VERTICAL MOVEMENT OF NITROGEN IN MAJOR RICE SOILS OF KERALA

BY

GEORGE T. ABRAHAM

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DECLARATION

I hereby declare that this thesis entitled **"VERTICAL MOVEMENT OF NITROGEN IN MAJOR RICE SOILS OF KERALA"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

College of Agriculture,
Vellayani,
30 - 6 -1995.

(George T. Abraham)

CERTIFICATE

Certified that this thesis entitled **Vertical movement of Nitrogen in major rice soils of Kerala"** is a record of research work done independently by Mr. George T. Abraham, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Dr. S. Pushkala,
Chairman, Advisory Committee
Associate Professor,
Department of Soil Science &
Agricultural Chemistry,
College of Agriculture.

Vellayani,
30-6-1995.

APPROVED BY:

CHAIRMAN

DR. S. PUSHKALA

MEMBERS

DR. P. PADMAJA

DR. ALICE ABRAHAM

DR. V. L. GEETHAKUMARI

EXTERNAL EXAMINER

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(GEORGE T. ABRAHAM)

CONTENTS

LIST OF FIGURES

INTRODUCTION

More than 90% of the rice (Oryza sativa L) in the world is produced in Asia. Within Asia, rice production has been increasing on an average rate of 2.7% annually, slightly faster than the population growth. The increased production is primarily due to higher yields per hectare, rather than increased land area under cultivation. Twenty four percent of the increase in the Asian rice production from 1965 to 1980 was attributed to the use of nitrogenous fertilizers alone. Nitrogen represents approximately 70% of the total fertilizer nutrient consumption in Asia, and approximately 60% of the nitrogen fertilizer consumed in Asia is used in rice production.

Fertilizers have played an important role in improving the productivity of food grain crops. Nitrogen is one of the essential nutrients for increasing crop productivity. Nitrogen is a highly mobile nutrient and is lost from uncropped as well as cropped lands in substantial quantities, due to various factors.

Urea accounts for more than 75% of total nitrogen fertilizer consumption in Asia. It is estimated that 40% of the total consumption of nitrogen in India is devoted to rice, urea being the main source of nitrogen carrier. By rough estimate, about 6.25 million tons of urea (equivalent to 2.88 million tons) of nitrogen is used by rice farmers. The nitrogen use efficiency in rice largely ranges between 25 to 35% and it seldom exceeds 50%. The low recovery of nitrogen by rice is mainly attributed to the loss of nitrogen from the reach of the crop, temporarily or permanently. and it cannot be improved unless the loss mechanism is properly understood. in fact, out of every four bags of urea applied to rice by farmers, only one bag is utilized by the rice crop.

Among the three major nutrients, i.e., N, P and K, losses of nitrogen is found to be more prominent than the losses of P or K. Also, because of our tropical climatic conditions, our soils are generally low in nitrogen.

The poor utilization of nitrogenous fertilizers by rice is thought to be largely caused by greater loss of nitrogen from the soil. Some of the major nitrogen loss mechanisms are peculiar to the waterlogged soils and this accounts for the low nitrogen use efficiency of rice as compared to other irrigated upland crops. The nitrogen fertilizers applied to wetland soils undergo various changes due to their peculiar physico-chemical and biological characters, which is not there in the case of uplands. The four major methods by which nitrogen is lost from the wetlands are through ammonia volatalisation, leaching, denitrification and runoff. In this experiment, the study of two of these loss mechanism, viz., leaching and runoff has been done.

Leaching is the movement of nutrients from the surface to lower layers, and it becomes inaccessible to plant roots or it is lost to the ground water. Runoff loss is the loss of nutrients dissolved in flood water in the runoff form.

The loss of nitrogen by leaching vary with different soil types. The soil factors, physical as well as chemical, which are related to nitrogen leaching for ;the different rice soils of Kerala are not yet studied in detail. There is a need to have in depth studies on soil factors, which influence the leaching and runoff losses in the rice soils of Kerala.

In the present investigation, an attempt has been made to study the losses of nitrogen occurring through leaching and runoff in paddy fields with the following objectives.

1. To study the vertical movement pattern of nitrogen when applied as urea under submerged conditions.
2. To study the runoff loss of nitrogen when applied as urea from different soils at different intervals after application.
3. To correlate these losses with the physico-chemical of the soils.

REVIEW OF LITERATURE

2. Leaching Losses Of Nitrogen

The leaching loss of nitrogen was found to be a major mechanism for the loss of nitrogen from paddy fields. Several works done on this aspect are reviewed below.

2.1. Loss of nitrogen from soils.

Applied nitrogen is lost in different forms such as nitrate ammoniacal etc.

2.1.1. Nitrate (NO_3) - N form.

Collison and Mensching (1930) from their studies observed that more than 99% of the N in the leachate from lysimeters in New York was present as nitrate.

It has been reported by Abhichandini and Patnaik (1958) that the maximum leaching loss of nitrate occurs within four to five days of waterlogging and started decreasing from the fifth day onwards.

Ghose et al. (1960) observed that ammoniacal nitrogen added in the form of fertilizers to rice soils, got oxidized to nitrate nitrogen in the surface layer and got leached down.

The nitrate present in the root zone of a submerged soil at the beginning of the season is invariably lost by denitrification or by being leached out of the root zone before the plants are large enough to utilize the nitrogen has been reported by Patrick and Mahapatra (1968).

From studies conducted by Palaniappan and Raj (1970), they observed that the increase of nitrogen dose increased the leaching loss of nitrogen and the nitrate forms of N suffered the greatest loss.

Wetting and drying of upland lateritic rice soils of Eastern India, accelerates N loss even if N is applied in the NH_4 form, because NH_4 gets oxidized to NO_3-N. This results in substantial loss of fertilizer nitrogen (Patrick and Wyatt, 1964). The nitrate thus formed gets leached down along with percolating water and the loss incurred will be about 45 to 60%, under pot culture conditions (Pande and Adak, 1971).

Data from green house experiments with ^{15}N showed that nitrate nitrogen leached was 4 to 25.6% from ammonium nitrate and 1.2 to 16.2% from urea (Daftardar,1973).

Haunold and Zuara (1976), observed from soil column studies observed that a higher amount of total N was received in the case of nitrate fertilizer. After nitrate application, 29.6% and 22.6% was found in drainage water, 18.1% and 16.7% remained in the soil and 52.3% and 60.6% was lost.

was in the nitrate form (Pleysier et al., 1987; Black, 1968; Palaniappan and Raj, 1970; Rao et al., 1983; Miller and Donahue, 1992). Singh and Singh (1988) reported a nitrate leaching loss of 25% from sandy loam soils.

In another study by MacDonald et al.(1989), where ^{15}N labelled fertilizer was applied to winter wheat crop, not more than 5 kg nitrate nitrogen per hectare got leached down (0.4 - 3.6%).

In leaching experiments carried out in soil columns of clayey red latosols, nitrate and chloride leached showing less retaining capacity of the soils for these ions (Fereira et al., 1990). Smith et al.(1990) reported that the dominant soluble forms of nitrogen are nitrate, which tends to move down the soil profile with the initial infiltrating water of a storm event.

Intermittent wetting resulted in more heavier loss of nitrogen in the nitrate form than under continuous submergence has been reported by Mahajan and Tripathi(1991).

The leaching loss of nitrates increased as the quantity of percolating water increased has been observed by Miller and Donahue (1992). Katyal (1991) observed that maximum leaching of fertilizer nitrogen took place in the nitrate form and moves freely in the negatively charged soil because of repulsion. Nitrogen that escapes denitrification and crop uptake is liable to leaching. Each time more water is added, depth of nitrate front increases. Regions of

A wasteful removal of soil nitrogen may occur either by the loss of nitrate in leaching water or by volatilization has been reported by Ramamurthy and Velayutham (1978).

In a pot experiment, leaching losses from flooded rice soils using ^{15}N labelled urea, $^{15}NH_4NO_3$ or $NH_4{}^{15}NO_3$ at 150 kgN/ha; losses were greater from nitrate nitrogen (4 to 25.6%) than from urea (1.2 to 16.2%) (Daftardar et al.,1979).

Saharawat (1980) reported that 70% of the applied NO_3-N was leached down into the soil after seven days of incubation. Shinde et al. (1982), from their studies concluded that about 6.37% of nitrogen was lost from urea applied to cotton fields by leaching, out of which nitrate nitrogen accounts for 4.88%.

Jakkola (1984) reported a leaching loss of 2 to 7 kg nitrate nitrogen per hectare from a field experiment on a clay soil in Finland. High annual NO_3 leaching rate of up to 55 kg/ha has been reported from agricultural fields by Jacobs and Gilliams (1985).

Gould et al. (1987) observed that the leaching loss of urea may occur in soil by two processes- (i) urea is leached per se from soil and (ii) urea migrating below the rooting zone, is hydrolyzed, nitrified and then leached as nitrate.Many other experiments conducted in different soil types using different N fertilizers revealed that, major part of N lost through leaching intensive farming on sandy soils are more prone to leaching of nitrogen resulting in ground water pollution.

2.1.2 Ammoniacal (NH^4) nitrogen form

Collison and Mensching (1930) observed a loss of less than 1% ammoniacal nitrogen through leaching from lysimeter experiments in New York.

According to Harada and Kutsuna (1955), ammonium ion is subjected to leaching from soils, where the primary source of negative charge is organic rather than inorganic. Ponnamperuma (1955) reported that an appreciable amount of ammoniacal nitrogen was lost from a sandy loam submerged soil by leaching.

Ammoniacal nitrogen is less subjected to leaching from the soil than nitrate nitrogen because of its adsorption on the cation exchange complex. Nonethless, loss of ammoniacal nitrogen by leaching is more severe in a waterlogged soil than in a well drained soil because (i) ammonium ion is not as likely to accumulate in a well drained soil as in a waterlogged soil; (ii) reduction reactions in a waterlogged soil produces ferrous and manganous ions which displaces ammonium ion from the exchange complex to the soil solution, where it is more subjected to removal and (iii) the constant water head resulted in a greater downward percolation of the soil solution(Patrick and Mahapatra, 1968).

Pande and Adak (1971) concluded from their studies that over 90% of nitrogen leached from the soils are in the ammoniacal form. Data from green house experiments with ^{15}N showed that the leaching loss off ammoniacal nitrogen from ammonium nitrate was negligible (Daftardar, 1973).

Haunold and Zuara (1975) observed from their soil column studies that, a lower amount of nitrogen was received in the drains in the case of ammoniacal fertilizers. When fertilizing with ammonium, 7.6 and 6.6% was leached out; 37.9 and 33.7% remained in the soil and 54.5 and 59.7% was lost as gaseous nitrogen.

Negligible ammoniacal nitrogen leaching losses were reported from a pot experiment conducted in flooded rice soils applied with labelled ammonium nitrate and labelled urea at the rate of 150 kgN/ha (Daftardar et al., 1979). Shinde et al. (1982) reported a leaching loss of 1.25% as ammoniacal nitrogen out of total 6.37% leaching loss of nitrogen in a cotton field.

Obcema et al.(1984) concluded from their studies that the general movement of ammonium ion in the soil after the deep placement of ammonium sulphate was downward > lateral > upward from the placement site.

A high leaching loss of 84% was reported for ammonium from coarse textured sandy soils by MacKowen and Tucker (1985). The values of ammoniacal nitrogen in the leachate ranged from 11.6 mg to 168.4 mg. Mengel (1985) reported that ammoniacal nitrogen leaching may occur only in a sandy and organic soils, since they are less capable of ammonium adsorption.

Juang and Wong (1987) observed that in paddy soils, the movement of ammonium ions was slow because of its fixation by expanding clay minerals.In a column study in a coarse textured soil using calcium cyanamide, urea and calcium ammonium nitrate, it was observed that, the nitrogen retained in the soil columns was mainly in the ammonium form irrespective of the source of nitrogen used(Pleysier et al., 1987). Singh and Singh (1988), from their lysimeter studies with rice, reported that , the leaching loss of nitrogen was mainly through ammoniacal nitrogen and accounted for as much as 96% of the total leaching loss.About 40% of applied ammoniacal nitrogen was lost from a flooded organic soil by leaching has been reported by Reddy et al.(1990).

Miller and Donahue (1992) reported that ammonium and nitrate ions are very soluble in water but the positively charged ammonium ion is held to the cation exchange sites and resists leaching.

2.2. Soil Factors

Many of the physical and chemical properties of the soils affect the leaching losses of nitrogen in the soils. Management, climatic and environmental factors also affect nitrogen loss.

2.2.1. Physical Factors

Soil physical properties such as compaction, texture, water holding capacity and porosity influences leaching losses of nitrogen from the soil.

2.2.1.1 Texture

The loss of nitrate by leaching occurs more readily from coarse textured soils than fine textured soils has been reported by Morgan and Street (1939).

De and Diger (1955) observed a nitrogen leaching percentage of 15.4 and 10.4 from sandy loam and clayey soils respectively using ammonium sulphate as the nitrogen source. Ponnamperuma (1955) reported that an appreciable amount of ammoniacal nitrogen was lost by leaching from a sandy loam submerged soil.

The downward displacement of nitrate, upon entry of 10 cm water into the soil originally at field capacity, was about 45 cm in sandy soils, 30 cm in soils with 20 - 40% silt + clay and 20 cm in clayey soils has been reported by Harmson and Kolebrander (1965).

A leaching loss of 0.4% nitrogen from ammonium sulphate was observed in experiments conducted in a sandy loam soil of New

Delhi (Datta et al., 1971). Leaching losses obviously depend on soil texture and water content has been observed by Koshino (1975).

The leaching studies conducted on a 4' column containing loamy soil showed that the applied nitrogen and chloride were almost completely leached due to heavy irrigation or rainfall (Reddy and Dakshinamurthy, 1976). Sharma and Ghosh (1976) from experiments conducted in columns using sandy loam soils under 5 cm standing water showed that the total nitrogen lost by leaching was 94.8% and 59.8% for urea and ammonium nitrate at 5 - 6 hours after application, 11.2 and 5.6% at 50 hours after application and 3.5 and 1.0% at 60 hours after application. Most of the nitrogen was lost in the first leachate.

Leaching of nitrate in light soils is one of the pathways by which nitrogen can be lost (Anonymous, 1977). Cleemput et al. (1977) studied the fate of ^{15}N labelled nitrate in a sandy loam soil. When surface applied, the ^{15}N leached out of the top soil and got accumulated at 70 - 80 cm depth and only a small portion was detected at a depth exceeding 110 cm. Subramanyan and Vasudevan (1977) concluded that about 50% of the applied urea can be lost by leaching from a light textured soil.

Kissel and Smith (1978) reported that, about 40% of the fertilizer nitrate applied to a swelling clay soil got leached down into the soil. From a pot experiment to assess the leaching losses of nitrogen from flooded rice soils applied as labelled urea and labelled ammonium nitrate at the rate of 150 kgN/ha, it was observed that, the loses were greater from a kaolinitic clay loam soil than from montmorillonitic sandy loam soil (Daftardar et al., 1979).

A loss of 69.5% of applied nitrogen has been reported by Meelu and Beri(1980) in a submerged clayey soil of Bihar. Mahapatra (1981) reported that in the sandy loam alluvial soil at Cuttack, at a percolation rate of 10 - 15 mm/day, about 43 and 16% of nitrogen applied through labelled urea and ammonium sulphate respectively was lost through leaching during 11 weeks of crop growth. In a vertisol at Hyderabad, at a percolation rate of 1 - 2 mm per day, leaching loss of basal applied urea nitrogen at the rate of 100 kgN/ha, was measured to be only 75% in the three rice crop seasons (Mahapatra, 1981). For a lateritic sandy clay loam soil of Pattambi, a loss of 31.5% and 37.8% was shown to occur in autumn and winter seasons respectively, when the fields were fertilized with 100 kg N/ha as ammonium sulphate, when the percolation rate of flood water was 3.9 mm/day during autumn and 8.0 mm/day in winter (Mahapatra, 1981).

In columns containing dry sandy loam, urea applied to the soil surface was leached by irrigation water, and peaks of urea coincided with the wetting front; but in a sandy soil, the wetting front moved faster than the urea peak. In the initially wet soil, urea peak did not coincide with the wetting front even after 24 hours. More urea was received in sandy soils than in sandy loam soils following infiltration and redistribution for 24 hours. Urea leached down to only 30 cm with 5 cm and 7.5 cm of irrigation water, whereas, with 10 and 15 cm of irrigation water, urea penetrated to deeper layers (Singh et al., 1981).

Lysimeter experiments conducted in dernopodzolic soils showed that nitrogen migration in the soil profile depended on the mechanical composition of the soil, the amount of precipitation and the amount of nitrogen fertilizer applied to the soil. On a sandy loam soil, the average amount of fertilizer nitrogen leached annually (over 4 years) below the 82 - 100 cm of soil layer ranged from 21 to 39 kg/ha depending on the rate of nitrogen fertilizer and on a loam soil it was 1.1 to 3.7 kg/ha. Leaching of fertilizer nitrogen to a depth of 82 cm did not exceed 1.2 and 0.7 kg/ha respectively. The highest concentration of mineral nitrogen was at a depth of 30 cm. More than 97% of the nitrogen in the lysimeter water occurred as nitrates (Bezlyludmyl, 1982).

Studies conducted at IARI, New Delhi, indicated that in an alluvial sandy loam soil (15% clay), 10% of the applied nitrogen was lost by leaching when ammonium sulphate was surface applied. Also in a sandy loam alluvial soil at Cuttack, percolating at an average rate of 6.75 mm/day, 17 and 4.7% of nitrogen applied through urea and ammonium sulphate respectively was lost through leaching during 11 weeks of crop growth (Rao et al., 1983).

A high leaching loss of 84% has been reported for ammonium from coarse textured sandy soils, by MacKowen and Tucker (1985). Snyman et al.(1985) from their studies concluded that nitrate leaching was considerable and much higher from the sandy soil than from sandy loam soil. Soil columns with sandy soil showed that virtually no ammoniacal nitrogen was leached from these soils.

In a study to assess the leaching loss of nitrogen from ammonium sulphate, calcium ammonium nitrate and urea in sandy soils of Andhra Pradesh, cumulative losses were 76.5, 73.8 and 53.3% for urea, calcium ammonium nitrate and ammonium sulphate respectively has been reported by Narayana et al.(1987).

In another study, where the leaching loss of nitrogen applied as calcium cyanamide (17% N), urea (46% N) and calcium ammonium nitrate (26% N), to a coarse textured kaolinitic ultisol profile was studied in the laboratory using soil columns. The columns were leached with an amount of water equivalent to the annual rainfall of the sampling site. The results showed that most of the nitrogen lost through leaching was in the nitrate form and the nitrogen retained in the soil columns was mainly in the ammonium form irrespective of the source of nitrogen used (Pleysier et al., 1987).

Singh and Singh (1988a) reported that in lysimeter studies with rice grown on Benli silty clay loam soil showed greater leaching losses through urea super granules as compared to prilled urea. Leaching was mainly through ammoniacal nitrogen and accounted for as much as 96% of the total leaching loss. It was also reported by that Singh and Singh (1988b) that the movement of urea, ammoniacal and nitrate nitrogen was significantly faster in sandy loam. They also reported that about 60 to 70% of leaching of urea nitrogen took place within 2 days of urea super granules placement. Leaching of ammoniacal and nitrate nitrogen increased till 14 and 21 days of urea super granules placement in sandy loam and silty clay loam respectively. Nitrogen leached through urea, ammoniacal and nitrate forms were respectively 64, 25 and 25% higher from sandy loam soils.

Katyal and Carter (1989) observed that the concentration of ^{15}N in the leachate was negligible (less than 0.5%) in a submerged silty clay loam soil.

Tomasek and Ryglevicz (1989) reported that leaching losses of NO_3 varied with soil properties, especially with texture, there was an increasing trend from coarse to fine textured chernozems.

Lysimeter studies conducted in 1985 and 1986 in three soils of varying texture to quantify the leaching loss of nitrogen due to precipitation showed that the maximum leaching was recorded as 53.9 kg/ha in 1985 and 38.7 kg/ha in 1986, in light textured soils (clay 2%). When nitrogen was applied at the rate of 200 kg/ha along with 10 t/ha of farm yard manure, the leaching loss of nitrogen increased from 14.2 to 30.9% with decrease in clay content from 22.2 to 9.2% (Sharma, 1990).

Singh et al.,(1991) reported that in lysimeters planted with rice, leaching loss of nitrogen as urea, NH_4 and NO_3 beyond 30 cm depth of a sandy loam soil for 60 days were about 6% of the total urea nitrogen applied and 3% of the total ammonium sulfate nitrogen applied in three equal split doses.

In an experiment under rainfed rice field, the leaching loss of nitrogen in a coarse textured lateritic soil varied between 27 to 50, depending upon the method of fertilizer placement and scheduling of fertilizer placement (Mandal and Kar, 1991). Little leaching loss of nitrogen was reported by Dhyani and Mishra (1993) from soils having high clay content.

2.2.1.2 Soil Water

De and Diger (1934) reported that when ammonium sulphate was applied to waterlogged soils, 30.3 and 27.6% was lost from Tollygunge soil and Chinsurah soil respectively.

It has been reported that fertilizer nitrogen loss occur within 3 - 4 days of waterlogging and progressively increase with the period of submergence. The loss has been found to be more with ammonium nitrate than ammonium sulphate. The nitrate nitrogen in all the treatments decreased rapidly and only traces remained in the soil after 4 to 5 days of submergence (Abhichandini and Patnaik, 1958).

The constant water head resulted in the greater downward percolation of nitrogen along with the soil solution has been observed by Patrick and Mahapatra (1968).

Studies conducted by Singh (1972) reported that over 67% of the water required by the rice crop is lost through percolation, the accompanied loss of nitrogen, however, has not been measured under field conditions.

The leaching studies conducted on a 4' column containing loamy soil showed that the maximum amount of nitrogen accumulated in the 15 - 30 cm of soil when three-fourth filed capacity level of irrigation was given and in 30 - 45 cm depth if the irrigation applied was full field capacity. About 35% of the applied nitrogen was leached from 0 - 30 cm of the soil with three times field capacity of irrigation (Reddy and Dakshinamurthy, 1976).

Other studies have indicated that there maybe a greater movement of nitrogen into the subsoil when rice fields are drained after a crop than occurs normally during the cropping period itself (Maeda and Onikura, 1976; Koyama <u>et al</u>., 1977). Krishnappa and Shinde (1978) observed a leaching loss of 7.51% of basal applied ^{15}N as urea to a wetland rice soil. Under prolonged submergence in rice culture, the intensity of NO_3 leaching depends on the rate of percolation of water through the soil (Ghildyal, 1978). He has also reported that in coarse textured soils with high hydraulic conductivity, such leaching losses was found to be high.

A loss of 69.5% of applied nitrogen has been reported by Meelu and Beri (1980) in a submerged clayey soil in Bihar. Obceema et al.(1984) concluded from their studies that the downward movement of NH_4 - nitrogen was prevalent in the dry season from fertilizer placed at 5, 7.5 or 15 cm. In the wet season, the downward movement of deep placed nitrogen was found to be minimum.

In a study to assess the leaching loss of nitrogen from ammonium sulphate, calcium ammonium nitrate and urea in sandy soils of Andhra Pradesh, it was found that increase in water levels caused lower nitrogen accumulation in soil, but increased the leaching losses from all three fertilizers (Narayana et al., 1987).

The negligible leaching loss of NH_4 and NO_3 (0.2 to 0.4%) from three field trials in a puddled rice soil was attributed to the low percolation rate resulting from a high ground water table (Panda et al., 1989). Experiments conducted in Benli silty clay loam proved that in the case of urea super granules, the vertical movement of urea resulted in high local concentration in the deeper layers partly due to high percolation rates and partly due to the constant head of water maintained at the soil surface (Singh and Singh, 1989).

In soil columns, the movement of urea applied on soil surface and mixed in 0 - 5, 5 - 10 or 10 - 15 cm deep layer of soil and its subsequent redistribution as ammoniacal nitrogen was studied in the initially dry and moist sandy soil. It was found that, the depth of urea movement increased with increase in amount of water applied and was more in initially moist soil. The zone of ammoniacal nitrogen accumulation widened and shifted to lower depths with increase in amount of water and initial moisture content of the soil (Praveenkumar et al., 1990).

Singh and Singh (1993) reported that the two major factors controlling the leaching loss of nitrate are concentration of nitrate in the soil profile at the time of leaching and the quantity of water passing through the soil profile. The fertilizer nitrogen application generally increases leaching losses when high fertilizer losses are combined with heavy irrigation regimes on light textured soils, leaching loss of nitrate can be substantial.

2.2.1.3. Structural Attributes

In a study conducted to determine the extend of urea leaching in soils, it was observed that most of the urea leached down with the water front in the initially dry soil. In soils maintained at 50% field capacity, the urea peak lagged below the wetting front. A part of the applied nitrogen remained close to the surface when water was applied 24 hours after urea application, which was probably adsorbed as hydrolyzed urea (NH_4^+) (Beri et al., 1978).

Craswell and De Datta (1980) reported that high leaching loss of nitrogen occurs in a paddy soils without am impervious layer below the plough layer.

2.2.2 Chemical Factors

Chemical factors like organic matter content, cation exchange capacity are also found to affect the leaching loss of nitrogen from soils.

2.2.2.1 Organic Matter

Ponnamperuma (1955) reported that the addition of organic matter increased the amount of ammonium in the soil solution instead of immobilising the nitrogen as might be expected. This has also been reported by Kiuchi and Omukarai (1959). Soils with high organic matter decreased the leaching losses of nitrogen has been reported by Reddy and Patrick(1980).

Sharma (1990) reported that when nitrogen was applied at the rate of 200 kg/ha along with 10 t/ha farm yard manure in lysimeters, the leaching loss of nitrogen increased from 14.2 to 30.9 % with decease in clay content from 22.2 to 9.2%.

2.2.2.2. Cation exchange capacity (CEC)

The increase in concentration of the ammoniacal nitrogen in soil solution resulted in leaching loss of ammonium, particularly, if the soil has low CEC and high permeability has been reported by Somani and Totawat (1978).

In a study conducted to estimate the losses of applied ammonium sulphate, urea and organic nitrogen (rice straw) using ^{15}N, soils with high CEC decreased the leaching losses of nitrogen (Reddy and Patrick,1980). Savant et al.(1982) reported that ammonium leaching in paddy soils were low due to high CEC and low percolation rate.

The dominant soluble forms of nitrogen are nitrate, which tends to move down the soil profile with the initial infiltrating water of a storm event and ammonium which tends to attach to the soil's cation exchange complex (Smith et al., 1990).

2.2.3. Management

In New York, Lyon et al.(1930) recorded an average annual loss of 76 kgN/ha and 6 kgN/ha from fallow and cropped lands. Lipman and Conybeare (1936) estimated the loss of nitrogen from cropped land of the U. S. by leaching to be 20 kgN/ha annually. The loss of nitrate by leaching is greater from a bare soil than from a cropped soil because of the absence of plants to absorb nitrate and water has been reported by Black (1968).

Morakul and El-Hamid (1975) observed that more ammonium sulphate was lost through leaching from limed soil columns than from unlimed soil columns.

Viswanath et al.(1978) concluded that under three split applications, the nitrogen losses from ragi sown fields due to leaching from ammonium nitrate, ammonium sulphate nitrate, calcium ammonium nitrate, ammonium suphate and urea were 19.5, 9.7, 9.4, 7.7 and 7.4% respectively over a period of 12 weeks.

Vlek et al.(1980) observed a significant leaching loss of ^{15}N when urea super granules was deep placed in silt loam soil and percolation increased from 4.4 mm/day to 18.3 mm/day.

Mahapatra (1981), from experiments conducted in a vertisol at Hyerabad, at a percolation rate of 1 - 2 mm/day, reported that a maximum of 6.8% of applied nitrogen was lost by leaching during first crop season following nitrogen application. When the nitrogen rate was reduced to 80 kgN/ha, and applied in three splits, the loss was only 1.16% in the two crop seasons.

In an experiment where nitrogen was applied at the rate of 90 kgN/ha as calcium ammonium nitrate to bare fallow and cropped plots, in a coarse textured, kaolinitic ultisol, the results showed that the splitting of nitrogen from one to three applications reduced the leaching loss of applied nitrogen from 53 to 28%. In bare fallow, with one applications of nitrogen during each crop season, 37% of the total applied nitrogen(240 kgN/ha) got leached down to 0 - 120 cm depth at the end of the second cropping season (Arora and Juo, 1982).

In a vertisol of Hyderabad, percolating at the rate of 1 - 2 mm/day, the leaching loss of basally applied urea (100 kg/ha) measured was found to be only 7.5% in 3 cropping seasons. When the nitrogen rate was reduced to 80 kg/ha and applied in three splits, the loss was only 1% (Rao et al., 1983).

Chatterjee and Maiti (1985) observed that if a basal nitrogen dressing is applied to a wet rice field in the form of nitrate, this nitrate will get easily leached into the reduced layer where it gets lost by denitrification.

The values of ammoniacal nitrogen in the leachate ranged from 11.6 mg to 168.4 mg in Rositas loamy sand amended with natural zeolite (MacKowen and Tucker, 1985).

An experiment to study the fate of 100 kgN/ha applied as ^{15}N urea and its modified forms was conducted in 4 successive field grown wetland rice crops in a vertisol. It was reported that about 18 - 20, 12 - 17 and 14 - 18 kg of ^{15}N urea/ha was leached during 1st, 2nd and 3rd crop seasons respectively. The basal application of neem coated urea resulted in a leaching of 0.5 kgN/ha as labelled

NH_4^+ + NO^3-N than split application of uncoated urea. In the first 3 seasons in which ^{15}N was detectable, the loss of fertilizer nitrogen through leaching as NH_4^+ + NO_3-N amounted to 0.5 kg/ha for neem coated urea. At the end of 4 crops, most of the labelled fertilizer N (about 69% on average) was located in the upper 0 - 20 cm soil layer, showing very little movement beyond this depth. In the profile sampled up to 60 cm depth, totally about 13.8 kg labelled fertilizer nitrogen per hectare from neem coated urea, 12.7 kg from coal tar coated urea and 11.8 kg from split urea were recovered (Rao and Shinde, 1985).

In laboratory experiments, using PVC columns, the extend of leaching of urea in 2 sodic soils reclaimed by gypsum application and kept submerged for 7 or 14 days after fertilizer application depended mainly on soil texture has been reported by Singh and Bajwa (1986). In silty clay loam, urea penetrated to 2 cm depth with peaks in concentration at 12.5 cm at both 7 and 14 days of submergence. In loamy soils, urea nitrogen moved up to 25 cm depth after 7 days and to 35 cm depth after 14 days. In sandy loam sodic soils, peaks of urea nitrogen concentration were observed at 12.5, 22.5 and 7.5 cm depths after infiltration of 5, 7.5 and 10 cm depth of water respectively. Leaching with 20 and 30 cm depth water moved urea deeper and below 50 and 70 cm respectively. It was concluded that leaching may not be an important mechanism of loss of urea nitrogen in loamy or silty clay loam sodic soils. However in sandy loam soils, it will create serious problems.

Juang and Wong (1987) reported from their studies in paddy soils that the concentration of urea nitrogen and ammoniacal nitrogen were low for all treatments and nitrogen losses were insignificant for both broadcasting and deep placement. Velu et al. (1988) in their experiment to study the leaching loss of nitrogen from different sources during south - west and north - east monsoon season reported that green manure + urea combination, neem cake coated urea, lac coated urea, coal tar coated urea and urea super granules showed lower leaching loss than urea. The proportions of applied nitrogen lost through leaching ranged from 1.5 to 6.2% during South west - monsoon and 1.8 to 3.7% during north - east monsoon season.

In lysimeters planted with rice, application of urea even in a single dose at transplanting did not result in more nitrogen leaching loss (13%) compared to those observed from potassium nitrate (38%) applied in three splits. Nitrogen contained in potassium nitrate was readily leached during the first week of its application. More nitrogen was lost from the first dose of nitrogen applied at transplanting than from the second or third dose (Singh et al., 1991).

Mandal and Kar (1991) reported that leaching loss of nitrogen was more with lesser number of splits. Broadcasting with high doses of fertilizer increased leaching more than that of band placement (18% higher).

According to Miller and Donahue (1992), leaching loss of nitrates are increased as the quantities of percolating water increased and when there is little or no growing crop cover to use the nitrates as rapidly as they are produced by nitrification.

2.2.4 Climatic Factors

The nitrate loss due to leaching from direct drilled land was reported to be 20 - 30 kgN/ha with wide seasonal variations (Coulborn, 1985)

Lindan (1981) concluded from his studies that under Swedish conditions, the amount of nitrogen leached out of the soil averaged 20 - 30 kg/ha/yr. The nitrogen leaching was generally restricted to cold seasons and almost all leached out nitrogen consisted of nitrate.

The nitrate loss due to leaching from direct drilled land was reported to be 20 - 30 kgN/ha with wide seasonal variations (Coulborn, 1985).

Leaching loss of nitrogen under different sources and methods of nitrogen application in clay loam soils of Cauvery delta, was studied during south - west and north - east monsoon seasons of 1984 and 1985. Leaching losses ranged from 9.1 to 13.8 kgN/ha during south - west monsoon and 5.8 to 6.4 kgN/ha during north - east monsoon. Leaching loss of nitrogen was higher during south - west monsoon due to higher percolation rate than during north - east monsoon. The rate of leaching loss of nitrogen in soil was higher during 3rd to 9th day after fertilizer application and was influenced buy percolation rate of flood water and the source and time of fertilizer application (Velu et al., 1988).

Miller and Donahue (1992) observed that in fields where fertilizer application was poorly timed for plant use or coincides with heavy rainfall, a leaching loss of 50 -80 kgN/ha will occur.

2.3. Management practices to reduce nitrogen losses

Daftardar et al. (1979) reported that the leaching losses of nitrogen from flooded rice soils were low from split applications than from a single basal dressing and were reduced by cropping with rice in comparison with fallows.

Deep placement of briquettes, urea super granules or sulphur coated urea efficiently prevented the loss of nitrogen by leaching from a flooded soil has been observed by Craswell and De Datta (1980).

2.4. Runoff Losses

Runoff losses of nitrogen is also another form of loss of nitrogen in paddy fields, which can reach high values under special situations. The results of various works in the field are reviewed below.

Apart from denitrification loss in waterlogged rice soils, losses of nitrogen due to leaching and surface drainage maybe considered to be high in magnitude. In waterlogged soils, particularly with high water table and impeded drainage, nitrogen losses from applied fertilizer occur to a great extend in the surface drained water as runoff, following heavy downpour of rain after fertilizer application. These losses are likely to be more, particularly, when surface application of fertilizer is done in greater depth of standing water has been reported by Abhichandini and Patnaik (1958).

Broadbent et al.(1958) observed that the leaching and runoff losses of nitrogen will be increased in paddy soils, when the hydrolysis of urea was slow. According to Barrows and Kilmer (1963), the losses reported for soluble nitrogen salts in runoff water were exceedingly low and were of little economic importance. However, it is possible that under different conditions, the loss of soluble nitrogen salts might be increased considerably. This could occur in the runoff from the fields, where high rates of nitrogen fertilizer have recently been applied.

It was reported by Moe et al.(1967) that mineral nitrogen loss from fallow and sod plots established on an Indiana fragipan soil ranged from 2 to 15% of the applied ammonium nitrate (224 kg/ha) after 12.7 cm of rainfall. The degree and length of the slope, surface cover, infiltration rate and soil structure was found to be the important factors affecting surface runoff.

Morakul and El-Hamid (1975) observed that the losses of nitrogen by runoff and leaching are probably the most important in relation to water pollution.

Dunigan *et al*.(1976) reported that less than 5% of the applied fertilizer nitrogen was found to be lost as agricultural runoff from Louisiana clay. Similar observation has been made by Alberts *et al*.(1976) in Iowa state.

A loss of 16 kgN/ha through surface runoff from paddy fields has been reported by Yatazawa (1979). Takamura *et al*.(1977) showed that, in Japan, nitrogen fertilizer loss through runoff from paddy fields ranged from 4 to 16 kgN/ha.

Singh (1978) found that a loss of 2.6 kgN/ha from runoff, from 4 irrigated paddy sites in Laguna province, Philippines. Padmaja and Koshy (1978) reported that almost 70% of the applied nitrogen was lost when draining was done on the same day of manuring, that the loss was reduced to 44% after 48 hours and that it was negligible after the fifth day of fertilizer application.

Reddy and Rao (1983) observed that under particular experimental conditions, less than 7% of the mineralised nitrogen was received as inorganic nitrogen in flood water. When calculated on a hectare basis, the loss was about 350 kgN/ha/yr. Reddy and Patrick (1986) from their studies reported that 5% of the applied ^{15}N to rice, was lost as runoff.

Smith *et al*.(1990) reported that nitrogen moves in the surface runoff in both soluble and particulate forms. The dominant soluble forms are nitrate and ammonium. According to Katyal (1991), on an average, 10 kgN was lost per hectare per annum through surface runoff.

2.4.1. Different forms of nitrogen lost through runoff

Different studies show that the nitrogen is lost from the surface soil by runoff in different forms.

2.4.1.1. Nitrate(NO_3) nitrogen

Patrick and Mahapatra (1968) found that NO_3 nitrogen can also be lost from a flooded field by runoff, but the nitrate content of flood water exceeds few ppm.

During monsoon, large part of the rainfall runs off the flooded rice fields and nitrogen may get lost, but the NO_3 content of the flood water was found to be generally low has been observed by Ghildyal (1978).

Hetherington (1985) reported that the peak nitrogen concentrations measured in two small tributary streams as nitrate was 9.3 mg/l after 7 weeks of aerial application. Sharpley *et al*.(1985) reported that for many agricultural water sheds, the soluble nitrogen concentrations in runoff were fairly low and well within potable limits (10 mg/l for NO_3-N). Jacobs and Gilliam (1985) reported that from the middle coastal plain watershed with 1299 ha of predominantly well to moderately well drained soils, the losses of nitrate nitrogen in surface drainage water were 2.5 kg/ha. The lower coastal plains watershed with 6998 ha of somewhat poorly to poorly-drained soils had a nitrate loss of 0.5 kg/ha/yr.

Smith et al.(1990) reported that for many agricultural watersheds, the soluble nitrate concentrations in the runoff was very low(10 mg/l).

2.4.1.2. Ammoniacal (NH_4^+) Nitrogen

When surface application of fertilizer was done with varying depths of waterstanding on soil surface, ammoniacal nitrogen in surface water initially increased with increase in water depth (10, 20 and 30% of NH_4^+ nitrogen in 1.0, 2.5 and 5 cm standing water). From 2nd to 10th day of fertilizer application, there's no difference whether fertilizer has been applied in 2.5 and 5 cm depth of standing water. With 1 cm depth of water, the NH_4^+ nitrogen in surface water during the 10 day period after fertilizer application was very much lower than that at other depths. The danger of applied fertilizer getting washed away in surface drained water due to heavy downpour of rain occurring within 48 hours of application, will, therefore be greater if surface application is done with large depth of standing water (Abhichandini and Patnaik, 1958).

Wetselaar _et al_. (1977) reported that ammonia loss from applied fertilizer may occur in paddy water for as long as 21 days. In Philippines, Singh _et al_.(1978) reported runoff loss equal to 3.6 kgN as NH_4^+/ha per season following application of ammonium sulphate at the rate of 60 kgN/ha to wetland rice fields.

Savant _et al_., (1982) reported that when basal fertilizer nitrogen , when mixed in a puddled soil just before transplanting, it will result in an increase in ammoniacal nitrogen in flood water and surface soil(10 - 20 cm depth). Hetherington (1985) observed that the peak nitrogen concentration measured in two small tributaries as ammonium was 1.9 mg/l, 24 hours after application.Sharpley _et al_. (1985) reported that for many agricultural water sheds, the soluble nitrogen concentration in the runoff was fairly low and well within potable limits (i.e., 0.5 mg/l as NH_4^+-N). A loss of 0.5 mgNH_4^+/l was reported in runoff losses from many agricultural water sheds (Smith _et al_., 1990).

2.4.1.3. Total nitrogen and urea nitrogen

The lower efficiency of urea in comparison to ammonium sulphate was because of the high mobility of non - polar urea in the runoff water during the initial 48 hours of application, after which the hydrolysisi of urea to ammonium carbonate occurred has been reported by Patnaik and Nanda (1967). Padmaja and Koshy (1978) reported that urea nitrogen was weakly held by the soil and most of it is free to move in the soil water.

Studies using urea and ammonium sulphate showed that the runoff losses from urea (30 - 51%) were extensive and much greater than from ammonium sulphate (5 - 24%). Experiments proved that nitrogen in flood water remained in the form of urea, and the concentration of flood water nitrogen decreased rapidly in the the three to five days after application (Craswell and De Datta, 1980).

From the middle coastal plain watershed with 1299 ha of predominantly well to moderately well drained soils, the losses of total nitrogen in surface drainage water was 4.5 kg/ha/yr and the lower coastal plains watershed with 6998 ha of somewhat poorly to poorly drained soils had a total nitrogen content of 2.5 kg/ha/yr (Jacobs and Giliiam, 1985). Hetherington (1985) reported a peak value of 14 mg/l as urea (after 12 Hours) in 2 small tributaries, after 7 weeks of aerial application in a Douglas fir forest.

2.4.2. Factors affecting nitrogen loss.

Various physico-chemical properties of soil, and other factors affect the runoff loss of nitrogen from soils.

2.4.2.1 Physical properties

2.4.2.1.1 Texture

In Georgia, White et al.1967) found only 0.15 to 2.35% of broadcast nitrogen (224 kg/ha as ammonium nitrate) in surface runoff from sandy loam soils with 5% slope.

In a study conducted in Houston black clay to estimate the nitrate and total nitrogen losses in surface runoff, it was found that, in general, a small and probably insignificant amount of nitrogen was lost to the surface waters, when crops were fertilized at the recommended nitrogen rate. For the entire five years of study, the mean concentration of nitrate in the runoff was 2.9 and 2.3 ppm nitrate for duplicate water sheds. The mean total loss of nitrate was 3.2 kg/ha/yr. The loss of nitrate varied considerably during the study, depending on the event before each runoff producing storm (Kissel et al., 1976).

When 60 kgN/ha as urea were incorporated in a puddled Mahas clay just before transplanting IR 36, the concentration of urea nitrogen and ammoniacal nitrogen in the static (0 - 2 cm) flood water were approximately 54 and 8 ppm, respectively, has been reported by Savant and De Datta (1982).

In a field experiment in a clay soil in Jokoninan, Finland, the annual nitrogen runoff from the surface of a moderately fertilized (100 kgN/ha/yr) cereal plot varied during 1976 - 1982 from 21 to 301 mm has been reported by Jaakkola, (1984). Miller and Donahue (1992) observed that heavy rain or irrigation following nitrogen application can wash the fertilizer off the soil into the surface flow and carry urea and nitrate deep into the drainage water; sandy soils are particularly more susceptible to this.

2.4.2.1.2 Soil water

Abhichandini and Patnaik (1958) reported runoff losses to the extend of 6 to 30% of nitrogen broadcast on the soil surface as ammonium sulphate during thecourse of 1 to 6 days depending upon the soil water conditions of the rice field. The concentrations of nitrates were usually highest just after fertilizer application, when the soil was near field capacity and the lowest when large amounts of water infiltrated into the dry soil immediately before the runoff (Kissel et al., 1976)

2.4.2.2. Chemical factors

2.4.2.2.1. Cation exchange capacity

Craswell and De Datta (1980) reported that the CEC of the soil greatly influenced the extent of adsorption and thence the amount of ammonium which appeared in the flood water. Studies conducted at IRRI (1980), reported that when urea super granules was applied to sandy soils with a low CEC, high concentration of urea was observed in the flood water, which resulted in ammonia volatalisation.

2.4.2.3. Management factors

Singh (1972) reported that in lowland rice fields, the net change in the nitrogen content of water varied from a loss of 5.6 kgN/ha to a gain of 2.6 kgN/ha depending upon the fertilizer and water management practices. Takamura et al. (1977) recorded 63 ppm nitrogen in paddy water following surface application of fertilizer nitrogen. They probably, therefore, recorded a large loss of added nitrogen (approx. 66%) due to runoff from the field.

A maximum loss of 9 kgN/ha/crop from broadcast application was lost through runoff from paddy fields under continuos flow irrigation during the dry season (Hauck, 1979). Most nitrogen was lost through runoff when there was a continuos flow of water across the paddy soil and the fertilizer was broadcast without incorporation has also been reported by Craswell and Vlek (1971).

In green house and field experiments with meadow chernozemic soils, the top dressings with nitrogen fertilizers increased the nitrogen concentration in the water. Concentration of nitrogen compounds in the water of rice fields are small, but because of the large volume of water discharged, large amounts of nitrogen escape into the estuaries (Bochkarev et al., 1980)

The presence of a high concentration of fertilizer nitrogen would promote extensive losses if the surface water was lost or replaced through runoff (Craswell and De Datta ,1980).

Khan et al. (1983) found that the fertilizer application in rice fields developed in the past have transferred 40 to 70% of the fertilizer to the flood water during the placement. They found that up to 40% of the placed fertilizer undergoes transfer to flood water through dissolution during transit from the furrow bottom; this is the main cause of fertilizer transfer.

A study conducted in autumn sown cereal crops in the absence of mole drains, nitrate loss in the surface drainage averaged 6 kgN/ha compared with 4 kgN/ha, in the presence of drains (Dowdell et al. , 1987).

In pot studies, the nitrogen concentration in flood water were high, when either prilled urea or large granular urea was placed on top of the soil than when deep placed has been observed by Prins and Rauw, (1989).

According to Katyal (1991), nitrogen lost through runoff mainly occurs when broadcast application of urea occurs. Savant et al., (1991) reported that the farmers method of broadcasting of urea without incorporation can lead to very serious runoff losses of applied urea nitrogen or ammonia volatalisation losses from standing flood water.

The upward movement of urea from the placement site to the flood water may occur when proper care is not taken with the placement of urea super granules. The transformations undergone by urea broadcast into the wetland rice soil are unique in three ways : firstly, the fertilizer dissolves almost immediately in the flood water; secondly only few millimeters of surface soil are aerobic; the water blocks the diffusion of atmospheric oxygen into most of the soils, creating reduced conditions in much of the plough layer. Finally, the water layer provides a head pressure, which promotes runoff and seepage loss if the water is not confined laterally (Craswell et al., 1980).

Obceema et al., (1984) reported that the flood water with split application of fertilizer contained 78 - 98 microgram nitrogen per milliliter, while that with deep placed fertilizer contained only a negligible amount of nitrogen.

It was observed that high concentration of soluble nitrogen may occur in the runoff, when a soil horizon barrier (e.g.: fragipan) exists in the profile resulting in interflow (Lehman and Ahuja, 1985; Kissel et al., 1976; Smith et al., 1990) that reappears as surface runoff in the fields.

MATERIALS AND METHODS

The study on "Vertical movement of nitrogen in major rice soils of Kerala" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani using undisturbed vertical columns of soils representing six soil types of Kerala. The details of the soil types used are given below.

No.	Location	Soil Type	Order
1	RRS, Kayamkulam	Onattukara	Entisol
2.	RRS, Moncompu	Karappadam	Inceptisol
3	R-Block, Moncompu	Kayal	Entisol
4	Thakazhy, Allapuzha	Kari	Entisol
5	Chathankole, Trichur	Kole	Inceptisol
6	RARS, Pattambi	Lateritic Alluvium	Ultisol

3.1. Collection of soil columns and arrangement for percolation studies.

The soils were collected from all locations after the harvest of the first crop, when the fields were moist. PVC tubes of 60 cm length and 8 cm inner diameter were used for collecting the soil columns. Lateral holes of 2 cm diameter were made at 15 , 30 and 45 cm depths. Tubes were placed randomly on the surface of the soil and driven in to the desired depth by hammering on a wooden plank placed on the top of the PVC columns, leaving a vacant space of 5 cm on the top of the column. The tubes were excavated by removing the soil on all sides, and the columns along with the soil were lifted up carefully by closing the lower end with the palm of the hand (Plates 1 and 2). The base and top ends of the columns were closed with PVC end caps and lateral holes with rubber corks to prevent soil and moisture loss during transport. The columns from each location were labelled and carefully transported to the laboratory, causing minimum disturbance.

The vertical columns were supported on a metal frame after removing the end cap at the upper end. The lower end cap was permanently sealed to prevent leakage by using "M Seal" (Plate 3). The corks covering the holes were replaced with a one holed rubber cork fitted with a glass tube(8 mm dia.) was inserted and sides of the cork with the hole were sealed permanently using "M Seal". The bottom end of the rubber cork was plugged with a thin layer of cotton to prevent the entry of soil into the glass tube. The glass tubes were fitted with pinch clips to collect the leachates.

3.1.1. Application of urea fertilizer

The soil columns were maintained in a waterlogged state by adding tap water on the surface of the column, so that 5 cm of standing water remained in all the tubes. After 15 days, surface water was removed by siphoning to simulate the rice field condition during fertilizer application. Urea at the rate of 90 kg N/ha(49

Plate 1. Soil column

Plate 2. Taking out the soil column.

Plate 3. Arrangement of columns for leaching study

Plate 4. Runoff study in porcelain pots.

mg N/column) was applied in the form of solution and mixed with the upper 5 cm of the soil. The columns were waterlogged with 5 cm standing water after eight hours. The details of the urea fertilizer used are given below.

Common name	-	Urea
Structural formula	-	H_2NCONH_2
Molecular formula	-	CH_4N_2O
Molecular weight	-	60
Melting point	-	132.7 ^0C
Nitrogen content	-	46%

3.1.2. Collection of leachate

Leachate was collected by opening the pinch clip and permitting to drain for one hour, noting the volume of leachate in each case. After the removal of leachate, water was added to the soil column and 5 cm standing water was maintained uniformly through out the course of the study. The leachate was collected at intervals of 24 hours, till the fifth day, and then on the 10^{th}, 15^{th}, and 20^{th} days.

3.1.3. Analysis of the leachate

10 ml of the leachate immediately after collection was digested with concentrated sulphuric acid and total nitrogen estimated by Microkjeldahl method (Jackson, 1973).

3.1.4. Analysis of residual soil

After the experiment, soil columns were removed and dried. The columns were partitioned to 15, 30 and 45 cm from the surface. Samples were taken, air dried and powdered with a wooden mallet, sieved through a 2 mm sieve and the total nitrogen was estimated by Microkjeldahl method (Jackson, 1973).

3.1.5. Design of the experiment.

The study was conducted as an experiment in Completely Randomized Design with six soil types, collected from three depths (15, 30 and 45 cm), and each replicated three times.3.3.

3.2. Collection of soil samples for runoff loss study.

Surface samples to a depth of 15 cm were collected from the same locations as used for the leachate studies and transported to the laboratory in air tight plastic covers.

Two kilograms each of the soil samples were transferred to porcelain pots (13 X 22 cm) after closing the side holes at the bottom and were maintained under water for 15 days. Surface water was siphoned out and urea at the rate of 90kg N/ha (127mg N/pot) was mixed with the surface 5 cm of the soil and allowed to remain as such for eight hours. Afterwards, the pots were filled with water to a level of 5 cm. The surface water from the respective pots was completely removed by siphoning on the 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 10^{th} day. The volume of water was measured in each case and aliquots were used for determining the total nitrogen by Microkjeldhal method to estimate the run off loss.

3.2.1. Design of the experiment

The study was conducted as an experiment in Completely Randomized Design with six soil types and six intervals of sampling of runoff water replicated three times. Thus a total of 108 soil samples were used for the study.

3.3. Soil analysis.

The soil samples collected were analyzed for various inherent properties according to standard procedures.

3.3. Physical properties of soils.

The physical properties of soils related to the loss of nitrogen by leaching and run off were estimated in core samples collected from each location with the help of core samplers (Gupta & Dakshinamurthy, 1980).

The physical properties such as bulk density, particle density, water holding capacity and porosity were estimated (Gupta & Dakshinamurthy, 1980). The mechanical composition of the soil samples was determined by Bouyoucos hydrometer method (Gupta and

Dakshinamurthy, 1980).

3.4. Chemical properties

pH, CEC, organic C, total nitrogen, available nitrogen, phosphorus, potassium, exchangeable calcium and magnesium were estimated on the soil samples collected from depths of 0-15 ,15-30 and 30-45 cm from the different locations following the procedures described by Jackson(1973).

3.5. Statistical analysis

The data obtained from the two set of experiments were subjected to statistical analysis according to the procedures of Panse & Sukhatme(1967). Correlation was also worked out, relating the nitrogen leaching and runoff losses with inherent characteristics like soil clay content, porosity, cation exchange capacity, organic matter and water holding capacity. Correlation between the quantity of leachate collected with nitrogen leaching loss was also carried out.

RESULTS AND DISCUSSION

The results of the study conducted to assess the physico-chemical properties of six rice soils and the data on the leaching and runoff losses of fertilizer nitrogen in these soils are discussed below.

4.1. Physico-chemical properties of soils

Soil samples collected from different depths of each soil type are subjected to physico-chemical analysis and the data obtained are presented in Tables 1 and 2.

4.1.1. Soil reaction (pH)

The data obtained shows a range of values from 5.13 to 5.36 for Onattukara, 4.43 to 4.56 for Karappadam, 4.10 to 4.16 for Kayal, 4.30 to 4.76 for Kole, 5.06 to 5.63 for Lateritic Alluvium (Pattambi) and 3.46 to 4.66 for Kari soils. Statistical analysis reveals that there is no significant difference in mean pH values of these soils. All the soils are acidic, the Kari soils being the most acidic and Pattambi soils, the least acidic.

The pH of Onattukara and Pattambi soils increased in the second layer and then decreased again in the third layer. In the case of Karappadam and Kayal soils, surface layer had the highest pH value, which decreased in the second layer and again increased in the third layer. For Kari soils, pH increased with depth and in Kole soils, the pH decreased with depth.

Table 1. Chemical properties of soils

Soil	Depth cm	pH	O.M. %	CEC cmols/kg	Total N %	Avail N kg/ha	Avail P_2O_5 kg/ha	Avail K_2O kg/ha	Exch. Ca cmols/kg	Exch. Mg cmols/kg
Onattukara	00-15	5.13	0.54	5.97	0.13	174.33	19.27	33.90	1.76	1.48
	15-30	5.36	0.29	4.57	0.10	146.83	12.80	55.10	0.86	1.20
	30-45	5.20	0.05	4.57	0.11	122.47	11.03	121.13	0.98	0.93
	Mean	5.23	0.29	5.03	0.11	148.04	14.36	70.04	1.20	1.20
Karappadam	00-15	4.56	2.54	7.47	0.24	352.93	16.10	186.03	4.79	3.54
	15-30	4.43	2.39	3.10	0.18	408.33	14.63	100.66	3.73	2.86
	30-45	4.50	2.33	11.40	0.18	239.17	12.57	157.80	4.06	3.05
	Mean	4.59	2.39	7.32	0.20	333.47	14.43	148.16	4.19	3.15
Kayal	00-15	4.16	5.56	14.20	0.28	656.97	38.17	231.73	2.63	2.32
	15-30	4.10	3.41	13.80	0.21	320.73	21.27	202.96	2.81	1.70
	30-45	4.16	3.20	9.87	0.24	117.23	23.30	117.70	2.35	2.29
	Mean	4.14	4.05	12.62	0.21	364.98	27.58	184.13	2.59	2.10
Kole	00-15	4.76	4.94	5.33	0.11	391.97	18.47	128.43	1.86	1.49
	15-30	4.73	3.22	4.97	0.06	313.20	16.37	74.60	1.51	1.33
	30-45	4.30	2.47	4.10	0.06	235.13	11.30	78.76	1.20	1.11
	Mean	4.59	3.54	4.70	0.07	313.43	15.38	93.93	1.52	1.31
Pattambi	00-15	5.06	1.88	7.50	0.14	432.17	30.57	216.95	1.96	0.48
	15-30	5.63	1.22	7.10	0.07	331.00	22.10	125.60	1.93	0.36
	30-45	5.50	0.91	7.30	0.07	243.17	18.00	167.67	1.56	0.39
	Mean	5.41	1.33	7.30	0.09	335.44	23.55	170.07	1.81	0.41
Kari	00-15	3.46	6.47	6.03	0.17	457.27	21.17	129.93	2.35	2.03
	15-30	4.33	1.16	3.13	0.11	103.87	18.57	101.46	1.90	1.59
	30-45	4.66	2.11	4.96	0.10	63.10	17.77	116.63	1.77	1.30
	Mean	4.15	3.24	4.70	0.12	208.08	19.17	116.00	2.00	1.64
CD	Soil	0.19	0.03	0.04	0.01	11.99	0.41	12.79	0.09	0.07
	Depth	0.13	0.02	0.03	0.01	8.48	0.29	9.04	0.06	0.05
	Inter.	0.33	0.05	0.07	0.02	20.77	0.72	22.16	0.15	0.12

4.1.2. Organic matter

The organic matter content of all the surface soils are high, when compared to that of the lower layers. Statistical analysis reveals that there is no significant difference between the organic matter content of different soils.

The Kayal soil is observed to have the highest mean value for organic matter (4.05%), while Kari soil recorded a maximum value (6.47%) for the surface soil alone. Onattukara soil is observed to have the lowest mean value of organic matter content (0.29%) [Table 1]. All the soils, except Onattukara, are high in their organic matter content.

4.1.3. Cation exchange capacity (CEC)

Results show that the Kari soils recorded the lowest mean value for CEC (4.71 cmols/kg), while Kayal soil recorded the highest mean value of 12.62 cmols/kg. The value of CEC decreased with depth in the case of Kayal and Kole soils. However, in the case of Onattukara, Karappadam, Pattambi and Kari soils, the CEC decreased in the second layer and then increased.

The high value of CEC in Kayal soil maybe because of its very high organic matter content (4.05%) and clay content (44.33%) . The lower value for Kole soils maybe due to the high content of sand fraction (58.33%) with low CEC.[Tables 1 and 2]

Fig 1. Organic Matter %

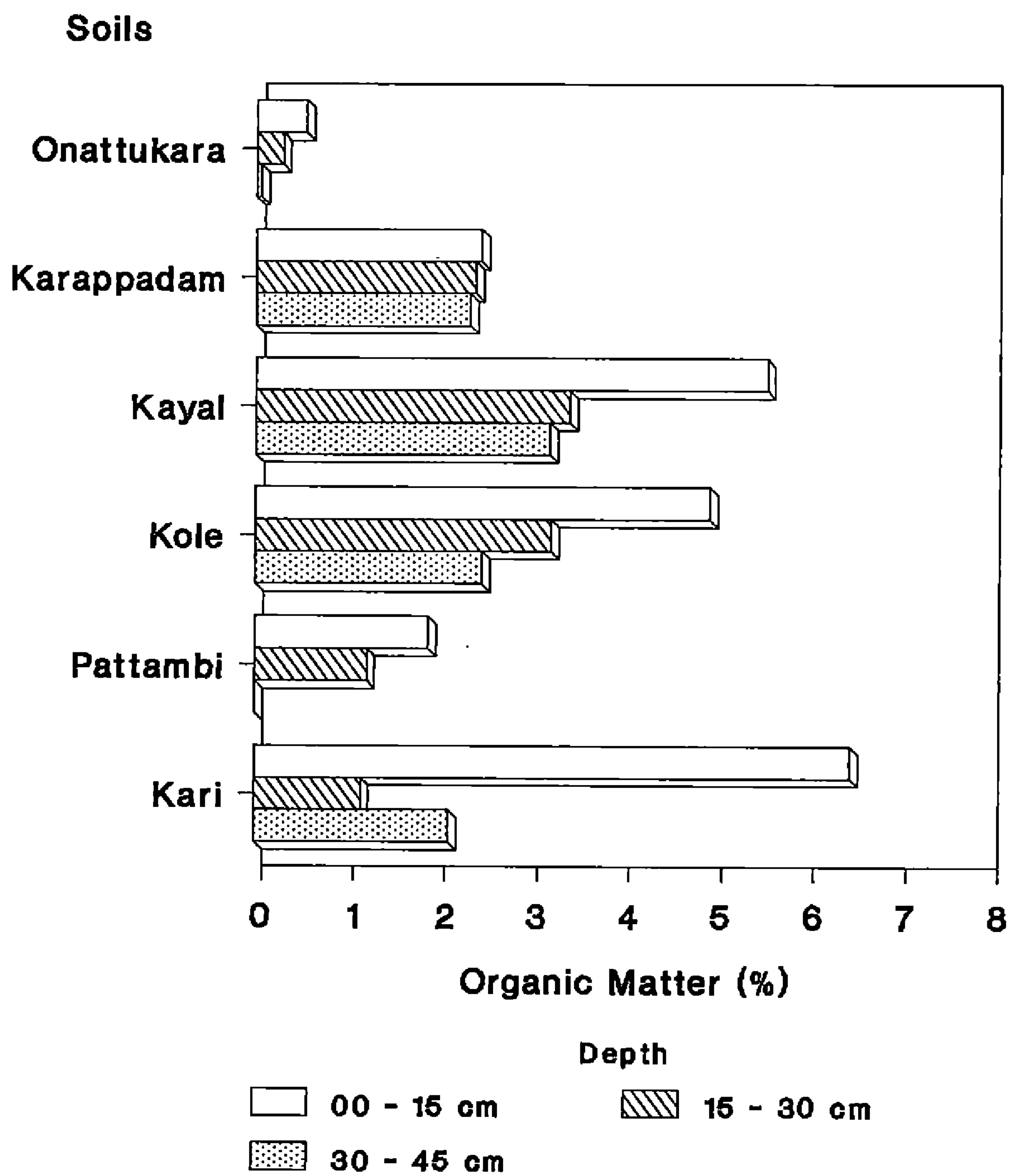

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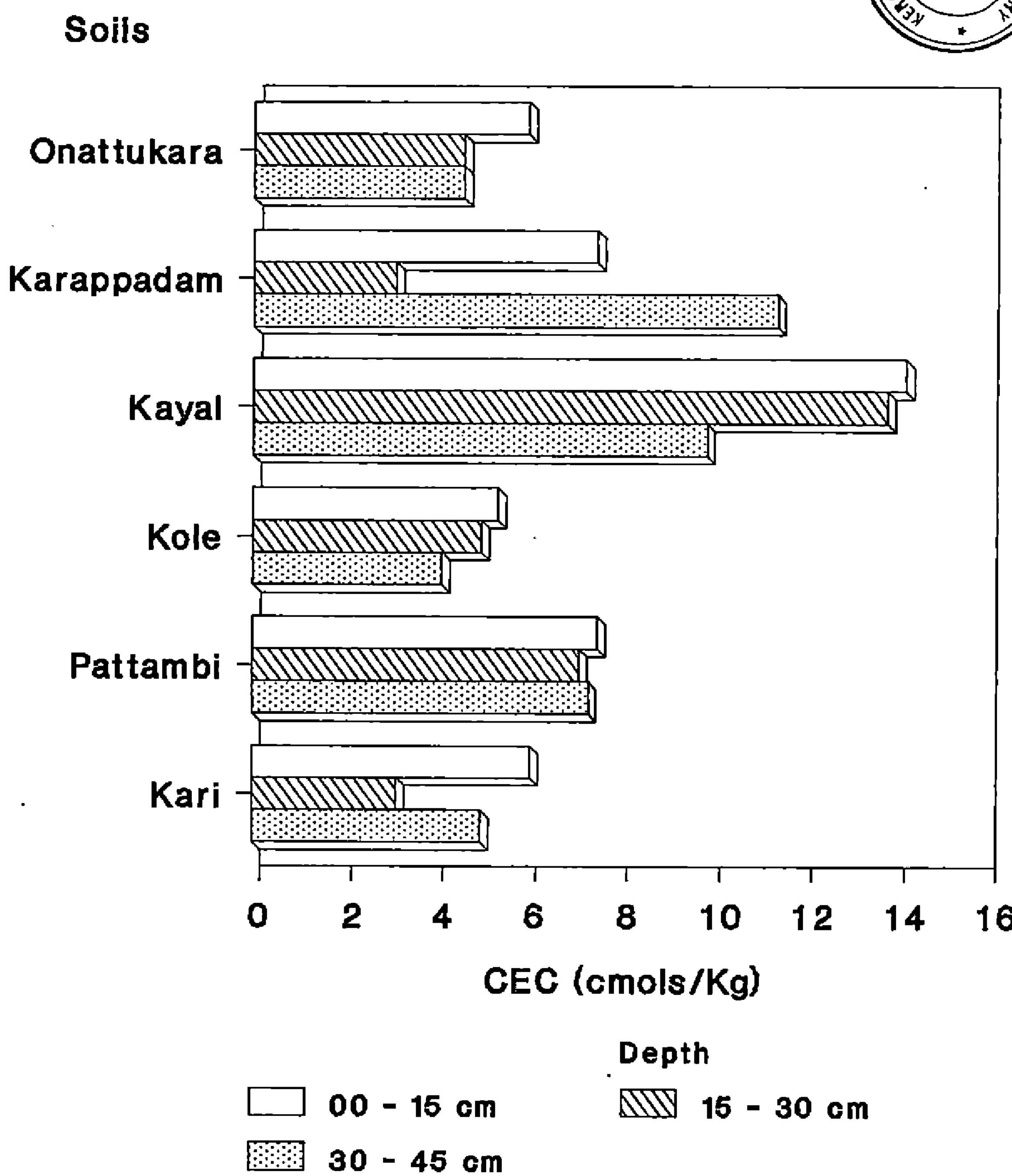
Fig 2. Cation exchange capacity of soil



4.1.4. Total nitrogen

Generally, the total nitrogen content of the different soils shows a decreasing trend with depth. Analysis reveal that Kole soil is having the lowest mean total nitrogen content (0.08%), while Kayal soil is having the highest (0.21%) [Table 1]. The mean total nitrogen content of Pattambi and Kole soils are found to be on par.

4.1.5. Available nitrogen

The data obtained on analysis reveals that the available nitrogen content of Pattambi and Karappadam soils are on par. The lowest mean value is observed for Onattukara soil (148.04 kg/ha) and the highest mean value for Kayal soil (364.98 kg/ha). Onattukara and Kari soils are found to be low in available nitrogen content, while for all others, it is found to be medium.

The low nitrogen content of Onattukara and Kari soils maybe because of the low organic matter (0.29, 3.54%) and low total nitrogen (0.11, 0.07%) contents of these soils [Tables 1 & 2].

The low available nitrogen content in Onattukara soils can be attributed to the lower mean organic matter content (0.29%). Considering the Kari soils, the organic matter content as well as the available nitrogen are found to be comparatively higher in the surface soil. Going deeper into the soil, the sand content is found to be increasing and the clay content decreasing. This maybe considered as a reason for the lower content of available nitrogen in Kari soils.

4.1.6. Available phosphorus (P_2O_5)

Kayal soils are found to have the highest mean value for available phosphorus (27.58 kg/ha). All soils except Kayal and Pattambi soils, are found to be medium in their phosphorus content. The lowest mean value observed is for Onattukara soil (14.36 kg/ha). Both Onattukara and Karappadam (14.36, 14.42 kg/ha) are found to be on par in the available phosphorus content.

4.1.7. Available potassium (K_2O)

All soils are found to be significantly different in their available potassium content. The mean lowest value is observed for Onattukara soil (70.04 kg/ha) and the highest for Kayal soil (184.13). Kayal, Pattambi and Karappadam soils may be classified as medium in potassium content, while that of Kari, Kole and Onattukara soils as low in their available potassium content. [Table 1].

The value of available potassium is found to be increasing with depth in the case of Onattukara soil. The low value of clay content (11.66%), CEC (5.03 cmols/kg) and organic matter (0.29%) maybe the reason for the low potassium content of this soil, while these properties are influencing the nutrient contents in the Kayal soil, which shows a high values for total nitrogen, available nitrogen, phosphorus and potassium [Tables 1 and 2].

4.1.8. Exchangeable calcium

The exchangeable calcium content of all soils are found to be significantly different. The maximum mean value is noted for Karappadam soil (4.2 cmols/kg) and the minimum for Onattukara soil (1.2 cmols/kg). the high values maybe because of the higher clay content of Karappadam soil (43.33%), when compared to that of Onattukara (11.66%)[Tables 1 and 2].

4.1.9. Exchangeable magnesium

The maximum mean value is recorded for Karappadam soil (3.15 cmols/kg) and the minimum for Pattambi soils (0.41 cmols/kg). The higher sand content of Pattambi soils maybe the reason for this low exchangeable magnesium content [Table 1].

Higher clay content might have increased the adsorption capacity of the soil complex, thereby leading to an increased value of exchangeable calcium and magnesium content in Karappadam soils.

4.1.10 Mechanical analysis

The data obtained from mechanical analysis are presented in Table 2. Using the data, the soils are classified into different textural classes, depth wise, based on the textural diagram. The textural classes of each soil are given below.

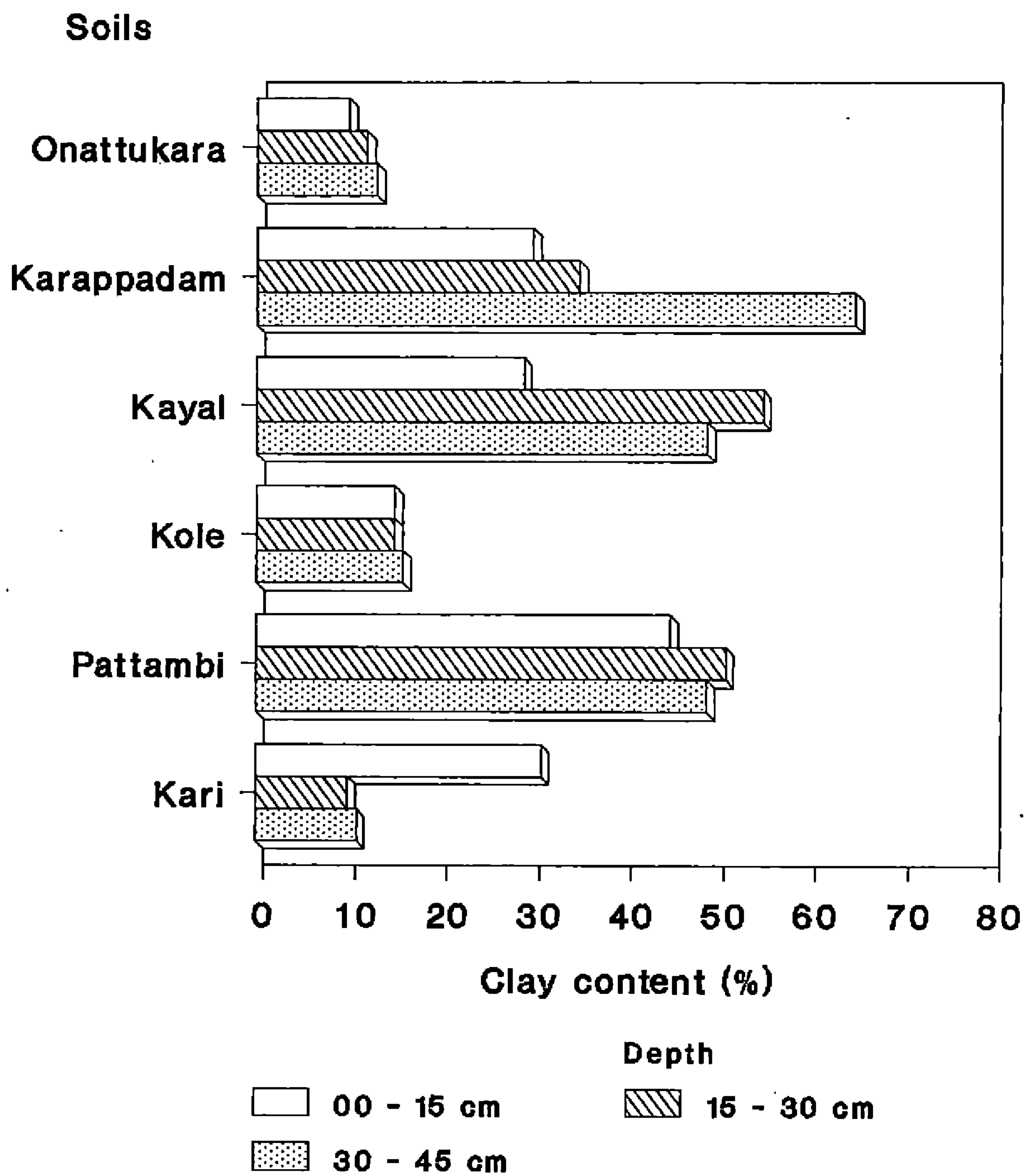
Soil Type	00 - 15 cm	15 - 30 cm	30 - 45 cm
Onattukara	Loamy sand	Loamy sand	Loamy sand
Karappadam	Silty clay loam	sandy clay loam	clay
Kayal	Silty clay loam	Clay	Sandy clay
Kole	Sandy loam	Sandy clay	Sandy clay
Pattambi	Sandy clay	Sandy clay	Sandy clay
Kari	Sandy clay loam	Sandy loam	Loamy sand

The mean sand content varied from 22.33% (Karappadam and Kayal) to 74.66% (Onattukara). The mean silt content varied from 13.66% (Onattukara) to 33.33% (Kayal soil) . The mean clay content varied from 11.66% for Onattukara to 48.33% for Pattambi soils [Table 2].

It is observed that the sand content is increasing with depth in the case of Kayal and Kari soils. In the case of Karappadam soils, it increased first and then decreased at a depth of 30 - 45 cm.

The silt content decreased with depth in the case of Karappadam and Kayal soils. For Kari soil, the silt content increased in the second depth and then decreased towards lower

Fig 3. Clay Content of Soils



depth. For Onattukara and Pattambi soils, the silt content first decreased and then increased. In the case of Kole soil, it increased in the case of second depth only.

4.1.11. Single value constants

The lowest mean value of particle density is observed for Kayal soil (2.3 g/cc) and the maximum mean for Kole (2.6 g/cc), which may be due to its higher sand content (58.33%) when compared to Kayal soil (22.33%) [Table 2].

Onattukara soil is observed to have the lowest mean value for bulk density (1.19 g/cc), while Karappadam soils recorded the highest mean value of 1.72 g/cc. This maybe because of the higher clay content of Karappadam soils (43.33%). Comparing the Onattukara and Kayal soils, the sand content is higher in the case of Onatttukara soil, while clay content is more in the case of Kayal soil. This has influenced the particle and bulk densities of these soils [Table 2]

Kayal soil recorded the highest mean value for water holding capacity [WHC] (49.36%) and the least for Kole soil (17.42%). The high value of Kayal soil maybe due to its higher content of organic matter (4.05%) and clay (44.33%) and low proportion of sand (22.33%). Kole soil, even though it has a fairly high organic matter content, it has shown a low value for water holding capacity (17.42%), since the sand fraction is found to be high (58.33%).

The Onattukara soil, being a loamy soil, having more percentage of sand content, especially in the surface layer has given a high value for porosity (54%). The least is noted for Kayal soils(29%).

4.2. Percolation loss of nitrogen

A percolation study is conducted in PVC columns, by applying urea fertilizer at the rate of 90 kgN/ha (49 mgN/column). The results obtained are discussed below.

Data from table 3 shows that Onattukara soil is having the highest percentage of leaching loss of nitrogen (56.10) followed by Kole (54.65), Kari (47.73), Pattambi (36.42), Karapaddam (31.09) and Kayal (24.21) soils. For all soils except Pattambi, leaching loss decreased with depth. In the case of Pattambi soils, the loss increases in the second layer and then decreases in the third layer. For all soils except Karappadam, Kayal and Kari soils, the leaching loss is found to decrease with period. However, in the third layer of Karappadam, Kayal and Kari soils, the leaching loss increases initially with period and then it decreases.

As nitrogen passes down through the soil profile, it gets adsorbed on the soil colloids. This maybe the reason for the low

Table 3. Total leaching loss of nitrogen.

Soil	Depth cm	Period(Days)								Mean
		1	2	3	4	5	10	15	20	
Onattukara	00-15	19.97	4.74	1.48	0.06	0.00	0.00	0.00	0.00	26.25
	15-30	13.70	5.11	2.97	0.91	0.15	0.00	0.00	0.00	22.84
	30-45	8.20	3.58	3.51	2.28	1.67	0.00	0.00	0.00	19.24
Karappadam	00-15	5.69	3.74	2.39	1.52	0.89	0.40	0.21	0.00	14.84
	15-30	3.20	2.96	2.91	1.63	1.12	0.64	0.34	0.00	12.80
	30-45	0.00	0.40	0.50	0.70	0.71	0.63	0.51	0.00	3.45
Kayal	00-15	2.76	3.13	3.01	1.53	1.10	0.44	0.22	0.09	12.26
	15-30	0.82	1.89	2.58	1.64	1.29	0.59	0.32	0.07	9.20
	30-45	0.00	0.00	0.46	0.62	0.68	0.52	0.36	0.11	2.75
Kole	00-15	16.43	5.09	2.23	0.91	0.33	0.00	0.00	0.00	24.99
	15-30	10.62	4.86	3.60	1.48	0.57	0.00	0.00	0.00	21.13
	30-45	3.01	1.71	1.46	1.44	0.91	0.00	0.00	0.00	8.53
Pattambi	00-15	7.29	4.12	2.39	1.50	0.70	0.27	0.08	0.00	16.35
	15-30	5.51	3.74	3.34	2.54	1.55	0.79	0.34	0.00	17.81
	30-45	1.32	1.21	1.32	1.11	0.87	0.56	0.39	0.00	6.78
Kari	00-15	11.08	5.81	3.09	1.40	0.46	0.24	0.00	0.00	22.08
	15-30	7.23	4.85	3.69	2.06	1.18	0.76	0.00	0.00	19.77
	30-45	0.89	1.29	1.49	1.00	0.59	0.62	0.00	0.00	5.88

content of nitrogen in the leachates from lower layers.

In the case of Onattukara soil, the leaching loss occurs till the fourth day (Table 3) in the surface layer. For the two lower layers, it continued till the fifth day. By the fifth day, the loss decreased to a minimum value. Thus it may be inferred that, in Onattukara soil, leaching loss of N ceases by the fifth day and further loss by leaching is completely stopped.

For Karappadam soils, the leaching loss continued till the 15th day for all the three depths. No leaching loss is observed for the third layer for the first day, which may be due to the clayey texture of the third layer, which has retained nitrogen coming through from the top layers.

Kayal soil is the only soil from which leaching is observed for 20 days. But, by the 10th day, the leaching loss diminished and is found to be negligible.

In the case of Kole soils, leaching loss completely stopped after the fifth day. For Pattambi soils, the loss is found to occur till the 15th day and for Kari soil up to the 10th day. In all cases, the leaching loss of nitrogen, towards the end of the period is found to diminish and attain only negligible values.

For the first day, in all soils, the leaching loss decreases with depth. It is 19.97, 13.70 and 8.20% for Onattukara, 5.69, 3.20, 0% for Karappadam, 2.76, 0.82, 0% for Kayal, 16.43,

Fig 4. Total Leaching Loss of Nitrogen

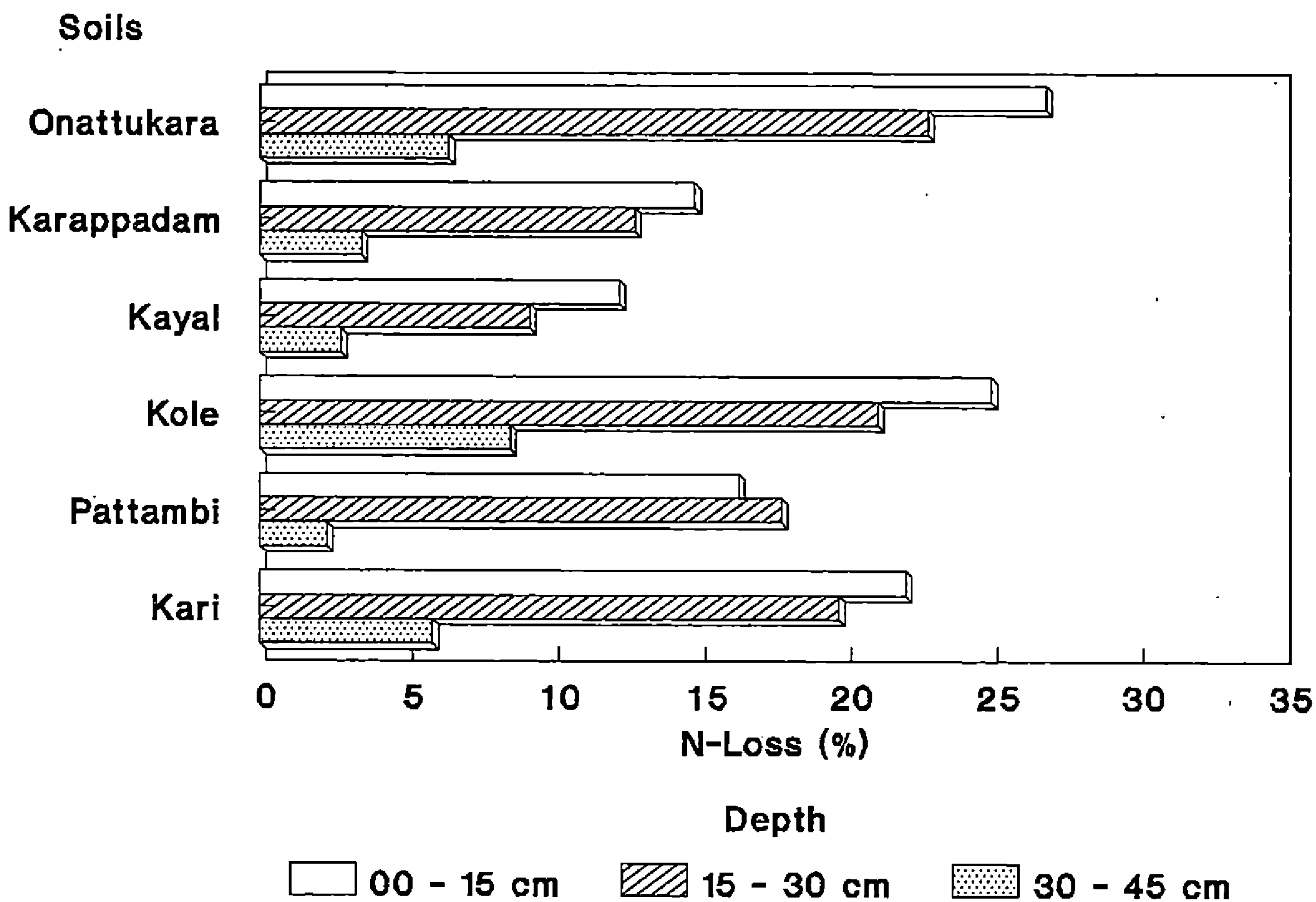
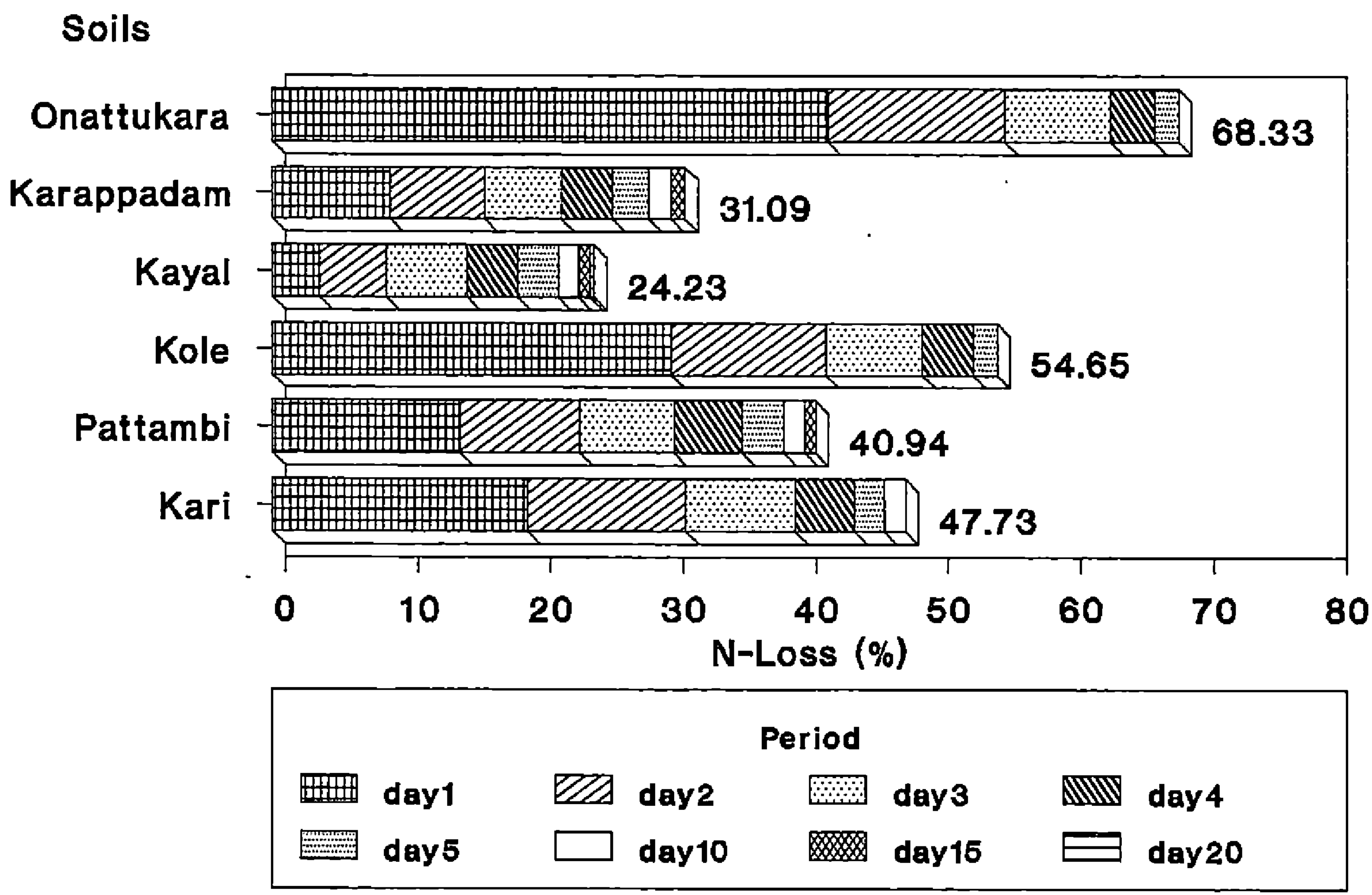


Fig 5. Total loss of Nitrogen
Period wise



10.62, 3.01% for Kole, 7.29, 5.51, 1.32% for Pattambi and 11.08, 7.23 and 0.89% for Kari soils. On the second day, the same trend is shown by all soils except Onattukara, where it is found to increase with second layer and then decreases in the third layer (4.74, 5.11, 3.58% respectively). For the other soils it is as follows: 3.74, 2.96, 0.40 for Karappadam, 3.13, 1.89, 0% for Kayal, 5.09, 4.86, 1.71% for Kole, 4.12, 3.74, 1.21% for Pattambi and 5.81, 4.85, 1.29% for Kari soils. On the third day, the leaching loss increased with depth in the case of Onattukara soils (1.48, 2.97, 3.51%). However, in the case of Karappadam (2.39, 2.91, 0.50%), Kole (2.23, 3.60, 1.46%), Pattambi (2.39, 3.34, 1.32%) and Kari (3.09, 3.69, 1.49%) soils, the loss increased with depth and then decreased. In the case of Kayal soil (3.01, 2.58, 0.46%), the loss decreases with depth. For the fourth day, Onattukara soil shows increase in loss with depth (0.06, 0.91, 2.28%). For all other soils, the loss increased with depth first and then decreased [Karappadam (1.52, 1.63, 0.70%), Kayal (1.53, 1.64, 0.62%), Kole (0.91, 1.48, 1.44%), Pattambi (1.50, 2.54, 1.11%) and Kari (1.40, 2.06, 1.00%)]. On the fifth day, all soils except Onattukara and Kole, shows increase in leaching loss with depth and then it decreases. The losses are 0.89, 1.12 and 0.71% for Karappadam, 1.10, 1.29, 0.68% for Kayal, 0.70, 1.55, 0.87% for Pattambi and 0.46, 1.18 and 0.59% for Kari soils. In the case of Onattukara (0, 0.15, 1.67%) and Kole (0.33, 0.57, 0.91%) soils, the leaching loss increases with depth. On the 10th day, all soils except Onattukara and Kole soils shows increase in leaching loss with depth and then it decreases in the third layer [Karappadam (0.40, 0.64, 0.63%), Kayal (0.44, 0.59, 0.52%), Pattambi (0.27, 0.79, 0.56%) and Kari (0.24, 0.76. 0.62%). For the 15^{th} day, all the soils which has leaching loss, shows an increase in the leaching loss with depth [Karappadam (0.21, 0.34, 0.51%), Kayal (0.22, 0.32, 0.36%) and Pattambi (0.08, 0.34, 0.39%). On the 20^{th} day, leaching loss was found in Kayal soils only . Here, the leaching loss decreases first and then increased with depth(0.09, 0.07, 0.11%).

The data obtained on statistical analysis [Table 4] reveals that all soils and all intervals of observations are significantly different.

Interaction effects reveals that, on the first day, the maximum mean leaching loss is for Onattukara soil (13.96%) and the minimum mean leaching loss is for Kayal soil (1.19%). Same trend is observed for the second day also[Onattukara (4.78%), Kayal (1.67%). During the third day, maximum loss is for Kari soil (2.76%) and the least for Karappadam soil (1.93%) soil. Kari and Onattukara; Kole and Pattambi and Karappadam and Kayal soils are found to be on par with each other. For the fourth and fifth days, Pattambi soil recorded the maximum mean leaching loss of 1.71 and 1.04% respectively. The least loss for the fourth and fifth days are observed for Onattukara (1.09%) and Kole (0.60%) soils. For the fourth day, Karappadam, Kayal and Kole soils are found to be on par. For the fifth day, Pattambi, Kayal and Karappadam; and Kari, Onattukara and Kole soils are found to be on par with each other in their leaching loss.

Table 4. Mean leaching loss (%) of fertilizer nitrogen from the six soils as influenced by period of sampling.

Soil	Period (Days)								Mean
	1	2	3	4	5	10	15	20	
Onattukara	13.96	4.78	2.66	1.09	0.61	0.00	0.00	0.00	2.85
Karappadam.	2.96	2.36	1.94	1.28	0.91	0.56	0.35	0.00	1.30
Kayal	1.19	1.67	2.02	1.26	1.03	0.51	0.30	0.15	1.02
Kole	10.02	3.89	2.44	1.28	0.60	0.00	0.00	0.00	2.28
Pattamabi	4.71	3.03	2.35	1.71	1.04	0.54	0.27	0.00	1.71
Kari	6.40	3.99	2.76	1.48	0.74	0.54	0.00	0.00	1.99
Mean	6.54	3.24	2.36	1.35	0.61	0.36	0.15	0.02	

CD values Soil=0.08 Period=0.07 Interaction=0.18

Table 5. Mean leaching loss of fertilizer nitrogen from the three depths as influenced by period of sampling.

Depth cm	Period (Days)								Mean
	1	2	3	4	5	10	15	20	
00-15	10.54	4.44	2.43	1.15	0.58	0.23	0.08	0.01	2.43
15-30	6.85	3.90	3.18	1.71	0.98	0.46	0.17	0.02	2.16
30-45	2.24	1.37	1.46	1.19	0.91	0.39	0.21	0.04	0.97
Me-an	6.54	3.24	2.36	1.35	0.82	0.36	0.15	0.02	

CD values Depth=0.06 Period=0.07 Interaction=0.12

Fig 6. Leaching Loss of Nitrogen
Depth wise

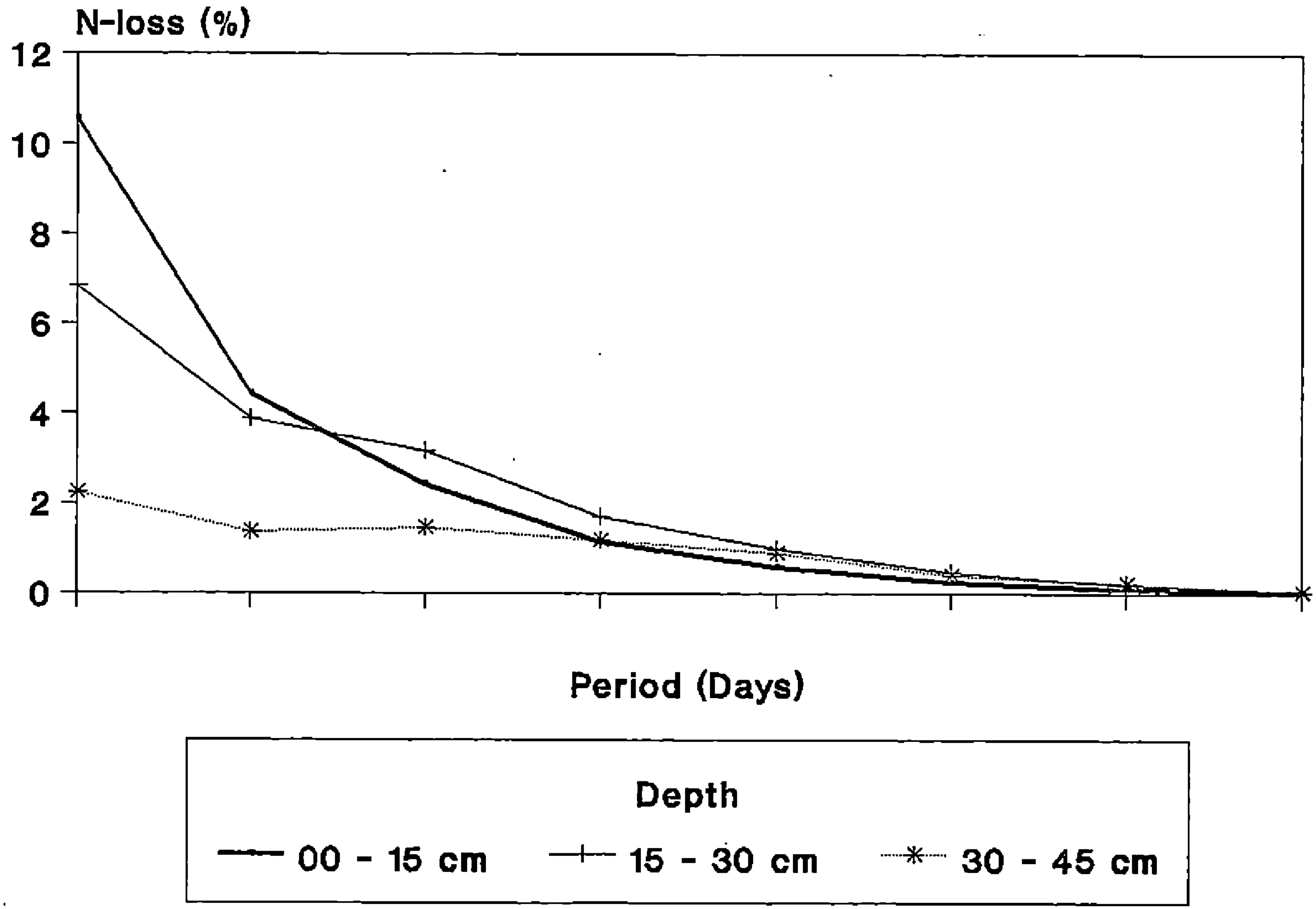
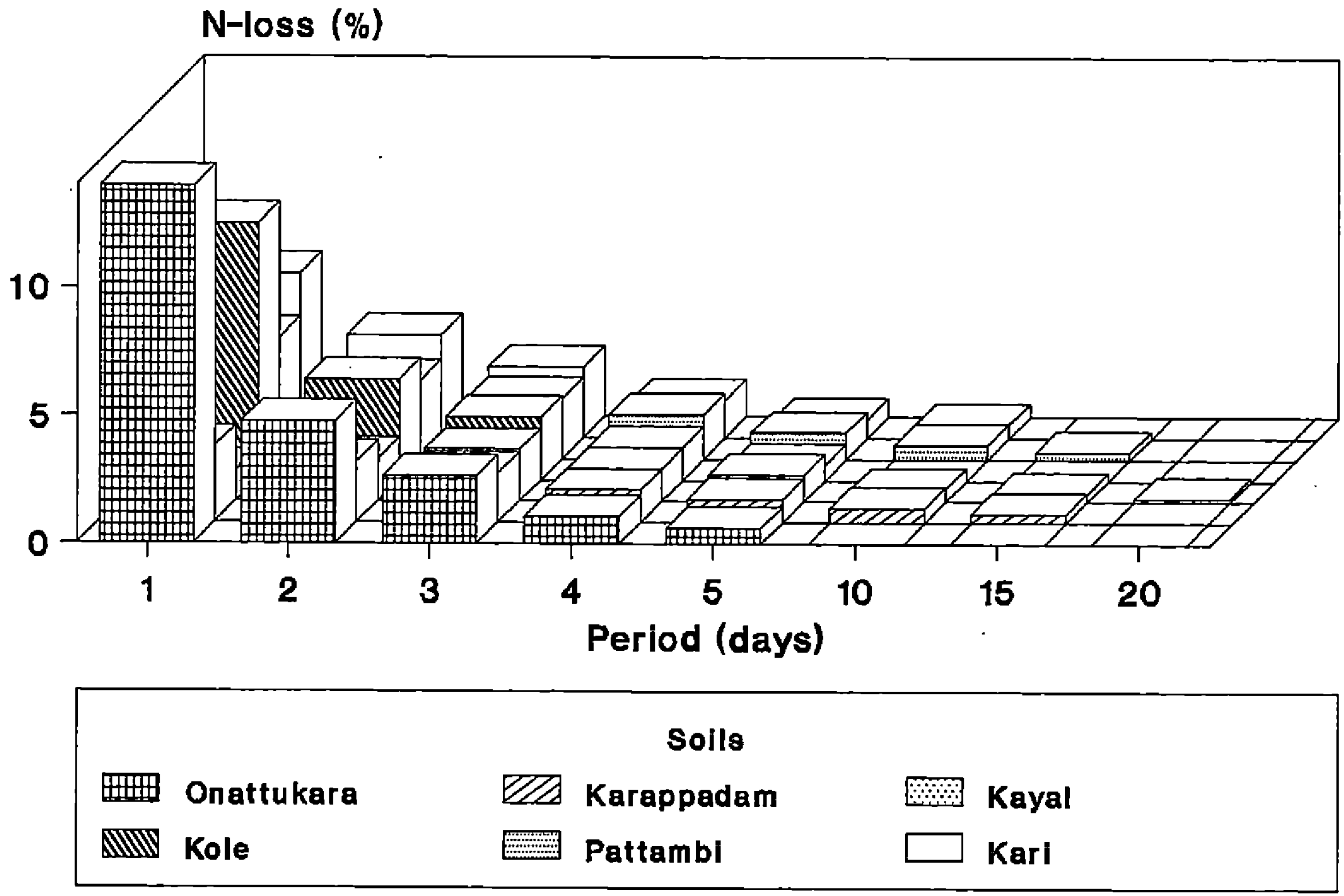


Fig 7. Mean leaching loss of soil as influenced by interval



In the case of the 10th day of observation, no leaching loss is observed from Onattukara and Kole soils. The leaching losses of all other soils are on par. The maximum mean loss is observed in the case of Karappadam (0.56%) and the minimum mean loss for Kayal soil (0.51%).

On the 15th day, mean nitrogen losses are found to occur only from Karappadam, Kayal and Pattambi soils and the losses are found to be on par with one another. On the 20th day, leaching loss is reported only from Kayal soil (0.15%).

The data of leaching loss of nitrogen [Table 5] shows that, as the days advance, the loss of nitrogen by leaching generally decreases, irrespective of the different depths. The maximum mean leaching loss is observed during the first five days. Mahajan and Tripathi (1991) have reported that there is a drastic reduction in nitrogen leaching loss from third day onwards from a submerged soil. They have also reported that the leaching loss of nitrogen was heavy during the first and second day. This is in confirmation with the results of the present study.

Statistical analysis of data obtained [Table 5] reveal that all intervals are significantly influenced by the leaching loss of nitrogen. The maximum mean leaching loss is observed for the first day (6.54%) and the least on the 20th day (0.02%). In the surface layer, leaching loss on the 15th and 20th day are found to be on par. In the second layer, the losses on all days are

Table 6. Mean leaching loss (%) of fertilizer nitrogen from six soils as influenced by depth.

Soil	Depth (cm)			Mean
	00 - 15	15 - 30	30 - 45	
Onattukara	3.28	2.86	2.41	2.85
Karappadam	1.86	1.60	0.43	1.30
Kayal	1.53	1.16	0.36	1.02
Kole	3.12	2.64	1.07	2.28
Pattambi	2.04	2.23	0.85	1.71
Kari	2.76	2.47	0.74	1.99
Mean	2.43	2.16	0.97	

CD values Soil=0.08 Depth=0.06 Interaction=0.14

Table 7. Mean leachate collected per unit time (ml) from six soils as influenced by depth.

Soil	Depth (cm)			Mean
	00 - 15	15 - 30	30 - 45	
Onattukara	187.00	184.79	184.75	185.51
Karappadam	162.21	158.67	150.83	157.24
Kayal	162.29	150.79	153.71	155.60
Kole	175.46	172.96	172.25	173.56
Pattambi	167.25	168.38	166.04	167.22
Kari	166.04	170.17	169.79	168.67
Mean	170.04	167.62	166.23	

CD values Soil=1.66 Depth=1.18 Interaction=2.88

significantly different. In the third layer, the losses on second and third day are found to be on par.

In all depths, the maximum difference in leaching occurred within the first five days, i.e., 94.48% for 0 - 15 cm; 85.71% for 15 - 30 cm and 59.49% for 30 - 45 cm layer. In all cases, by the 20th day more than 98% of the total fertilizer nitrogen leached is found to be lost.

The data obtained on statistical analysis [Table 6] reveals that the Onattukara soil had the highest mean leaching loss of fertilizer nitrogen (2.85%); while, the lowest is observed for Kayal soil (1.02%). The decreasing order of percentage mean leaching loss of all rice soils is as follows: Onattukara (2.85) > Kole (2.28) > Kari (1.99) > Pattambi (1.71) >Karappadam (1.2964) > Kayal (1.02).

It is found that all soils are significantly different in their leaching losses. Even though Kayal soil recorded the least value for leaching, the difference in percentage of the three depths is found to be maximum (76.60%). Same trend is followed in Karappadam soils also. In both these cases, the leaching loss is more confined to the surface layers, when compared to other soils. The leaching loss of nitrogen is much confined to the surface layer. This loss is also less for Kayal and Karappadam soils , when compared to other soils. However, the Onattukara soils recorded the lowest difference in leaching percentage (26.74%). In the case of

Onattukara soils, the leaching losses are found to be almost uniform in all the three layers and it is much higher than the other soils.

The general trend noted is that , as depth increased, the leaching loss decreased. The maximum mean leaching loss is recorded for the first layer, i.e., 0 - 15 cm (2.43%) and the least for the third layer, i.e., 30 - 45 cm (0.97%). Statistical analysis shows that the leaching losses in all the three depths are significantly different.

The interaction effects shows that for the first two depths, losses from all soils are significantly different. For the third depth, Pattambi and Kari and Karappadam and Kayal soils are found to be on par.

For all the three depths, Onattukara soil recorded the maximum mean leaching loss closely followed by Kole soils. Kayal soils show the minimum leaching loss for all depths.

The high leaching loss of nitrogen from Onattukara soil maybe because of its low mean organic matter content (0.29%), low mean CEC (5.03 cmols/kg), high mean sand fraction (74.6%), low mean clay content (11.66%), low mean bulk density (1.19 g/cc) and low mean WHC (21.16%). Lowest leaching loss for Kayal soils maybe due to its high mean value of organic matter (4.05%); high CEC (12.62 cmols/kg); low sand content (22.33%); high clay content (44.33%);

higher bulk density(1.61 g/cc) and higher WHC (49.36%), when compared to that of Onattukara soils (Tables 1 and 2).

The Kole soil which has a sand fraction of 58.33% with low clay content (16%), low CEC (4.76 cmols/kg) and low bulk density (1.23 g/cc) have also recorded higher leaching losses as that of Onattukara soils. The Onattukara soil which have a higher CEC and WHC values than Kole soil, the leaching is found to be more higher than Kole soil. This can be because of its high sand content, low organic matter, low clay, low bulk density and low WHC, though the Kole soils recorded high organic matter content. (Tables 1 and 2).

The soil with the third highest leaching loss is Kari soil. Even though the Kari soil has a very high organic matter content on the surface soil (6.47%), the average organic matter content is only 3.24%. Also, the soil has got a higher mean sand content (43.3%), low mean clay content (17.3%), lower WHC (26.94%) and bulk density (1.49 g/cc) values than the Karappadam soil towards deeper layers (Tables 1 and 2).

The physico - chemical properties of the Pattambi soils (Tables 1 and 2), which reduced the leaching loss of nitrogen are higher clay content (48.3%), bulk density (1.49 g/cc), CEC (7.3 cmols/kg) and comparatively higher porosity (41.20%). But the mean sand content of 45.33% and low mean organic matter content of 1.33% has helped in the leaching of nitrogen to some extend when compared with the loss of nitrogen from Kayal and Karappadam soils.

Karappadam soils, which recorded the second lowest leaching loss, comes in the fifth place in the decreasing order of leaching loss of nitrogen. It has a lower porosity (28%) and higher bulk density (1.72 g/cc). Even then, its higher loss when compared to Kayal soil may be because of its lower organic matter content (2.39%), lower CEC (7.32 cmols/kg) and lower clay content (43.3%).

The Kayal soil is observed to have the lowest leaching loss of fertilizer nitrogen. Obviously, this maybe due to its high mean content of organic matter (4.05%), CEC (12.62 cmols/kg), clay content (44.33%), WHC (49.36%) and low mean sand content (22.33%).

The analysis of soils at each depth after the 20th day didn't show any increase in the total nitrogen content of the soil samples. This may be because of the very low quantity of nitrogen that was applied to each column (49 mgN/column).

4.2.1. Correlation studies

The data obtained in the present study is used to correlate the leaching loss of the fertilizer nitrogen irrespective of the soils, with their physico - chemical properties. However, the leaching loss varies with each type of soil. Hence, the correlation is done for each soil also. The correlation revealed that leaching loss is negatively correlated with the organic matter content, clay content, cation exchange capacity, bulk density and water holding capacity. The results are discussed below.

4.2.1.1. Organic matter content of the soil

In general, the total leaching loss of any soil is negatively related to the organic matter content of the soil (-0.5593) [Table 11]. This implies that as the quantity of organic matter in the soil increases, the leaching loss of nitrogen decreases. This same trend has been noted in the case of individual soils, viz., Onattukara (-0.5714); Karappadam (-0.6133); Kayal (-0.1753); Kole (-0.2314); Pattambi (-0.2414) and Kari (-0.8550) soils [Table 12]. Kari soil has the highest negative influence of organic matter on leaching loss of nitrogen and the least is observed for Kayal soil. This high effect of Kari soils maybe due to the high content of organic matter in the surface layer, than in the lower layers. The negative correlation effect of organic matter on the leaching loss of nitrogen has also been reported by Reddy and Patrick (1980) as " with increase in organic matter content the leaching loss of nitrogen is decreased".

Urea moves in soils about as readily as nitrate. Soils high in organic matter is fount to restrict the movement of urea has also been reported by Tisdale et al. (1985).

4.2.1.2. Cation exchange capacity

The CEC of the soil also have a negative (-0.4560) correlation with the leaching loss of nitrogen in general [Table 11]. In effect, the correlation implies that, as CEC of the soil increases, the N loss through leaching is inhibited. Taking the case of each soil, Onattukara had a 'r' value of -0.0901; Karappadam - -0.9861; Kayal - -0.6495; Kole - -0.6400; Pattambi - -0.5360 and for Kari soils it was -0.9992 [Table 12]

The Kari soil have the highest negative effect of CEC on leaching loss, while the least was observed for Onattukara soil, which maybe due to its low organic matter and clay content. This can also be due to the high sand content and low CEC. Somani and Totawat (1970) and Miller and Donahue (1992) have observed an increase in leaching loss of nitrogen in a highly permeable soil with low CEC.

Reddy and Patrick (1980) and Mishra (1993) have reported a decrease in leaching loss with high CEC, as found in the present investigations.

4.2.1.3. Clay content

The clay content of all the six soils have a negative correlation with the leaching loss (-0.5864) [Table 11]. The effect of clay content of each soil is as follows. Onattukara (-0.4168); Karappadam (-0.8681); Kayal (-0.4607); Kole (-0.5549); Pattambi (-0.3966) and Kari soil (-0.9148) [Table 12]. Among the soils, Kari soil shows the highest negative correlation and the least was shown by Pattambi soils.

Morgan and Street (1939) and Tomasek and Ryglevicz (1989) observed from their studies that leaching loss of nitrogen is more in coarse textured soils than from fine textured soils. Dhyani and Mishra (1993) reported that little leaching loss of nitrogen occurs from soils having high clay content, which also confirms the findings of the present study.

4.2.1.4.Bulk density

Bulk density is also negatively correlated with the nitrogen leaching loss (-0.3213) [Table 11]. The decreasing order in which bulk density influenced the leaching loss of each soil is as follows: Karappadam(-0.9735) > Kayal (-0.8309) > Kari (-0.7559) > Kole (-0.7359) > Karappadam (-0.7244) > Pattambi (-0.2285). [Table 12]

The correlation study reveals that as the bulk density increased, the leaching loss of nitrogen decreased. Generally, when the bulk density increases, mass per unit volume also increases. This can happen when the mineral matter or sand content increases in a soil. The organic matter, on the other hand, will enhance the compaction of the soil without increasing the mass per unit volume. In the present study, in Karappadam soils, which recorded a maximum correlation (97.35%) in the leaching loss shows that this soil has a low content of organic matter (2.39%), while the mineral clay content is high (43.33%).

A compacted impervious layer present below the plough layer in paddy soils has an influence in preventing the leaching loss of nitrogen from these soils as reported by Craswell and De Datta (1980) also confirms the present study.

4.2.1.5. Water holding capacity

Irrespective of all soils, WHC also have a negative correlation of -0.5544 with the leaching loss of nitrogen [Table 11]. Taking each soil, the 'r' value was -0.0290 for Onattukara, -0.0666 for Karappadam, -0.2977 for Kayal, -0.3499 for Kole, -0.2307 for Pattambi and -0.8418 for Kari soils [table 12]. The leaching loss of Onattukara soil was least affected and that of Kari soils, the maximum affected,by WHC.

The WHC is measured on the basis of oven dry weight of the soil. The soil water retention is highly dependent on the clay content as well as organic matter content of the soil. Though Kari soil shows a lower value of organic matter in the second and third layer, it has a comparatively higher value of 6.47% in the surface layer with 31% clay. This might have influenced the WHC of this soil.

Koshimo (1975) observed that leaching loss of nitrogen obviously depend on the soil texture and water content of the soil. Patrick and Mahapatra (1965) reported that the constant water head resulted in the greater downward percolation of nitrogen along with the soil solution. Ghildayal (1978) observed that the leaching loss of nitrogen is high from coarse textured soils with high sand and permeability.

4.3. Leachate collected per unit time

The quantity of leachate collected at each sampling is noted for studying the relationship between the leachate collected per hour and the nitrogen leaching loss. The details of the statistical analysis are given below.

Statistical analysis [Table 7] reveal that Onattukara soil is having the highest mean leaching loss of soil solution (185.51 ml); followed by Kole (173.56 ml), Kari (168.67 ml), Pattambi (167.22), Karappadam (157.24 ml) and Kayal (155.60 ml).

A high leaching loss of soil solution is observed in Onattukara soil. This maybe because of its higher sand content (74.6%), low clay (11.66%) and lower WHC (21.16%), when compared to that of Kayal soil (sand - 22.33%; clay - 44.33%; WHC - 49.36%) [Tables 1 and 2]. The leachates collected from Karappadam and Kayal

Table 8. Mean leachate collected per unit time (ml) form six soils as influenced by period of sampling.

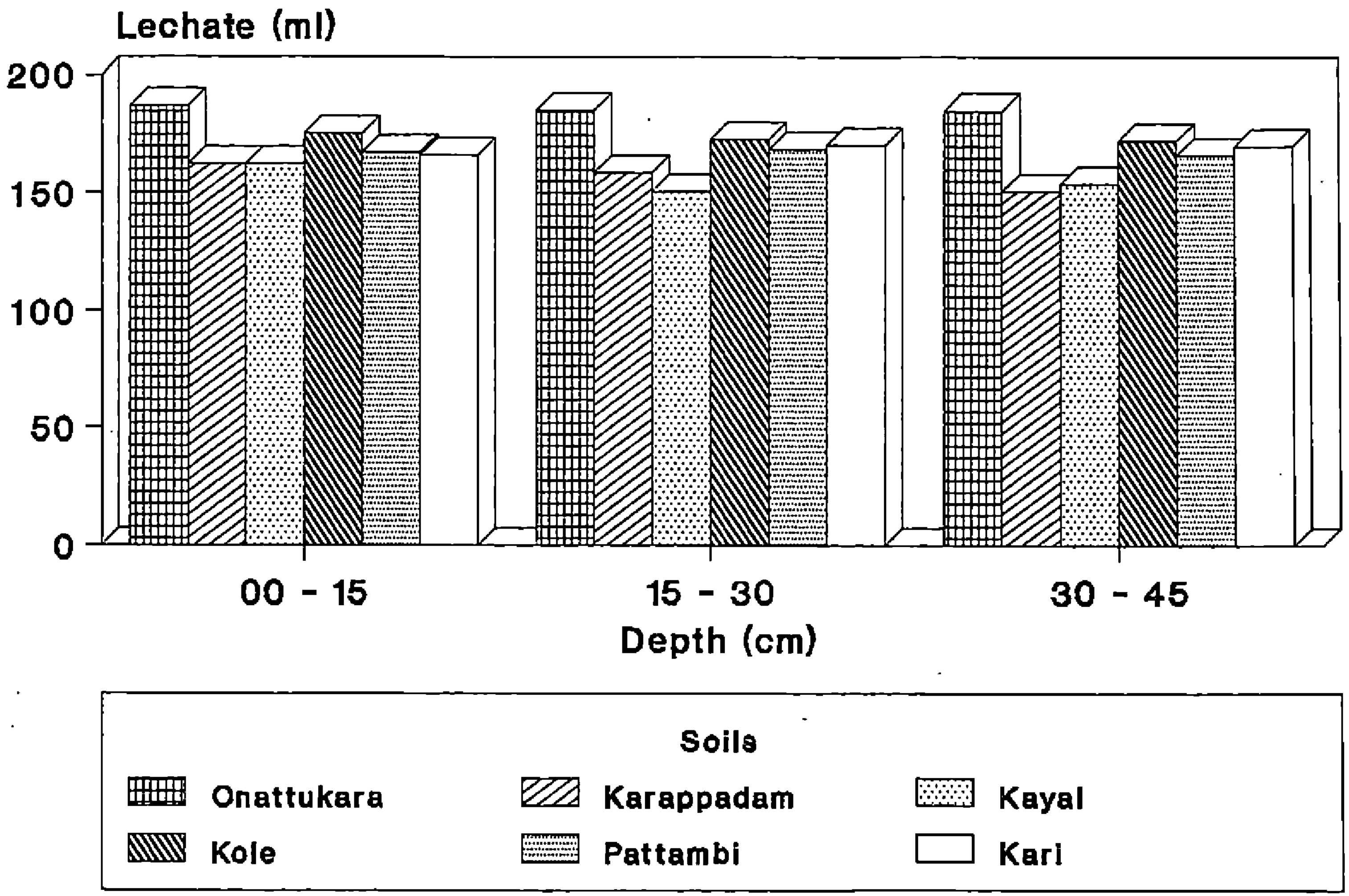
Soil	Period (days)								Mean
	1	2	3	4	5	10	15	20	
Onattukara	183.22	186.33	185.44	184.55	185.44	186.33	187.33	185.44	185.57
Karappadam	157.33	159.66	157.77	155.33	155.55	154.55	159.22	158.44	157.23
Kayal	156.11	157.00	159.44	156.66	153.77	154.66	152.11	155.00	155.54
Kole	173.00	173.77	172.88	174.55	174.55	173.22	172.33	174.11	173.85
Pattambi	164.22	167.33	169.55	166.66	167.22	169.55	166.22	167.00	167.72
Kari	168.22	168.55	170.55	169.11	169.99	168.33	167.55	167.55	168.87
Mean	167.02	168.77	169.27	167.81	167.66	167.78	167.46	167.93	

CD Values Soils=1.66 Depth=1.50 AInteraction=3.67

Table 9. Total runoff loss of applied nitrogen.

Soil	Nitrogen loss (%)						Total (%)
	Period (Days)						
	1	2	3	4	5	10	
Onattukara	10.05	7.95	6.79	6.13	5.83	3.66	40.41
Karapadam	4.10	3.29	2.92	2.47	2.01	0.91	15.70
Kayal	3.92	3.44	3.13	2.72	2.01	1.33	16.55
Kole	7.49	6.23	5.44	5.17	4.26	2.21	30.80
Pattambi		3.93	3.40	3.09	2.85	1.70	19.63
Kari	6.19	5.31	4.64	4.05	3.42	2.00	25.61

Fig 8. Mean leachate collected per unit time



and Pattambi and Kari soils are found to be on par.

Depth wise, the leachate collected from the three depths are found to be significantly different from one another. The maximum mean leachate is noted in the first depth (170.04 ml) and the least in 30 - 45 cm depth (166.23 ml).

The data on statistical analysis [Table 8] shows that the maximum amount of leachate collected per hour was found to be maximum on the third day (169.27 ml) and the least on the first day (167.02 ml). No significant difference is observed between the leachate collected at each interval.

4.3.1. Correlation study

The quantity of leachate collected for one hour at each time of sampling is used for correlating it with the leaching loss of nitrogen from all the six soils.

The quantity of leachate collected was the only factor which has a positive correlation with the leaching loss of nitrogen. It has an 'r' value of +0.8876 when all soils were taken together and related [Table 11]. For individual soils, it is +0.33 for Onattukara, +0.2886 for Karappadam, +0.0213 for Kayal, +0.8322 for Kole, +0.9646 for Pattambi and +0.9996 for Kari soils [Table 12].

That is, an increase in leaching loss occurs with increase in the quantity of leachate collected. Ghildayal (1978) reported that under prolonged submergence in rice culture, the intensity of nitrate leaching depends on the rate of percolation of water through the soil. It was also reported by Pande and Adak (1971) that the nitrate formed gets leached down along with the percolating water and the loss incurred will be about 45 to 60% under pot culture. Miller and Donahue (1992) observed that the leaching loss of nitrate increased as the percolating water increased and when there is little or no growing crop cover to use the nitrate.

4.4. Correlation of leaching loss of nitrogen from soil surface layer alone, with the surface layer soil characteristics.

The maximum root zone depth of a rice plant is only about 10 - 15 cm. With this point in view, a general correlation study is carried out to find out the leaching loss of nitrogen in the surface layer with the physico - chemical properties of the surface layer alone.

The results point out that, as in the case of whole soil columns, all the soil properties, viz., organic matter content (-0.3612), CEC (-0.3651), clay (-0.4459), bulk density (-0.5258) and WHC (-0.8607) has a negative correlation with the leaching loss of applied nitrogen in the surface soil also [Table 13]. However, the leachate collected per unit time has a positive effect

(+0.9942). Among the soil properties, WHC has the highest negative effect and organic matter, the least.

4.5. Runoff loss of nitrogen

A pot study was conducted to estimate the runoff loss of nitrogen from paddy soils. Nitrogen is applied at the rate of 90 kgN/ha (127 mgN/pot) and the surface water is collected from each corresponding unit and analyzed for total nitrogen. The results obtained are discussed below.

Data in table 9 shows that the highest runoff loss of fertilizer nitrogen is observed in the case of Onattukara (40.41%) and the least in the case of Karappadam (15.70%). The decreasing order of runoff loss of fertilizer nitrogen was as follows: Onattukara (40.41%) > Kole (30.80%) > Kari (25.61%) > Pattambi (19.63%) > Kayal (16.55%) > Karappadam (15.70%).

The runoff loss was found to decrease with increase in the period of observation. The maximum runoff loss was noted in the first day (6.15%) and the least on the tenth day (1.97%). More than 50% of the loss occurred within the first five days.

The statistical data from table 9 shows that the maximum mean runoff loss of fertilizer nitrogen is observed from Onattukara soil (6.74%) and the least from Karappadam soils (2.62%). The decreasing order of mean runoff loss percentage of fertilizer

Fig 9. Total runoff loss of Nitrogen

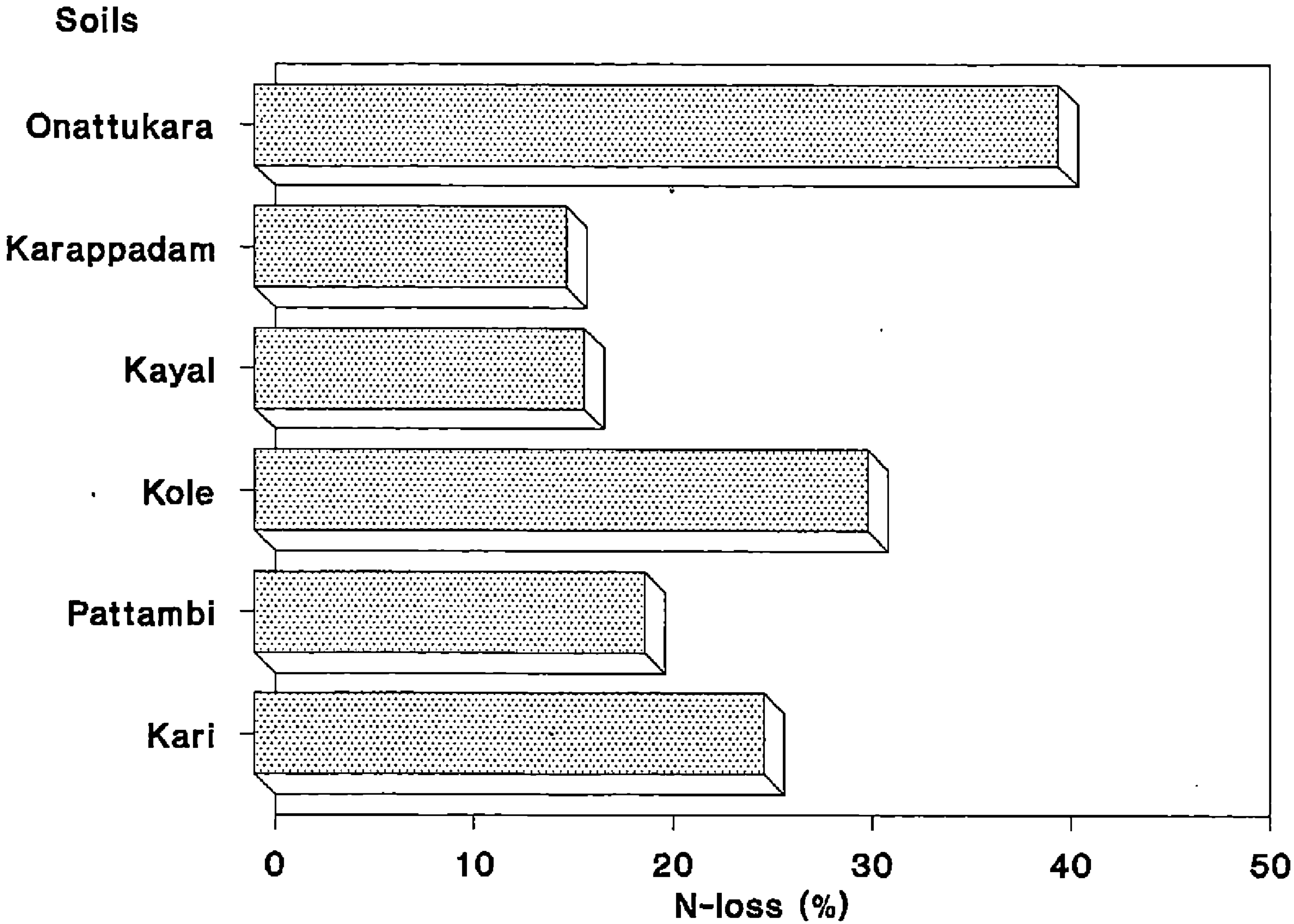
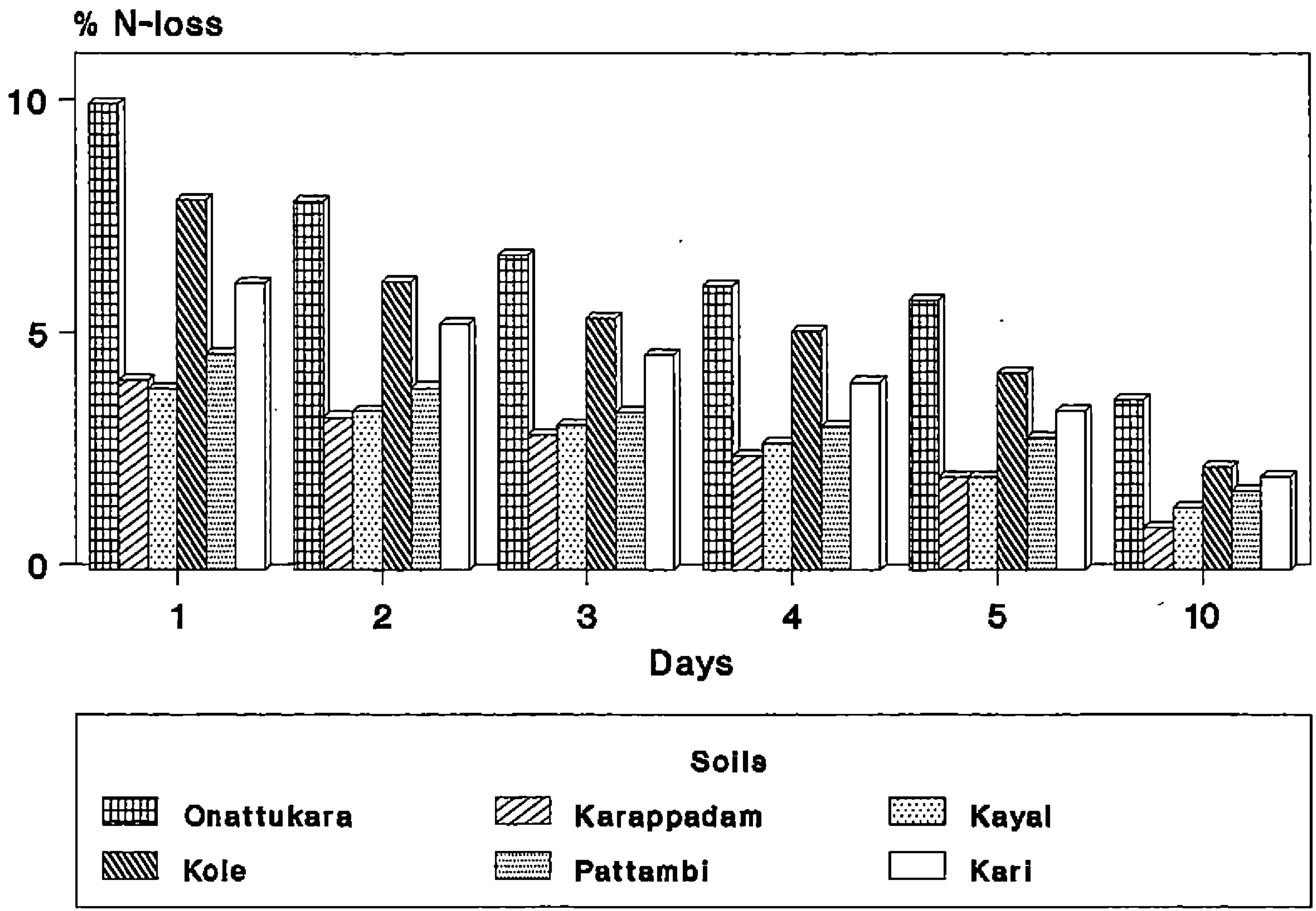


Fig 10. Mean runoff loss of Nitrogen



nitrogen is as follows: Onattukara (6.74) > Kole (5.22) > Kari (4.27) > Pattambi (3.27) > Kayal (2.76) > Karappadam (2.62).

The results obtained reveal that the runoff losses of all the six soils are found to be significantly different. The maximum mean runoff loss occurred on the first day after fertilizer application (6.15%) and the least on the 10^{th} day (1.97%). The runoff loss at each interval is found to be significantly different. For all intervals of sampling, Onattukara soil shows the maximum mean runoff loss, followed by Kole soils. However, Kayal soils showed the lowest runoff loss on the first day only (3.92%). For all other periods of observation, Karappadam soils shows the least runoff loss. The runoff loss of all soils, from each period of sampling is also found to be significantly different from one another.

The percentage reduction in runoff loss of nitrogen during the ten days is found to be maximum for Karappadam (77.78%) soils and it is the minimum in the case of Kari soils (61.337%).

4.5.1. Correlation studies

The data obtained is used to correlate the runoff loss of fertilizer nitrogen with the surface layer soil properties. The results obtained are discussed below (Table 14). The runoff loss of nitrogen is found to be negatively correlated with the organic matter content (-0.1248); CEC (-0.0324); clay (-0.4135); bulk density (-0.4659) and WHC (-0.6723) of the soil.

4.5.1.1. Organic matter

It is found that the organic matter content of the soil has a negative correlation on the runoff loss of nitrogen from paddy soils (-0.1248). This means that , as the quantity of organic matter increases, the runoff loss of nitrogen decreases.

Increasing rates of organic mulch in the soil significantly reduced the runoff loss of nitrogen as per the report of Singh et al. (1984), which is in confirmation with the results of the study.

4.5.1.2. Cation exchange capacity

CEC also has a negative effect on the runoff loss. As CEC increases, the runoff loss of nitrogen decreases.

A study conducted at IRRI (1980) confirmed the present finding and it is observed that when urea super granules is applied to sandy soils with low CEC, high concentration of urea is observed in the flood water.

4.5.1.3. Clay content

The correlation study revealed that as the clay content of the soil decreased, the runoff loss of nitrogen increased.

Chaudhary and Bhatnagar (1976); Goswamy et al. (1984) and Miller and Donahue (1992) reported that in coarse textured soils, the loss of nitrogen through runoff was very high. Kissel et al. (1976) observed that the runoff loss of total nitrogen from a clay soil was very meager.

4.5.1.4. Bulk density

Bulk density also has a negative correlation with the runoff loss of nitrogen. As the bulk density increases, the loss of nitrogen in the runoff decreases.

As the bulk density is increased, the compactness of the soil is increased and it attains a capacity to hold more water in the micropores. This reduces the loss of water as runoff from the surface soil. Studies in TNAU shows that by increasing the compactness of soil, the nutrient losses are reduced to a great extend (Anonymous, 1984).

4.5.1.5. Water holding capacity

The WHC has an r value of -0.6723 for the runoff loss of nitrogen. This indicates that as the WHC of the soil increases the runoff loss of nitrogen decreases. The study conducted by Abhichandini and Patnaik (1958) revealed that the runoff loss of

Table 10. Mean runoff loss of nitrogen (%) from six soils as influenced by period of sampling.

Soil	Period (Days)						Mean
	1	2	3	4	5	10	
Onattukara	10.05	7.95	6.79	6.13	5.83	3.66	6.74
Karappadam	4.10	3.29	2.92	2.47	2.01	0.91	2.62
Kayal	3.92	3.44	3.13	2.72	2.01	1.33	2.76
Kole	7.99	6.23	5.44	5.17	4.26	2.21	5.22
Pattambi	4.66	3.93	3.40	3.09	2.85	1.70	3.27
Kari	6.19	5.31	4.64	4.05	3.42	2.00	4.27
Mean	6.15	5.03	4.39	3.94	3.40	1.97	

CD values

Table 11. Correlation of leaching loss with soil properties in general.

Properties	'r' value
Organic matter	-0.5593
CEC	-0.4560
Clay	-0.5864
Bulk density	-0.3213
WHC	-0.5544
Leachate quantity	+0.8876

Table 12 Soil wise correlation of leaching loss with soil properties.

Properties	Onattukara	Karappadam	Kayal	Kole	Pattambi	Kari
Organic matter	-.5714	-.6133	-.1753	-.2344	-.2414	-.8550
CEC	-.0901	-.9861	-.6495	-.6400	-.5630	-.9992
Clay	-.4168	-.8681	-.4607	-.5549	-.3966	-.9148
Bulk density	-.7244	-.9735	-.8309	-.7359	-.2285	-.7559
WHC	-.0290	-.0666	-.2997	-.3499	-.2307	-.8418
Leachate	+.3300	+.2886	+.0213	+.8322	+.9646	+.9996

Table 13. Correlation of leaching loss of nitrogen from surface layer of soil with surface layer characteristics.

Properties	'r' value
Organic matter	-0.3612
CEC	-0.3651
Clay	-0.4459
Bulk density	-0.5288
WHC	-0.8607
Leachate	+0.9942

Table 14. Runoff loss of nitrogen correlated with surface layer properties.

Properties	'r' value
Organic matter	-0.1248
CEC	-0.0324
Clay	-0.4135
Bulk density	-0.4659
WHC	-0.6723

total nitrogen depended upon the soil water conditions of the rice field.

A comparison of leaching loss of nitrogen from the surface layers and runoff loss was done for comparing these losses [Tables 3 and 9]. The leaching loss from surface layer was taken into consideration since this is the maximum depth of rice root zone. The comparison was done up to the tenth day only since the runoff loss was estimated up to the 10^{th} day.

It can be seen that for all soils except Kayal soils, the leaching loss was found to be more when compared to the runoff loss from surface layer. The runoff loss from Kayal soil was found to be more than that of leaching. In the case of Onattukara, Kayal and Kole soils, the runoff loss was found to be higher from the second day onwards. For Karappadam, Pattambi and Kari soils, the leaching loss was found to be higher for the second day also. Thereafter, the runoff loss became more prominent than the leaching loss.

SUMMARY

An experiment was conducted at the College of Agriculture, Vellayani, to assess the leaching and runoff loss of applied nitrogen from six different rice soils and to correlate these losses with the physico-chemical properties of the soils.

Undisturbed soil columns for percolation study were collected from Onattukara (Entisol), Karappadam (Inceptisol), Kayal (Entisol), Kole (Entisol), Lateritic alluvium, Pattambi (Inceptisol) and Kari (Ultisol) soils in PVC tubes to a depth of 55 cm. For the runoff study, surface samples (0 - 15 cm) were collected from the same locations.

The soil samples at each depth, viz., 0 - 15, 15 - 30 and 30 - 45 cm were collected and analyzed for their physico- chemical properties.

All soils were found to be acidic. The Kari soil was the most acidic (4.15) and the least acidic was Pattambi soils (5.41). The total nitrogen content of the soils varied from 0.07 (Kole) to 0.21% (Kari). The lowest value for available nitrogen was observed for Onattukara soil (148.04 kg/ha) and the maximum value was for Kayal soil (364.98 kg/ha). Onattukara and Kari soils were low in their available nitrogen content, while all others were found to be medium in available nitrogen content. In the case of available phosphorus (P_2O_5), Kayal soils recorded the highest value (27.58 kg/ha) and the lowest was by Onattukara soil (14.36 kg/ha). All soils except Kayal and Pattambi soils were found to be medium in their phosphorus content. Onattukara soils had the lowest value (70.04 kg/ha) of available potassium (K_2O), while the highest was for Kayal soil (184.13 kg/ha). Kari, Kole and Onattukara soils were found to be low in available potassium content, while those of Kayal, Pattambi and Karappadam could be classified as medium in potassium status. Karappadam soils registered the highest value for exchangeable calcium and magnesium (4.2, 3.15 cmols/kg). Onattukara soil had the lowest exchangeable calcium content of 1.2 cmols/kg, while Pattambi soils had the lowest value for exchangeable magnesium content (0.41 cmols/kg).

The sand content of Onattukara soil was found to be the highest (74.66%), while Karappadam and Kayal reported the lowest (22.33%). Again, Onattukara soil had the lowest silt and clay content (33.33, 11.66%). Kayal soil recorded the maximum value for silt content (33.33%) and Pattambi soil recorded the maximum value for clay content (48.33%). Kayal soil had the lowest particle density of 2.3 g/cc, while Kole had the maximum value (2.6 g/cc). Onattukara soil had the lowest bulk density value of 1.19 g/cc, while Karappadam soil recorded the maximum (1.72 g/cc). Kayal soil had the highest value of WHC (49.36%) and the least was for Kole soil (17.42%). Porosity was found to be the maximum for Onattukara soil (54%) and it was the lowest in the case of Kayal soil (29%).

Percolation studies revealed that Onattukara soil was showing the highest percentage of leaching loss of nitrogen (56.10) followed by Kole (54.65), Kari (47.73), Pattambi (36.42), Karappadam (31.09) and Kayal (24.21) soils. For all soils except Pattambi, the leaching loss decreased with depth. In the case of Pattambi soils, the loss increased in the second layer and again decreased in the third layer.

In the case of Onattukara soils, leaching loss from the first depth stopped after the fifth day. However, for the two lower depths of Onattukara and all the three depths of Kole soil, the leaching loss stopped on the 10^{th} day onwards. In the case of Kari soils, leaching stopped on the 15^{th} day and in the case of Karappadam and Pattambi soils, it was on the 20^{th} day. In Kayal soils, leaching loss continued till the 20^{th} day.

As the depth of the soil column increased, the leaching loss also decreased. The maximum leaching loss, irrespective of soil depth was recorded in the first layer (2.43%) and the least in the third layer (0.98%). In the case of intervals of observation, the maximum leaching loss for all soils was noted on the first day (6.54%) and the lowest on the 20^{th} day (0.02%). The maximum leaching loss occurred within the first five days, i.e., 94.48 % for 0 - 15 cm, 85.71% for 15 - 30 cm and 59.49% for 30 - 45 cm layers. The analysis of soil for residual nitrogen showed no increase from the initial values for each depth, showing that the added nitrogen was not sufficient to produce any appreciable rise in the total amount of nitrogen in the soil. The difference in leaching for the three depths was found to be maximum for Kayal soils (76.6%) and the lowest in the case of Onattukara soils

(26.74%).

The correlation studies reveal that the leaching loss of nitrogen in all soils was negatively correlated with the physico-chemical properties of the soil like organic matter (-0.5593), cation exchange capacity (-0.4560), clay (-0.5864), bulk density (-0.3213) and water holding capacity (-0.5544).

The mean values fo the quantity of leachate collected per unit time, showed that the maximum quantity was collected in the case of Onattukara (185.51 ml) and the least in the case of Kayal soil (155.60 ml). The maximum leachate was observed in the first depth (170.04 ml) and the lowest in 30 - 45 cm depth (166.23 ml). The maximum amount of leachate was collected in the third day (169.27 ml) and the lowest on the first day (167.02 ml). Correlation studies revealed that the leaching loss of nitrogen was found to be positively correlated with the volume of leachate collected per unit time (+0.8876).

The correlation of leaching loss of nitrogen from surface layer (0 - 15 cm) with the surface layer characteristics shows that the leaching loss was negatively correlated with all the soil properties, viz., organic matter (-0.3162), CEC (-0.3651), clay (-0.4459), bulk density (-0.5258) and WHC (-0.8607). The leachate collected per unit time was the only factor which had an 'r' value of +0.9942.

The data from runoff study shows that the highest runoff loss of applied nitrogen was noticed in the case of Onattukara soils (40.41%) and the least in the case of Karappadam (15.70%). The decreasing order of runoff loss of nitrogen was as follows: Onattukara (40.41%) > Kole (30.80%) > Kari (25.61%) > Pattambi (19.63%) > Kayal (16.55%) > Karappadam (15.70%). The runoff loss of nitrogen was found to decrease with increase in period. The maximum mean runoff loss was noted in the first day (6.15%) after fertilizer application and the least on the 10th day (1.97%). The percentage reduction in runoff loss of nitrogen during the course of the experiment was found to be maximum for Karappadam (77.78%) and was the lowest for Kari soils (61.37%). Correlation studies reveal that the runoff loss of nitrogen was negatively correlated with the soil properties such as, organic matter (-0.1248), CEC (-0.0324), clay (-0.4135), bulk density (-0.4659) and Water holding capacity (-0.6723).

The results show that the maximum loss of applied nitrogen by leaching and runoff takes place in Onattukara soil, because of its high sand content, low values for organic matter, CEC, Clay, WHC and bulk density. Kayal soils showed the lowest leaching loss and Karappadam soil the lowest runoff loss. This maybe because of their high clay content, organic matter, bulk density CEC and low sand content, when compared to that of Onattukara soils.

It may be seen that Onattukara soil shows the highest leaching loss of applied nitrogen. To reduce the loss of nitrogen by leaching, management practices like addition of organic matter should be followed in advance to reduce the leaching los. As far as leaching of nitrogen is concerned, the Kayal soil was found to be the soil with the least leaching loss of applied nitrogen.

From the runoff loss study, it was found that, Onattukara soil showed the highest loss of applied nitrogen by runoff and the least by Karappadam soils.

The studies can be further done with other sources of fertilizer nitrogen, with or without crop and with different waterheads.

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APPENDICES

APPENDIX I

ANOVA table for leaching loss of applied nitrogen.

Source	Df	SS	MSS	F
A	5	159.845	31.969	589.326
B	2	173.187	86.594	1596.291
AB	10	21.058	2.106	38.819
Error 1	36	1.953	0.054	
C	7	1831.298	261.614	7274.871
AC	35	912.994	26.086	725.378
BC	14	579.041	41.360	1150.126
ABC	70	164.963	2.357	65.532
Error2	252	9.062	0.036	

A = Soil B = Depth C = Period

APPENDIX II

ANOVA table for runoff loss of applied nitrogen.

Source	DF	SS	MSS	F
A	5	232.153	46.431	12171.490
B	5	183.412	36.683	9616.321
AB	25	21.423	0.857	224.699
Error	72	0.275	0.003	

A = Soil B =,Period

APPENDIX III

ANOVA table for quantity of leachate collected.

Source	Df	SS	MSS	F
A	5	43800	8760	362.483
B	2	1072	536	22.179
AB	10	2800	280	11.586
Error 1	36	870	24.18	
C	7	200	25.571	1.814
AC	35	734	20.971	1.331
BC	14	266	19.000	1.206
ABC	70	744	10.623	0.675
Error2	252	3969	15.750	

A = Soil B =Depth C = Period

VERTICAL MOVEMENT OF NITROGEN IN MAJOR RICE SOILS OF KERALA

BY

GEORGE T. ABRAHAM

ABSTRACT OF THE THESIS

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An experiment was conducted at the College of Agriculture, Vellayani, to assess the leaching and runoff losses of applied fertilizer nitrogen in typical, major rice growing soils of Kerala, with varying physical and chemical properties. Undisturbed vertical columns were used for the leaching study. The runoff study was conducted as a pot experiment using surface soil samples.

The study revealed that the Onattukara soil recorded the highest leaching loss of applied nitrogen (56.10%). Kayal soil showed the lowest leaching percentage of 24.21. The quantity of leachate collected per unit time was also found to be the maximum in the case of Onattukara soil (185.51 ml/hr) and least in the case of Kayal soil (155.60 ml/hr). Correlation studies revealed that the leaching loss of nitrogen was negatively correlated with organic matter (-0.5593), cation exchange capacity (-0.4560), clay (-0.5864), bulk density (-0.3213) and water holding capacity (-0.5544). The leaching loss was positively correlated with the quantity of leachate collected per unit time (+0.8876). In the case of Onattukara and Kole soils, the loss of nitrogen through leaching was observed till the fifth day. For Kari soils, the loss stopped completely by the 10th day. The Karappadam and Pattambi soils showed leaching till the 15th day. However, in the case of Kayal soils, the leaching loss continued through the whole period of the study. In all cases, maximum amount of leaching occured during the first five days after fertilizer application and after that the loss was in negligible quantities.

In the case of runoff study also, Onattukara soil showed the highest runoff loss of applied nitrogen (40.41). The least loss was shown by Karappadam soil (15.70%). The runoff loss was found to decrease with increase in number of days. Even though, Karappadam soils showed the lowest runoff loss of applied nitrogen, it had the highest percentage difference in runoff loss (77.8%) and the least was shown by Onattukara and Pattambi soils (63.5%). Correlation studies revealed that the runoff loss of fertilizer nitrogen was found to be negatively correlated with the oprganic matter (-0.1248), cation exchange capacity (-0.0324), clay (-0.4135), water holding capcity (-0.6723) and bulk density (-0.4659).