrigations. Effluent from 35 and 55 m drain spacing areas contained 6.704 and 4.205 mg L^{-1} of NH_4^+-N, respectively, before irrigation, and 2.438 and 1.650 mg L^{-1}, after irrigation. The dilution effect was due to irrigation. Such concentrations were observed in case of restricted drainage i.e. 6 hr of pumping in a day. There was no trace of NH_4^+-N in the effluent from 25 m drain spacing for the obvious reason that the area was left fallow and no fertilizer had been applied. The absence of NH_4^+-N in the effluent through the 15 m spacing may be because the NH_4^+ is adsorbed as an exchangeable ion on the clays.

It may be recalled that the area under 15 m spacing was under reclamation for the last 10 yr which has improved the soil condition i.e. with a reduced salinity of 4.0 dS m^{-1} and ESP of 35.6. This might have allowed NH_4^+-N adsorption on the clay complex. The areas under the latter two spacings, which are at the initial stage of reclamation, have the average soil salinities of 14.2 and 22.9 dS m^{-1} and ESP of 52.8 and 61.5, respectively (Table VI). The exchange complex of the clay was so much saturated with Na^+ in these cases that it did not allow NH_4^+ ion to get adsorbed on the clay complex. Although the ammonification follows the first order reaction kinetics but in the presence of rice plants in wet lands, it could be modified (Savant and De Datta, 1982). Kinetic data on ammonia release in soil solution collected by Manguiat and Broadbent (1977) showed (i) an initial increase in NH_4^+-N in soil solution, attaining a maximum of 14 mg L^{-1} in 2 weeks time under submergence followed by a reduction to 1 mg L^{-1} after 8 weeks, and (ii) increased salinity created by varying amounts of sodium chloride remarkably increased NH_4^+-N concentration from 10 to 22 mg L^{-1} in the quasi-equilibrium soil solution. This could have been due to NH_4^+ replacement from the soil exchange complex by added Na^+. This could have happened in our experiment too. The data of Table IV indicate that there were NH_4^+ ions present in the soil solution of the areas with very high salinity and sodicity whereas, no trace of NH_4^+ ion was detected in any of the profiles in 15 and 25 m drain spacing. This might have happened because the soil was over saturated with sodium (Table VI) and the situation has led to NH_4^+ to remain in soil solution. This may enhance downward transport of NH_4^+, probably below the root zone (Savant and De Datta, 1982). The concentration of NH_4^+ in soil solution decreased as the depth increased. The maximum concentrations of NH_4^+ N in soil solution were 1.987 and 1.788 mg L^{-1} in 0–15 cm soil profile in case of 35 and 55 m spacing areas, respectively. The decrease in NH_4^+-N concentration with depth may be the result of surface application of urea combined with slow downward movement of NH_4^+ ions unlike NO_3^- ions which move downwards due to anion exclusion.

In the specific situation like the one in our study, since the exchange complex of the clay is saturated with Na^+ as the salinity of soil water is very high, NH_4^+ ion may have remained in diffused double layer and moved slowly downward along with the continuously percolating water, ultimately finding its way to sub surface drainage effluent. Vlek *et al*. (1980) suggested that leaching loss of NH_4^+-N in wet land soils could be very serious if the percolation rate exceeds 5 mm d^{-1}. In our experiment also, maximum loss of ammonium was found in the drainage effluent of 35 m spacing which was dewatering the soil profile at the rate of 5.6 mm d^{-1} (Table VI). Thus, there was substantial loss of NH_4^+-N via sub surface drainage effluent. These losses would be in addition to the loss via ammonia volatilization (Aulakh and Singh, 1997). At the experimental site however, no attempts were made to estimate the ammonia losses above the ground surface as the main focus was on estimation of losses via sub surface drainage system.

3.3. NITROGEN UPTAKE BY RICE PLANT AND GRAIN YIELD

Total nitrogen uptake data were obtained from the analysis of the rice plants sampled on 45 DAT. The results of plant analysis and the mean values of the triplicates are given in Table V. The difference in growth and health of rice plants in different drain spacing areas are evident from the dry weight of the plants/hill. Maximum dry weight of 32.1 g $hill^{-1}$ was observed in plants in the 15 m drain spacing area with the maximum nitrogen uptake of 0.412 g $hill^{-1}$. The grain yield from the area with 15 m drain spacing was 6.5 Mg ha^{-1}. The total N uptake by plants in the 55 m spacing area, which is practically unreclaimed presently, was just half of that observed in the area with 15 m drain spacing. The yield was also very low at 1.8 Mg ha^{-1}. Such a low yield was attributed to low availability of

TABLE V

Total N-uptake (g hill^{-1}) by rice plant on 45 DAT and grain yield (Mg ha^{-1}) after maturity

Drain spacing (m)	Dry weight of single hill (g)	Total nitrogen (%)	Total N in plant sample (g)	Grain yield (Mg ha^{-1})
15	32.1	1.25	0.412	6.5
25	n.a.	n.a.	n.a.	n.a.
35	26.1	1.06	0.284	1.9
55	15.1	1.39	0.211	1.8

n.a.: Not applicable.

nitrogen due to adverse soil and water environment on one hand and significant losses of NH_4^+-N through sub surface drainage on the other.

4. Conclusion

Results of the soil and water analyses suggest that significant NH_4^+-N losses occurred via subsurface drainage system while reclaiming the highly saline sodic coastal clay soils having an average exchangeable sodium percentage higher than 50. Also, the magnitude of the losses were higher in the narrower drain spacing; 6.43 kg ha^{-1} in case of 35 m spacing with an average drainage rate of 5.6 mm d^{-1} and 2.14 kg ha^{-1} in 55 m spacing with the drainage rate of 3.5 mm d^{-1} (Tables III and VI). The measurements were done after the third dose of nitrogen application of 30 kg ha^{-1}. On the basis of these measurements and assuming that at least this much concentration of NH_4^+-N in the drainage effluent throughout the crop growth season, there may be 5 to 6% of nitrogen losses in the form of ammonium through sub surface drainage effluent. This form of losses may be as low as nil from the area which is well reclaimed and salts have been removed from the soil profile. The losses are likely to be more after the first dose of application of 60 kg ha^{-1} -N at the time of transplanting, as that stage coincides with the beginning of the reclamation process when the soil conditions are more adverse and plant uptake of nutrient is also low. In case of unrestricted drainage, the losses might increase substantially.

TABLE VI

Statistical parameter of the soil, water and plant properties of the study area

Description of variables	Drain spacings (m)											
	15			25			35			55		
	Mean	Range	s.d.	Mean	Range	s.d.	Mean	Range	s.d.	Mean	Range	s.d.
Clay (%)	64.25	53–74	9.53	67.25	65–72	3.20	51.25	41–60	9.67	47.25	30–65	14.5
CEC (c.mol (p^+) kg^{-1})	56.3	50–61.3	9.00	50.35	43.8–51.3	5.14	50.33	47.5–52.5	2.57	42.52	31.3–53.8	9.41
ESP	35.60	25–45	8.25	52.75	44–63	8.95	52.85	49–58	4.27	61.50	49–68	8.79
Soil salinity (dS m^{-1})	4.0	3.8–4.1	0.14	5.23	3.9–6.2	1.11	14.23	9.2–20.1	5.23	22.90	16.5–28.9	5.35
Salinity of drainage effluent (dS m^{-1})	4.35	2.6–5.6	1.10	9.83	5.6–14.7	4.58	44.89	40.4–48.5	2.45	36.31	33.2–38.9	1.72
Drainage rate (mm d^{-1})	–	–	–	–	–	–	5.6	4.4–8.8	1.4	3.5	1.56–3.8	1.56
NH_4^+-N in soil sol^n (mg L^{-1})	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.601	1.298–1.987	0.303	1.100	0.717–1.788	0.479
NH_4^+-N in effluent (mg L^{-1})	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6.704	5.742–8.599	1.64	4.205	2.684–6.147	1.43
Dry wt. of single hill (g)	32.1	20.2–47.4	8.7	n.a.	n.a.	n.a.	26.1	18.6–31.2	6.7	15.1	6.4–25.3	6.5
Total N-uptake (g $hill^{-1}$)	0.421	0.285–0.585	0.155	n.a.	n.a.	n.a.	0.284	0.157–0.371	0.112	0.211	0.155–0.267	0.056

s.d.: Standard deviation; CEC: cation exchange capacity; n.d. : not detected; n.a.: not applicable.

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