विभिन्न पोषक तत्व प्रवंधन विकल्पों के अंतर्गत एल्फीसॉल मिट्टी में मक्का एवं बैंगन फसल में पोषक तत्वों की निक्षालन क्षति

Leaching loss of nutrients under different nutrient management options in maize and brinjal on an Alfisol

By
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DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
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Leaching loss of nutrients under different nutrient management options in maize and brinjal grown on an Alfisol

By

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A Thesis submitted to the Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi, in partial fulfilment of the requirements for the degree of

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CERTIFICATE

This is to certify that the thesis entitled ***“Leaching loss of nutrients under different nutrient management options in maize and brinjal grown on an Alfisol”*** submitted to the Faculty of the Graduate School, ICAR–Indian Agricultural Research Institute, New Delhi in partial fulfilment of the requirements for the degree of **Master of Science in Soil Science and Agricultural Chemistry**, embodies the results of *bonafide* research work carried out by **Mr. Subhajeet Sarkar** under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.

It is further certified that assistance and help obtained during the course of investigation as well as source of information have been duly acknowledged by him.

Date:11.09.2023
Place: Jharkhand

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	Per cent
°C	Degree Celsius
et al.	*Et alia* (and other)
fig.	Figure
i.e.	id est (That is)
LSD	Low standard deviation
sp.	Species
mm	Millimeter
cm	Centimeter
SEm±	Standard error of mean
EC	Electrical conductivity
ml/L	Millilitres per Litre
Ppm	Parts Per Million
DMRT	Duncan’s Multiple Range test

Chapter 1 Introduction

Chemical fertilizers are increasingly being used in agriculture due to crop intensification in both undeveloped and developed nations. Our agriculture needs to be modernized and developed to be more productive than present-day agriculture to appropriately feed the growing population and supply resources for rapid economic development. Therefore, agricultural practices must be both economically and environmentally sustainable. Agricultural effects on the environment, particularly those of high-input row crop practices, have drawn a lot of attention. Every plant needs a specific number of nutrients to grow. The potential yield may rise if the fertilizing intensity is increased. However, this yield eventually hits its limit, and further increases in fertilizing intensity have the opposite effect—they increase the costs rather than increase the yield. There is an additional cost to the ecosystem in addition to the obvious expenses of fertilizer and all farming-related activities (Heisler *et al.,* 2008; Howarth, 2008). Agriculture practices like increasing the use of inorganic fertilizer at the expense of severe groundwater pollution pose a serious threat to the ecosystem (Tilman *et al.,* 2002). Through the leaching of soluble nutrients deeper into the soil profile, the nutrient loss from the application of inorganic fertilizer reaches the groundwater. Nutrient leaching is the downward movement of dissolved nutrients with percolating water below the root zone in the soil profile. Leaching requires that the water content exceeds the field capacity with a positive water balance, which means that irrigation or rainfall input must be greater than evapotranspiration. One of the main issues with agricultural systems throughout the world is the loss of nutrients through leaching (Dominguez, 2004; Di and Cameron, 2002). Leaching causes the nutrients to be abandoned in the rhizosphere, which prevents the plants from using them any longer. Leaching also raises the danger of phosphorus and nitrogen compounds contaminating above- and below-ground waters.

With 65% of its population involved in agriculture, India is primarily an agricultural nation. Until the middle of the 20th century, organic manure was mostly used in Indian agriculture. Chemical fertilizer usage has significantly increased as a result of the construction of irrigation systems in the 1960s and the introduction of contemporary, high-yielding varieties. Nutrient leaching is especially common in soils having higher infiltration capacity and poor nutrient retention capacities, such as sandy soils and well-structured ferritic soils having low-activity clays and low organic matter contents (von Uexkull *et al.,* 1986). Most Indian soils, deficient in organic matter, have a poor capacity for holding nutrients, making them vulnerable to excessive nutrient leaching. By limiting rooting depth, subsoil acidity also tends to enhance nutrient leaching. According to estimates by Biswas *et al.* (2019), there are approximately 25 million hectares in India with a pH below 5.5 and 23 million hectares with a pH between 5.6 and 6.5. High-intensity irrigation and rainfall have a considerable negative impact on nutrient leaching. In India, just the monsoon season accounts for 75% of the rainfall. The flooding and high-intensity rainfall in a short window of time caused increased nutrient losses. The majority of farmers use check basins and flooding to irrigate their fields, which increases positive water potential and causes substantial nutrient loss through drainage and leaching.

The acidic sandy loam soils of Jharkhand are prone to leaching loss of nutrients. Soil acidity is one of the causes of the leaching loss of nutrients. Around 47.5% of the land in Jharkhand has a pH lower than 5.5, and 36.2% of the land has a pH between 5.5 and 6.5 (Jha *et al*., 2012). In this case, subsoil acidity is particularly widespread; the pH can be as low as 4, which adversely inhibits root growth. In this area, nutrient leaching is intensified by soil acidity, poor organic matter, sandy soil texture, and high rainfall.

The nutrient mobility in the soil increases its chances of leaching. Because it has little interaction with the negatively charged matrix of the majority of the topsoil and due to higher mobility in the soil, nitrate is one of the nutritional anions that is particularly quickly leached. Even in acidic soils, nitrate can become the dominant form of mineral nitrogen due to the varied nitrification rates found in tropical soils (Schroth *et al.,* 1999). Nitrate is also particularly vulnerable to leaching in seasonal climates because rewetting of dry soil frequently results in a mineralization flush of organic nitrogen that releases significant amounts of nitrate into the topsoil. Leaching may therefore have a large role in negative nitrogen balances of agricultural systems (Smaling *et al.,* 1993).

Sulphur has also been documented to undergo a mineralization flush upon rewetting dry soil (Havlin *et al.,* 1999). Sulphate is frequently leached from the top soils, with losses being highest in those with monovalent cations predominating (potassium) and lowest in those with significant levels of aluminium (Havlin *et al.,* 1999).

With the exception of some highly sandy and organic soils, leaching is minimal for phosphate because, in contrast to nitrate and sulphate, phosphate is immobile in most soils due to precipitation and adsorption to mineral surfaces (Wild, 1988). Phosphate is less mobile in soil than dissolved organic phosphorus forms (Havlin *et al.,* 1999). If soil particles at the earth surface get eroded by runoff, phosphorus may also be lost. Although excessive phosphorus treatments to soils with low P sorption capabilities increase the danger of phosphorus loss by leaching, phosphorus leaching losses from naturally drained soils can still be harmful to the ecosystem, even though they are less of an immediate hazard. This is especially true for sandy soils with low sorption capacities that receive substantial amounts of phosphorus.

Due to the electrical neutrality of the percolating soil solution that transports nutrients down the soil profile, anions are leached with corresponding amounts of cations. The two cations that leach from soils most frequently are calcium and magnesium. In West African savanna soils, there are strong correlations between the concentrations of calcium and magnesium combined and nitrate in the soil solution below the crop rooting zone. This suggests that nitrate fluxes and, to a lesser extent, chloride fluxes play a significant role in regulating calcium and magnesium leaching in these soils (Pieri, 1989). After applying potassium chloride or potassium sulphate fertilizers to sandy soils, significant amounts of magnesium may leach out (Havlin *et al.,* 1999). Potassium often leaches in considerably lesser amounts than calcium and magnesium, and in the research noted above in West Africa, it was not linked to nitrate fluxes. However, locations with high rainfall and sandy and organic soils may experience substantial potassium leaching (Malavolta, 1985).

The eastern plateau and hill region, which includes the states of Jharkhand, Chhattisgarh, and Odisha, has production constraints. The major production constraints for uplands include soil erosion and acidity, a lack of precipitation, and a scarcity of nutrients. Numerous variables, such as soil type, climate, water regime, amount and kind of fertilizer applied, land use system, and cultivable plant species, all have an impact on nutrient leaching loss. In order to increase the sustainability of crop production on soils with low water and nutrient-holding capacity, proper N and K fertilizer application and irrigation management can reduce nitrate and potassium leaching while preserving crop output.

Even though it is generally known that the majority of nutrients are mobile in soil and susceptible to leaching, their leaching losses have received the least attention. The majority of research on nitrate leaching behaviour is limited to examinations of the soil column without crops. Different rates of nitrogen uptake by plants from the soil and fertilizer occur during the crop growth cycle. The leaching loss of nutrients is substantially impacted by the various rooting behaviours of different crops. There is a dearth of research on simultaneous leaching loss estimation in crop-growing environments. In order to comprehend adsorption, mobilization, and nutrient leaching losses under various soil conditions, more research is required. With this context in mind, this investigation was undertaken.

Keeping all the above-mentioned points in view, the present investigation was carried out in the field at ICAR-Research Complex for Eastern Region, Farming System Research Centre for Hill and Plateau Region, Plandu, Ranchi, Jharkhand to have comprehensive information on nutrient mobility and quantify the leaching losses in different nutrient management options during crop growing period with the following objectives: -

1. To assess the effect of different nutrient management practices on leaching loss of major nutrients from soil under brinjal and maize crop

2. To study the effect of nutrient management practices on depth-wise distribution of available nutrients in post-harvest soil

Nutrient leaching depends on various factors like soil types, moisture content, and crop types. Relevant literature regarding the present investigation is reviewed under the following subheadings.

2.1 Nutrient leaching loss under different nutrient management

2.2 Nutrient leaching loss affected by soil properties

2.3 Effect of weather on nutrient leaching loss

2.4 Effect of vegetation on nutrient leaching loss

2.5 Effect of cropping system on nutrient leaching loss

2.6 Effect of manure on nutrient leaching

2.7 Effect of trees on nutrient leaching loss

2.1 Leaching loss under different nutrient management

The risk of nutrient leaching losses under humid tropical conditions is very high when generous rates of fertilizer are applied on freely draining soils of low exchange capacity. The nitrogen mineralization from applied fertilizer as nitrate as well as from atmospheric deposition plays a decisive role in leaching nitrate with the seepage water. The surplus nitrogen contained in the soil originates from previous intensive cultivation and is not efficiently utilized by plants. Consequently, this excess nitrogen is prone to be leached with seepage water.

Meissner *et al.* (1998) conducted a 3-year lysimeter study at field research station in Falkenberg, Saxony-Anhalt, Germany to obtain information on the impact of intensively-farmed drinking water protection areas on water resources. The treatments contain 10 lysimeters treated with permanent fallow (previously subjected to intensive farming), 10 lysimeters treated as ratoon fallow (previously subjected to intensive farming) and 10 lysimeters treated according to BMP (best management practices). Though all the lysimeter plots received the same amount of nutrients, the highest nitrate leaching loss was measured after three years under rotation fallow and even in the case of permanent fallow, the total amounts of nitrate leached were only approximately 6% below the values for BMP. As phosphate is bonded by specific adsorption with clay, therefore, changes in the farming scheme did not show any significant short-term impact on the leaching behaviour of phosphates. Irrigation and fertilization also have a promoting impact on sulphate leaching. This became clear when comparing the high level of sulphate leaching in the BMP treatment with the decreasing tendency in the case of the permanent fallow. Furthermore, ending the rotation fallow and resuming intensive cultivation was also connected with an increase in sulphate leaching.

An experiment was conducted in Jaboticabal, state of São Paulo, Brazil by Ghiberto *et al.* (2015) in an Ultisol (Arenic Kandiustults) for quantifying the leaching of N and S with the help of tensiometers and soil-solution extractors with porous cups. The increase in the contribution of different N-containing ionic species was identifiable and reflects the influence of N fertilization on the soil solution at 0.9 m depth, and increased mainly due to the increase in the NO_3^- concentration. The leaching of N was between 3.9 and 34.9 kg ha^{-1}. The mean percentage of fertilizer-derived N in the soil solution was 34.9%. The N leached derived from the 100 kg ha^{-1} applied N fertilizer was 22.5 kg ha^{-1}. The S leached was between 4.6 and 8.4 kg ha^{-1}. The mean percentage of fertilizer-derived S in the soil solution was 19.24%. The maximum leaching of P, K, Ca, and Mg were 1.2, 53.6, 135.7 and 39.8 kg ha^{-1}, respectively.

Another lysimeter-based study was conducted during the 1985-1992 period at the Agricultural University of Norway by Uhlen *et al.* (1994) to observe the effect of fertilization on nutrient leaching with the application of different graded doses of nitrogen ranging from 0-16 g m^{-2} in 10 lysimeter plots. In every treatment, oats were grown in 1985 followed by spring wheat, in the subsequent six years and in 1992 a barley crop was taken with no nutrient application for measuring possible residual effects. The leached amounts of nitrogen were influenced by nitrogen fertilizer rates increased with application, ranging from 6-8 to 10-12 g N m^{-2}. Following the application of higher fertilizer doses, the leached sulphur and chloride content did not change but nitrate content varied significantly.

Fertilizers play a crucial role in enhancing agricultural productivity by providing essential nutrients to plants. However, the excessive and improper use of fertilizers can lead to environmental issues, one of which is nutrient leaching. Wong *et al.* (1992) carried out research work with twelve undisturbed monolith lysimeters with a Typic Paleudult soil in IITA, Nigeria to measure the nitrogen loss using ^{15}N isotopes. Out of the 12 lysimeters, 8 were cropped with maize, followed by rice (treatment A) and the rest 4 were left fallow (treatment B). Two of the uncropped lysimeters received ^{15}N-labelled urea in the first season (treatment C) and the remaining two in the second season (treatment D). In the cropped lysimeters, Ca was leached in the greatest amount, the average total for the 2 seasons being 312 kg ha^{-1} in treatments A and B. The corresponding average amounts of Mg, K, Na, NO_3-N and Cl were 31, 33, 35, 144 and 110 kg ha^{-1} respectively. Much more nitrate was leached in the second season than in the first. Urea increased the amount of nitrate leached under the bare lysimeters from 131 kg NO_3-N ha^{-1} in treatment D to 236 kg NO_3^- N ha^{-1} in treatment C. The increase was equivalent to an additional 7.5 $kmol_c$ of nitrate ions ha^{-1} in the drainage water which was lost mostly with the equivalent amount of calcium and magnesium in the second season. As the bulk of the nitrate was derived from the soil, the mineralization of organic nitrogen and its nitrification had a bigger effect than the fertilizer in carrying basic cations into the drainage water. However, the acidifying fertilizer still carried with it a significant amount of cations.

2.2 Nutrient leaching loss affected by soil properties

Soil properties like buffering capacity, fixation capacity, and capacity to release non-exchangeable fractions are important for future balance and nutrient losses. Soils having high fixation capacity increase the storage by fixation thus reducing leaching losses. Particle size, mineralogy, organic matter level, pH or lime status also influence the nutrient leaching loss. The nutrient leaching loss is further influenced by the thickness of successive soil horizons or depth of the cultivated layer, soil density and the root volume. The soil porosity and topography affect the movement of nutrients on the soil surface as well as in different soil depths. The degree of leaching is related to the soil physical and chemical characteristics, viz., sandy texture, low organic matter content (< 2%), low pH and, low effective cation exchange capacity (< 1.5 me/100 g).

2.2.1 Nutrient leaching loss affected by soil types

Kemppainen (1995) studied the effects of soil type, spreading time and use of a nitrification inhibitor (Didin) on the leaching and uptake of nitrogen and phosphorus from cow slurry and fox manure in a lysimeter. Less water percolated through lysimeter soils fertilized with fox manure than through those fertilized with cow slurry. More ammonium N, organic N and total N leached from manure-treated peat soil than from fine sand soil. Peat soil was superior to fine sand soil with respect to nutrient storage. The leaching of ammonium N was about 50 times more from peat soil than from fine sand soil due to significant mineralization of its organic nitrogen and partly to manure ammonia. Owing to the low pH, ammonia oxidized slowly in peat and there was no significant difference in the leaching of nitrate N. Nitrification inhibitor, Didin did not decrease nitrogen leaching. The amount of total phosphorus leached from manure-treated peat soil was 23 times that from fine sand soil due to the low P-fixing capacity of peat soil. The difference in the leaching of soluble phosphorus was 39-fold. More phosphorus leached from fox manure than from cow slurry though nitrogen leaching did not vary significantly. In fine sand soil, leaching of total P was very low (100 g ha^{-1}) irrespective of manure type. There were no differences found between spring and autumn application of phosphorus, while, nitrogen leaching was highest in autumn application than spring.

Another study conducted by Meissner *et al.* (1995) demonstrated the influence of mineral fertilizers and different soil types by using a lysimeter experiment at Falkenberg, Germany. The highest seep-water quantities were measured in the lysimeters with sandy soil and the lowest in clay-sandy soils. This can be attributed to the physical characteristics of soil and to the water efficiency of the crops planted. Significant differences occurred between lysimeters simulating arable land and those simulating grassland. However, a decrease in the seepage in loess and clayey soil types due to increased water consumption by the plants with greater nutrient supplies. The lowest average yearly N loss of 6 kg ha^{-1} yr^{-1} was found in clay sand under grassland, and the highest average loss of 24 kg ha^{-1} yr^{-1} was found in the sandy soil of arable land. Arable land use on soil types, clay-sand and sand was generally characterized by significantly higher N leaching compared with clay and loess. Statistically reliable increased P leaching of sand compared with the other soil types due to less absorption of P by sand and to the increased seep-water volume. An increased soil moisture content (due to applied irrigation) enhances P solution reactions and improves the migration capability of phosphorus in sandy soil types. Grassland use had significantly higher P leaching compared with arable land use. Significantly increased K leaching was found on soil-type clay-sand compared with sand, clay and loess. K leaching was significantly increased under intensive grassland due to the high supplementary watering compared with water use in the grain-fodder crop rotation. The highest K leaching was found at the 50 per cent fertilization level in grassland.

2.2.2 Effect of CEC on nutrient leaching loss

The higher the CEC of soil, the more cations it can hold. This means that soils with high CEC are less likely to leach nutrients, as the cations are more tightly bound to the soil particles. Conversely, soils with low CEC are more likely to leach nutrients, as the cations are more easily released into the soil solution.

Farina and Graven (1973) reported losses of potassium by leaching up to 100 kg K $ha^{-1}yr^{-1}$ below the rooting depth in sandy loam soil, which was attributed to low CEC. As the surface horizon is not capable of fixing significant quantities of K, such losses were presumably due to movement down the profile. Failure of K dressings to maintain the original K status of the unfertilized soil was probably the result of other fertilizer materials increasing competition for exchange sites. Applications of N and P, resulted in highly significant decreases in the level of exchangeable K on soil K status. These K losses did not lead to any concomitant increase in the K status of lower horizons.

Liu *et al.* (2008) demonstrated that increasing NH_4^+ fixation can be a way in building up an available N pool in soils to optimize crop recovery and minimize N losses into the environment. The NH_4^+ adsorption by soil clay minerals after SOC oxidization accounted for 60 to 158% of that by unoxidized soils, suggesting a more important role of soil minerals than SOC on NH_4^+ adsorption. The phenomenon of temporary fixation and release of added fertilizer NH_4^+ may contribute to retard nitrification and thus reducing N losses from the soil–plant system via NO_3^- leaching and denitrification (N_2, N_2O).

Fischer *et al.* (1981) in an incubation study at Insrirur fur Bodenkunde and Chemisches Institut, Germany concluded that the losses of added fertilizer N (NH_4^+) were more than double in a Histosol with extremely low NH_4^+-fixing capacity as compared to that from clay containing Gleysol with high fixing capacity. In all incubation periods, exchangeable as well as NaOH and HCI-soluble N fractions were higher in the Histosol, whereas the gley soil contained more fixed NH_4^+. In the gley soil, the major part of the added N (47 per cent) was present in the fixed ammonium fraction, even after only 3 days' incubation but it was insignificant in the case of histosol. There was a very rapid loss of nitrogen during the first days, presumably caused by nitrification/denitrification at the high concentration of NH_4^+, ion in soil solution, and was more pronounced in the histosol.

2.2.3 Effect of soil pH on nutrient leaching loss

Soil pH significantly influences nutrient availability and solubility. Acidic soils tend to release more nutrients into the soil solution, increasing the potential for leaching. In contrast, neutral to alkaline soils can immobilize nutrients, reducing leaching loss. Soils of similar mineralogy are likely to have a smaller CEC when acid than alkaline, thus acid soils can hold less exchangeable potassium. Also, Ca^{2+} ions occupy a larger proportion of the CEC in neutral than in acid soils and K^+ can more readily replace Ca^{2+} than $A1^{3+}$ or H^+ ions. Thus again, more potassium will be retained in exchangeable form in alkaline soils.

Johnston (1988) summarised data from laboratory experiments from long-term at Rothamsted, which had very similar clay contents and mineralogies but different pHs, ranging from 5 to 8. The increasing amounts of K were added to the soils and were put through a 12-week cycle of alternate wet and dry periods each lasting one week. For each soil, the proportion of the added K which remained exchangeable was independent of the amount of K added and about 15% of the exchangeable K was water soluble. However, a larger proportion of the added K remained exchangeable in the acid soils, pH 5 to 6, than in the neutral soils, pH 7 to 8. Therefore, more of the K added to the acid soil was water soluble and at risk of leaching down the profile.

Bellini *et al.* (1996) showed that the application of lime led to reduced anion-exchange capacity and that Cl^-, NO_3^- and SO_4^{2-} appeared rapidly in the leachate, suggesting the release of anions previously held at exchange sites. The study was conducted in columns packed using a highly weathered soil from clayey, kaolinitic, thermic Typic Kanhapludult with different treatments of lime addition $0(L_0)$, $0.416(L_1)$, $1.04(L_2)$, $2.08(L_3)$ g $Ca(OH)_2$ kg^{-1} of soil which significantly increased pH and resulting an increase in CEC, a decrease in AEC by increasing net negative charge in the soil.

2.2.4 Effect of soil profile characteristics on nutrient leaching loss

Laboratory leaching experiments were conducted by Qafoku and Sumner (2001), with disturbed subsoil samples collected from different parts of the world, and examined the possible effect of the application of lime and P fertilization on generating a negative net charge. They observed that the nitrate salt retention was high in Japan soil treatment, rich in amorphous colloids and the gibbsite had the highest AEC among the treatments. The results show that the transport of $Ca(NO_3)_2$ was affected by soil mineralogy and chemistry. The magnitude of salt retention was higher in subsoils with appreciable AEC and equivalent amounts of CEC, where both kaolinite and Al/Fe oxides dominate the clay fraction. The cation and anion of the leaching electrolyte (Ca^{2+} and NO_3^-) adsorbed in the subsoil layer with no net release of other ions from exchange sites.

In a leaching study done by Martin *et al.* (1997) in a soil column using flooding-draining-leaching cycles procedure conducted in a histosol (euic, hyperthermic, lithic Medisaprists) of Florida. With treatments having different drainage conditions, it was noticed that watertable depth affected the NO_3^- release but was not significant in the case of ammonium and total organic carbon. The leaching of dissolved phosphate may be triggered by high groundwater levels or flooding causing reduced conditions in the soils.

Chakravorty *et al.* (2011) studied the environmental risk of P loss from different soil horizons, by using a modelling approach in the soil profile. The soil P storage capacities of the surface horizons are lower than those of B_h horizons, with a maximum value of 160 mg kg^{-1}, compared to 600 mg kg^{-1} for the B_h. As the spodic horizons have a higher P retentive capacity than surface horizons, once the P sorbing sites get saturated due to excess P loading, spodic horizons will release P and hence will be a P source.

Another lysimeter study filled with loamy soil was conducted by Uhlen *et al.* (1994) in Norway with different doses of nitrogen application in 20 lysimeters. The total leaching loss was 16 g N m^{-2} and varied from 4 to 12 g N m^{-2} in a seven-year period. The leached amounts of nitrogen were little influenced by N fertilizer rates from 6-8 to 10-12 g N m^{-2}. Higher rates increased leaching to about 20% of the total added N. In the absence of nitrogen addition, the nitrate content of the leachate increased during the period with no crops significantly higher in the winter when as much as 4.4 g N m^{-2} was leached from the lysimeter cells without any N being added. The total N loss without any addition of N recorded 10 g m^{-2} yr^{-1}. Large amounts of SO_4^{2-}-S, like those of NO_3^--N, are apparently liberated from the soil reserves. The higher net loss of sulphur for the No treatment than for the high-yielding treatments was attributed to a higher leaching volume combined with a high SO_4^{2-}-S concentration in the leachates. This could indicate that a proportion of the sulphate originates from deeper layers in the soil.

2.3 Effect of weather on nutrient leaching loss

One of the primary drivers of leaching loss is precipitation. Heavy and prolonged rainfalls can saturate the soil, leading to excessive water flowing through the soil profile, carrying essential nutrients like nitrogen, phosphorus, and potassium along with it. Soil temperature can also impact leaching loss. Warmer temperatures increase the rate of microbial activity, which, in turn, accelerates the breakdown of organic matter and the mineralization of nutrients. As a result, the availability of nutrients in the soil increases, making them more susceptible to leaching when excessive rainfall occurs.

Jabloun *et al.* (2015) conducted a study on the effect of variation in seasonal temperature and precipitation on soil water nitrate (NO_3^--N) concentration and leaching from winter and spring cereals cropping systems that was investigated over three consecutive four-year crop rotation cycles. Nitrate concentration and leaching were shown to be site-specific and driven by climatic factors and crop management. There were significant effects on annual N concentration and NO_3^--N leaching of location, rotation, previous crop and crop cover during autumn and winter. Precipitation during autumn, spring and summer significantly ($P < 0.001$) affected N leaching for both winter and spring cereals with the cumulative precipitation during autumn and spring having the greatest effect on N leaching for winter and spring cereals, respectively. A sensitivity analysis revealed that the predicted N concentration and leaching increased with an increase in temperature and precipitation due to a higher mineralization rate and higher leachate volume respectively, though there was a dilution effect with an increase of rainfall.

A column study of Ultisol and Oxisol in Thailand, by Nawaz *et al.* (2015) concluded that acid deposition caused by rainfall increases the proneness of cation leaching. The effect of acid rain studied with different treatments of acidic solution showed that leaching losses of nutrients increased significantly (p-value < 0.001) as the pH of applied solutions decreased. Maximum depletion of potassium was found under acidic treatment with pH 2, amounting to 18.6 mg kg^{-1} in Oxisol. Highly acidic treatment (pH 2) depleted high amounts of Ca^{2+} around 2215.2 mg kg^{-1} in Oxisol and 263.1 mg kg^{-1} in Ultisol. A moderately acidic solution (pH 3.5) also depleted a significant amount of Ca^{2+} losses and was found at 341.4 mg kg^{-1} in Oxisol and 139.45 mg kg^{-1} in Ultisol. Highly acidic treatment of pH 2 induced profound leaching losses of Mg^{2+} of 291.9 and 63.6 mg kg^{-1} from Oxisol and Ultisol, respectively. Higher cations were lost due to a decrease in cation exchange capacity with an increase of acid deposition.

2.4 Effect of vegetation on nutrient leaching loss

Vegetation, especially plants with deep and extensive root systems, significantly affects nutrient leaching. Roots act as channels, intercepting and absorbing nutrients that would otherwise leach into the groundwater. When plant roots take up nutrients, they retain them in their biomass and prevent their movement towards lower soil layers. This process enhances nutrient recycling within the ecosystem, promoting sustainable nutrient availability for plant growth. Diverse plant communities can have a positive impact on reducing nutrient leaching. Different plant species have varying nutrient requirements and uptake strategies.

A series of lysimeters (filled with disturbed soil) was set up in 1933 in Lexington, Kentucky, U.S.A. (Karraker *et al*., 1950). They reported the loss of nitrogen from White clover, red clover and Bluegrass as 58, 47, 5 kg N $ha^{-1}yr^{-1}$. The loss from the red and white clover depends on the incorporation in the soil in the winter. The nitrogen in the leachate content increased with incorporation.

Low and Armitage (1970) conducted a lysimeter study with the leachate with undisturbed monolith lysimeters cropped with white clover, meadow fescue and fallow treatment in Jealott's Hill Research Station, Bracknell, England. In the three-year study period, the leaching loss of nitrate was 256 kg ha^{-1} for fallow, 2.2 for grass and 128 for clover treatments. In the case of ammonium, the value was 13, 0.9 and 4.3 kg ha^{-1}. When the clover began to die out, the nitrogen leached increased sharply. After the crop removal, it was 4.3 times as great as it was when growth was normal. In the case of phosphorus, potassium, calcium and magnesium, the leaching loss was highest for fallow treatment, followed by clover and grass treatments. Nitrate is the main form of mineral nitrogen present in agricultural soils and its concentrations in the soil solution may rise rapidly not only through fertilization but also through transformations of the nitrogen present in the soil organic matter.

Beqaj *et al.* (2016) experimented with a nutrient leaching study in pots under greenhouse conditions at the Agriculture University of Tirana, Albania. Results indicated a relatively high amount of N and Ca leached especially from the loamy soil and in the absence of the plants. The presence of ryegrass plants significantly decreased the leached amount of N and Ca. Mg was leached in smaller amounts compared with the other two elements. The total nitrogen, calcium, and magnesium uptake by the plant, as well as leaching loss, was affected by both the fertilization rates and the soil type. The amount of nitrogen leached in the loamy soil fluctuated between 31 kg ha^{-1} (treatment of 50% of fertilizers with plant presence) and 85 kg ha^{-1} (treatment of 100% fertilization without plants). In the clay loam soil, the amounts of nitrogen leached were much lower than in the loamy soils reaching a maximum of 36 kg ha^{-1} in the treatment of 100% fertilization without the presence of the plants. The relatively high amounts of nitrogen that are leached in both soils don’t derive only from the fertilization N, but, also from the soil-borne mineral N present in the soil.

In a lysimeter-based experiment conducted in Ultisol of Nigeria by Wong *et al.* (1992) in two seasons, eight lysimeters were cropped with maize followed by upland rice and four were uncropped. They noticed that the fertilizer accounted for 38 per cent of the nitrate loss from the bare lysimeters but in the cropped lysimeters, it accounted for only 21 per cent. The cropped lysimeters lost 27 percent of the sum of the exchangeable Ca in the soil profile and the calcium added, and 29 percent of the corresponding sum for Mg. In the absence of a crop, the losses increased to 34 and 37 percent, respectively. The loss of potassium ranged from 6 percent in the unfertilized lysimeters to 10 percent in the cropped lysimeters. The bulk of the calcium and magnesium leached from calcium hydroxide and fertilizers was highly related to the amount of nitrate lost giving $(Ca + Mg)/NO_3$ charge ratios remained as one. Urea increased the amount of nitrate leached and led to a corresponding increase in the amounts of calcium and magnesium lost in the drainage water. The charge ratio remained unchanged when the cations were leached only with nitrate derived from the mineralization of soil organic matter.

2.5 Effect of cropping system on nutrient leaching loss

Traditional monoculture cropping systems involve the cultivation of a single crop species on a particular piece of land. This system is known to be more vulnerable to nutrient leaching, as it leads to imbalances in nutrient uptake and loss. Crop rotation is known to reduce nutrient leaching significantly. By rotating crops, the nutrient demands of each crop can differ, resulting in a more balanced nutrient uptake from the soil.

Lysimeters and suction cup-based studies were done by Tsimba *et al.*, (2022) to measure total N leaching in a high N maize crop system in the Waikato, grown in sequence with a ryegrass catch crop. Greatest losses were observed in the fallow rotation, averaging 60 and 88 kg N ha^{-1} for either season, respectively, despite a drier winter. Greater leaching was attributed to higher soil N concentration. Including rye grass reduced leaching by >85%, and took up at least 200 kg N ha^{-1}. Despite fertilizer rate having a direct influence on N leaching, actual losses can be modified by better crop management. Establishing a catch crop after maize was found to largely mitigate N leaching through increased uptake, and reduction of soil concentrations and water losses through transpiration, which impacted soil drainage volumes. Even in the absence of a catch crop, complete N leaching losses occurred despite the high N fertiliser input for the maize crop.

Hussain *et al*. (2020) examined the leaching of DOC, DON, NO_3^-, and NH_4^+ from no-till corn (maize) and perennial bioenergy crops and reported N fertilization had no effect in DOC leaching and poplar lost the most DOC at the leaching rates of 21.8 kg ha^{-1} yr^{-1} and volume-weighted mean concentration of 6.9 mg L^{-1}. The amount of DON leaching rates and volume-weighted mean concentrations were 4.5 kgha^{-1}yr^{-1} and 1.0 mgL^{-1}, respectively in corn, which was higher than in perennial grasses (1.5 kg ha^{-1}yr^{-1} and 0.5 mgL^{-1}, respectively) and poplar (1.6 and 0.5 mgL^{-1}, respectively). The NH_4^+ concentrations in soil water from all cropping systems were significantly low and NO_3^- comprised the majority of total N leaching loss of 59-92% in all systems. Average NO_3^- leaching under corn was 35.3 kg ha^{-1} yr^{-1}, which was higher than the leaching loss of perennial grasses and poplar having 5.9 and 7.2 kgha^{-1}yr^{-1}, respectively. Among the cropping system studied, perennial crops leached more NO_3^- in the first few years after planting, and markedly less afterwards. Among the fertilized crops, the leached N represented 14–38% of the added N over the study period and was highest in poplar plantation comprised of 38 % loss.

A lysimeter study in Germany by Meissner *et al.* (1998) in sandy loam soil indicated that changes in cultivation practices cause a significant decrease in the leaching of chloride and sulphate. A high level of sulphate leaching was found in the BMP (best management practices) treatment with a decreasing tendency in the permanent fallow, as irrigation and fertilization also have a promoting impact on sulphate leaching. Without fertilizer or irrigation inputs, chloride and sulphate are only sparingly supplied from the soil reservoir. When intensive cultivation was resumed after a rotation fallow, there was a rapid increase in anion leaching. Calcium and magnesium leaching was comparatively lower, where no external fertilizer is applied. Among the cations, calcium ions were leached most intensively. Magnesium leaching was less dependent on farming schemes, primarily changed with the amount of seepage water, saturation in the soil and the supply of mineral fertilizer salts. The amount of magnesium leached together with the seepage water showed significant differences among the various types of cultivation practices. The permanent fallow showed large leaching losses of the measured cations even three years after being set aside. In contrast, the leaching of the measured anions NO_3^-, SO_4^{2-} and Cl^- decreased significantly compared with the initial level. If cation leaching decreases from lack of additional supply, a shift of the pH into the acid range is to be expected. A one-year set aside in the form of a rotation fallow is connected with increased leaching of nitrate. Compared with intensively cultivated agricultural land, nitrate leaching in the year set aside increased by 55%, while it was 30% in the year of resuming intensive agricultural production.

2.6 Effect of manure on nutrient leaching loss

Nutrient release from organic sources is generally more difficult to predict than from mineral fertilizers and so developing practices to counteract leaching is particularly important. Nutrients are often released from organic sources at a time, when there is little crop uptake and consequently more opportunity for leaching.

Sandor *et al*. (2009) experimented with mesocosm (to create a field situation) at the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Romania and discovered that using manure and straw as organic fertilisers resulted in a greater loss of nutrients. The effect of different densities of earthworm *Lumbricus terrestris* and *Aporrectodea caliginosa* was measured in manure and straw treatment. The highest nutrient leaching capacity was observed in manure treatments compared with straw. The highest total NO_3^- was 1170 ppm, while the lowest was 641 ppm. There was an increase in leachate intensification with an increase in the biotic community, which was due to the higher rate of nitrification. The leaching capacity increased in order $K^+ > PO_4^{3-} > NH_4^+$. The amounts of nitrate, potassium and ammonium lost from the soil in manure treatments were significantly higher compared with straw treatments, but there were no significant differences in phosphate leaching. Nitrate, potassium, and ammonium were lost mostly during spring, while phosphate was lost in autumn.

Xue *et al*. (2013) evaluated the effect of different manure applications on soil P forms and quantities up to 200 cm depth in a Chinese alkaline Cambisol. They observed that the soil Olsen-P concentration increased significantly after manure application and amounting to 4–30 times that of the reference soils in the soil layers of 0–20 cm and 20–60 cm. They concluded that manure application increased P content in all fractions, while the increase was diminished with depth and remained visible up to the 60 cm depth, irrespective of cropping systems. Manure application increased the levels of inorganic P, with higher proportions in labile forms than in stable forms. After manure application for 8–15 years, available P (Olsen P) and DPS (degree of P saturation) values of the 0–20 cm layer in all sites increased and the risk of P loss by runoff is expected to significantly increase. The DPS values of the 0–20 cm layer of the manured soils were always greater than 30 %, while it was lower than 30 % below 20 cm, indicating a minimal risk of P loss via leaching from deeper soil.

Pal *et al*. (2018) conducted a leaching experiment to determine the leaching nature of phosphorus in the soil through a constructed column with a 20 cm soil height. With the increase in the application of FYM, the amount of leachable phosphorus also increased. With the application of 20 t FYM ha^{-1}, DRP (dissolved reactive phosphorus) concentrations were very low at the initial stage but increased with the 2nd to 5th leaching event with further increase of the manure addition. The DRP in leachates increased sharply up to the 4th leaching event (1.98 mg L^{-1}) and again fell sharply to a very low value (0.43 mg L^{-1}). When the application rate increased to 120 t FYM ha^{-1}, the dissolved organic carbon concentration was highest (961.27 mg L^{-1}) at 1st leaching event and decreased subsequently. The DRP (dissolved reactive phosphorus) in leachates increased sharply up to the 4th leaching (19.34 mg L^{-1}) event and again fell sharply to a very low value (9.72 mg L^{-1}). During the whole leaching event, P started to leach more rapidly as manure addition continued to increase.

2.7 Effect of trees on nutrient leaching loss

In a study conducted by Nidzgorski *et al.* (2016), there was a significant reduction in nutrient leaching to groundwater by urban trees. Trees had similar or lower N leaching than turfgrass. Trees reduced P leaching compared with turfgrass during the study period with lower leaching loss under deciduous than evergreen trees. For both N and P, deciduous trees had lower soil water nutrient concentrations than open turfgrass areas and evergreen trees had lower soil water P concentrations than turfgrass, but similar N concentrations due to extensive rooting system.

Gikas *et al*. (2016) studied the effects of trees in the reduction of leachable nutrient content in Xanthi plain in Northeastern Greece. In all systems, the greatest concentration of P-Olsen was measured in the surface layers and was gradually decreased in the deeper layers due to the lower mobility of phosphorus. The NO_3-N concentration in the deeper layers at all sampling sites was equal to or greater than that of the surface layers, indicating that NO_3-N has high mobility in soils. A stronger uptake by the tree root system and a lower migration to the watertable are indicated by the NO_3-N concentration in the deeper layers close to the tree row being lower than that of the surface. Additionally, compared to places far from trees, there was a drop in the depth-averaged P-Olsen and NO_3-N concentrations at the soil zone at a distance of 2.0-3.5 m from the tree row. This reduction varied between 15 and 50% and 36 and 54%, respectively. According to these observations, adding trees to farmed areas can help lower the amount of nitrate pollution in groundwater.

Tully *et al.* (2012) examined the effect of coffee agroforests on nitrogen and phosphorus leaching losses and observed that nitrogen fluxes at 100 cm soil depth were 127 and 111 kg N ha^{-1} yr^{-1} in organic and conventional agroforests whereas phosphorus fluxes at 100 cm were 1.5 kg P ha^{-1} yr^{-1} in both organic and conventional agroforests, respectively. Due to serving as nutrient traps, trees were found to lower nutrient fluxes. Nitrogen fluxes were dramatically reduced with depth, with conventional agroforest nitrogen fluxes 68% lower at 100 cm than at 15 cm and organic agroforest nitrogen fluxes 47% lower. Phosphorus losses, on the other hand, declined with increasing soil iron pools, which are independent of management decisions. Nitrogen leaching from the agroforestry system was far less than coffee monoculture, which leached around 300 kg N ha^{-1} yr^{-1}. The lower loss of nutrient leaching of agroforestry system was due to higher nutrient and water uptake by tree roots and caused higher immobilization by the increase of leaf litter.

Chapter 3 Materials and Methods

The field experiment was carried out in the research farm of ICAR- Research Complex for Eastern Region, Farming System Research Centre for Hill and Plateau Region, Plandu, Ranchi, Jharkhand, India from September 2022 to January 2023. The details of the study site, materials and methodologies adopted are described below.

3.1 Location

The field and laboratory studies were conducted at ICAR- RCER, FSRCHPR, Plandu, Ranchi, which is located 15 km from Ranchi. The site is located 651.5 above the mean sea level. The geographical location is 23◦ 16’ 50.4″ N latitude and 85◦ 24’ 39.4″ E longitude in the Chota Nagpur plateau.

Figure 3.1 ICAR-RCER, FSRCHPR, Plandu, Ranchi

Table 3.1 Initial soil properties

Parameter	**Value**	**Reference**
pH (1: 2.5)	5.4	Jackson (1973)
EC (1: 2.5) (dSm^{-1})	0.692	
Sand (%)	69.6	Bouyoucos (1962)
Silt (%)	14.1	
Clay (%)	17.3	
Texture	Sandy loam	
Available N (kg ha^{-1})	208	Subbiah and Asija (1956)
Available P (kg ha^{-1})	27	Bray and Kurtz (1945)
Available K (kg ha^{-1})	182	Hanway and Heidel (1952)

3.2 Climatic condition

The experimental area receives an annual rainfall of 1454.7 mm, of which 93% is received from June to October only. This area experiences dry humid tropical weather having all three distinct seasons (summer, rainy, and winter). The highest maximum temperature of 36.45 °C was recorded in May, whereas the minimum temperature of 12.13 °C was registered in January. Relative humidity ranges from 60% in winter to 86% in the rainy season.

Table 3.2 Weather parameters in Ranchi from June 2022 to May 2023

Months	Maximum temperature (^{O}C)	Minimum temperature (^{O}C)	Rainfall(mm)	Rainy days
June	34.69	24.83	102	8
July	29.88	23.73	285.3	18
August	28.90	23.32	592.3	20
September	29.48	23.32	273.7	13
October	28.46	20.45	93.4	5
November	26.36	14.27	0	0
December	25.20	12.42	0	0
January	25.20	12.13	0	0
February	28.61	14.16	0	0
March	30.42	18.33	57.4	3
April	34.13	22.17	37	3
May	36.45	24.07	13.6	2

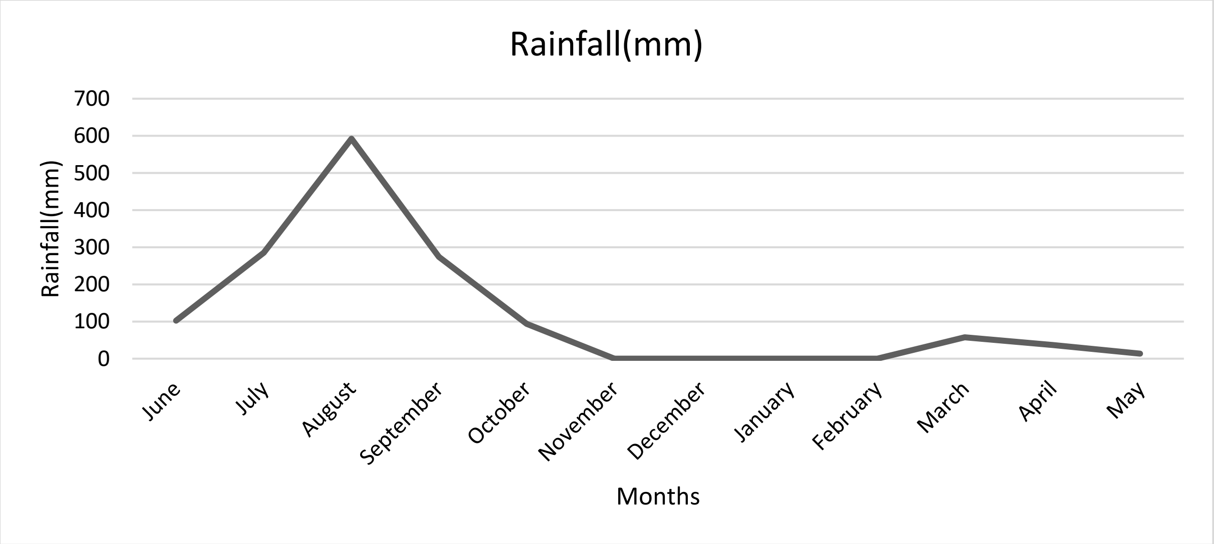

Figure 3.2 Rainfall temporal variation throughout the year

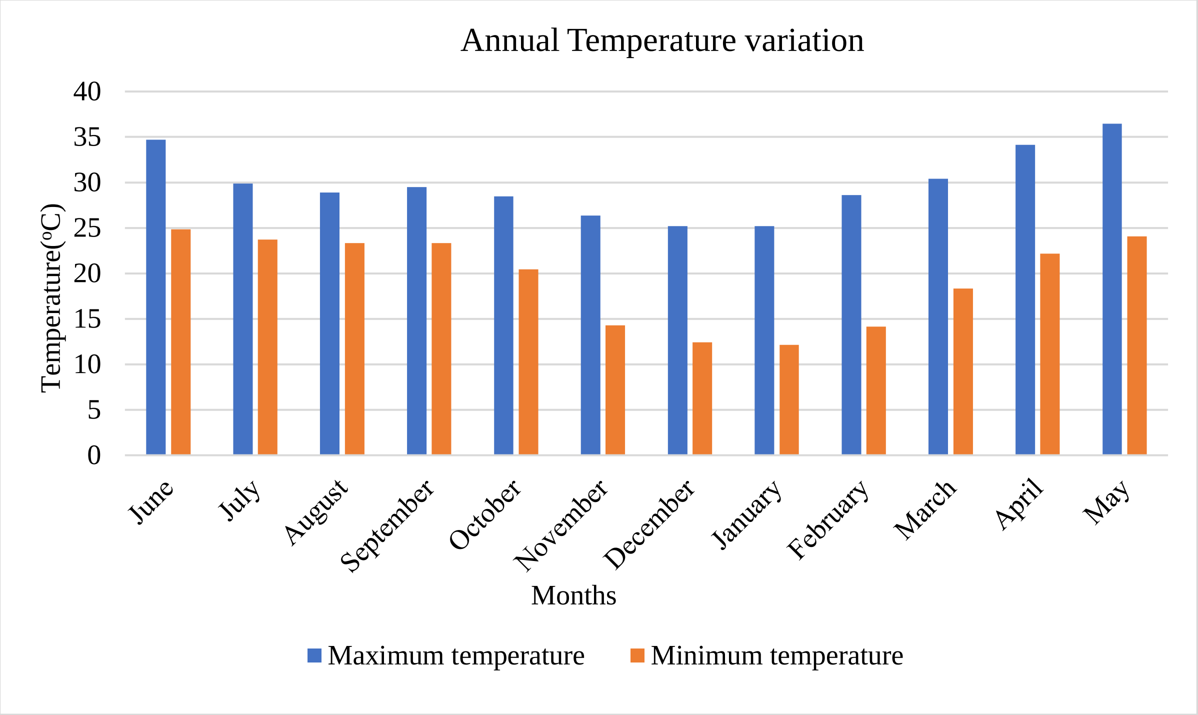

Figure 3.3 Annual temperature variation

3.3 Soil condition

The soil of the experimental site was Typic Haplustalf type (Order- Alfisol). The soil type was laterite soil with the texture being sandy loam at the surface. The soil was highly acidic (pH 4.5-5.5) with very low fertility status indicated by low organic carbon and low available nitrogen content. Soil textural class is sandy loam with 16.6% clay, 14.7% silt, and 68.7% sand (Bouyoucos, 1962).

3.4 Treatment details

This study was taken in the non-weighing lysimeter plots in the fifth year of the establishment of the lysimeter. The lysimeter was established in 2018. The experiment was laid out in randomized block design (RBD) with 4 treatments and 5 replications separately for two crops of maize and brinjal. The treatments consist of lysimeter plots with control (without any nutrient source), fully inorganic, fully organic, and INM. Maize and Brinjal are selected as experimental crops. Vermicompost applied as organic nutrient source contained 0.8% N, 0.2% P and 0.33% K whereas urea (46%N), diammonium phosphate (18%N & 46% P_2O_5) and muriate of potash (60% K_2O) were used as inorganic source.

Table 3.3 Treatment Details

Treatments	**Crops**	
	Fertilizer application	
	Maize (Nitrogen 120 kg ha^{-1}, Phosphorus 60 kg ha^{-1}, Potassium 50 kg ha^{-1})	**Brinjal (Nitrogen 120 kg ha^{-1}, Phosphorus 26 kg ha^{-1}, Potassium 50 kg ha^{-1})**
T$_1$ (Control)	Without any external nutrient source	Without any external nutrient source
T$_2$ (Inorganic)	The full dose of N, P, and K through inorganic fertilizer	The full dose of N, P, and K through inorganic fertilizer
T$_3$ (Organic)	The full dose of N, K, and half dose of P through vermicompost	The full dose of N, P, and K through vermicompost
T$_4$ (INM)	Half dose N, K, and 1/4th dose P through vermicompost; half dose N, K, and 3/4th dose P through inorganic fertilizer	Half dose of N, K and 3/5th dose of P through vermicompost; half dose of N, K and 2/5th dose of P through inorganic fertilizer

Table 3.4 Nutrient scheduling of Maize

Treatments	**At basal**	**30 days after sowing**	**50 days after sowing**
T$_1$ (Control)	-	-	-
T$_2$ (Inorganic)	300 kg ha^{-1} DAP, 100 kg ha^{-1} MOP	72 kg ha^{-1} urea	72 kg ha^{-1} urea
T$_3$ (Organic)	15t ha^{-1} Vermicompost	-	-
T$_4$ (INM)	224 kg ha^{-1} DAP, 50 kg ha^{-1} MOP; 7.5t ha^{-1} vermicompost	21.4 kg ha^{-1} urea	21.4 kg ha^{-1} urea

Table 3.5 Nutrient scheduling of Brinjal

Treatments	**At basal**	**30 days after planting**	**50 days after planting**
T_1 (Control)	-	-	-
T_2 (Inorganic)	37 kg ha^{-1} urea, 128 kg ha^{-1} DAP, 100 kg ha^{-1} MOP	86.6 kg ha^{-1} urea	86.6 kg ha^{-1} urea
T_3 (Organic)	15 t ha^{-1} Vermicompost	-	-
T_4 (INM)	22.5 kg ha^{-1} urea, 54 kg ha^{-1} DAP, 50 kg ha^{-1} MOP; 7.5t ha^{-1} vermicompost	43.3 kg ha^{-1} urea	43.3 kg ha^{-1} urea

3.4.1 Design of non-weighing lysimeter

Lysimeters were constructed by digging out the pits of size 4.0 × 3.0 × 1.0 m (length × width × depth). During the pit digging process, soil from each layer of 15 cm depth was kept aside without mixing. Prior to the removal of the soil, the bulk density of each of the 15 cm layers was recorded using a core sampler. The sides and bottom of the pits were smoothened by applying mud slurry (soil + water). To control the damage to polythene lining by rodents and termites, the solution of Biflex (2 ml/litre) was sprayed on the walls and bottom of the pit. Black polythene of 500-micron thickness was used for the lining of each lysimeter to avoid inflows and outflows from the lysimeter boundaries. Polythene was anchored on four sides by placing it in the trench and backfilling the trench with soil. A 63 mm diameter of PVC pipe was fitted at the bottom of the pit to carry the leachate from the lysimeter to the collector drum placed inside the collector trench. It was ensured that the joint between the polythene lining and outlet pipe was leakproof. A filter constituting pebbles (1–3 cm) and gravels (0.5–1.0 cm) was provided at the inlet of the pipe to preclude the entry of soil particles in leachate. A 200-litre cylindrical tank was kept in the trench below the level of the outlet pipe for the collection of leachates from each lysimeter. The excavated soils from different depths of 0–15, 15–30, 30–45, 45–60, 60–75, 75–90, and 90–100 cm of the pits was filled up in the lysimeters at their corresponding depths. Bunds of 15 cm in height were constructed on the borders of each lysimeter to avoid entry of runoff water and to prevent the spillover of irrigation water from the lysimeters.

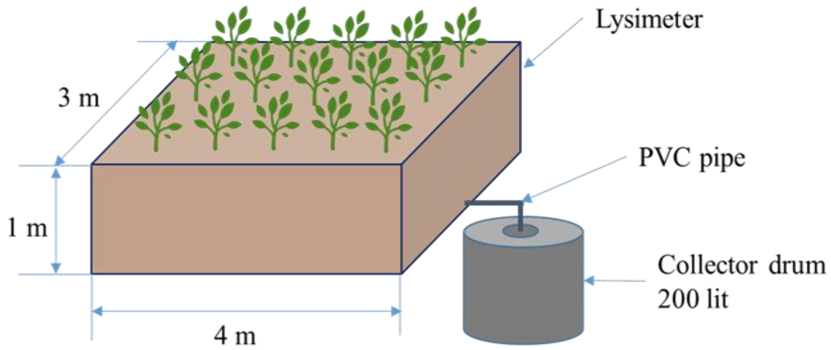

Figure 3.4 Non-weighing lysimeter

3.5 Collection of samples

Soil samples and water samples were collected from the lysimeter plots at ICAR- Research Complex for Eastern Region, Farming System Research Centre for Hill and Plateau Region, (ICAR-RCER, FSRCHPR). The experimental site was located at 23° 28’ N latitude, 85° 41' E longitude, and 651.5-meter mean sea level.

3.5.1 Collection of Water sample

Leachate (water samples) were collected from every collector drum connected to with corresponding lysimeters of each treatment. Irrigation has been given to each plot on a visual observation basis. Water samples were collected on a weekly basis from the collector drum in the 100 ml water bottle.

3.5.2 Collection of Soil Sample

Soil samples were collected before the sowing of the seeds of the crop on 28th August 2022 and after the final harvest on 21st January 2023. Soil samples were collected for all the treatments containing both crops (maize and brinjal) consisting of 4 treatments, 5 replications, and 4 different depths (0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm). All the collected samples were properly processed, tagged, and kept in a zipped polythene cover.

3.5.3 Statistical analysis

The data were subjected to analysis of variance (ANOVA) for randomized block design. The significance of the treatment effect was determined using the F test. Duncan’s Multiple Range Test (DMRT) test was used for multiple comparisons among the treatments at p =0.05 using the SPSS program (ver. 21.0).

3.6 Sample Analysis

3.6.1 Water Sample Analysis

3.6.1.1 pH

The pH of leachate was measured directly with a glass electrode pH meter (Thomas, 1996). The pH meter was previously standardized using pH 4.0, 7.0, and 9.2 buffer.

3.6.1.2 Electrical conductivity (EC)

The electrical conductivity of the leachate was measured directly by an electrical conductivity meter. The conductivity meter was previously calibrated using a standard KCl solution (Rhoades, 1996).

3.6.1.3 Dissolved Ammonium-Nitrogen content (NH_4^+-N)

Dissolved ammonium-nitrogen content was measured with the distillation-titration method (Mulvaney 1996). Distillation of 50 ml leachate was done with the help of the Kjeldahl distillation set. About 50 ml leachate is placed in the distillation tube with 10 ml of 40% NaOH solution. The volatilized nitrogen was collected in the 2% boric acid solution with mixed indicator placed in the conical flask. The colour of boric acid changed from pink to blue. Then the collected nitrogen sample with the boric acid was titrated with 0.02 N H_2SO_4 solution. After the titration of the solution, the endpoint colour was again back to pink colour. From the burette reading the expended H_2SO4 content was known. The nitrogen content was calculated from the normality basis with the help of this formula.

Calculation-

Amount of ammonium nitrogen (mg L^{-1}) = $\frac{14 \text{ x } N \text{ x } V_1}{V}$ x 1000

V_1 = volume of H2SO4 is used for the titration (ml)

N = normality of H2SO4

V = volume of leachate distilled in the distillation unit(ml)

Every time the normality was checked by titration with sodium carbonate of 0.1 N solution in the presence of methyl orange.

3.6.1.4 Dissolved Nitrate-Nitrogen content (NO3-)

Dissolved nitrate-nitrogen content was measured similarly with the distillation-titration method (Keeney and Nelson, 1983). Distillation of 50 ml leachate was done with the help Kjeldahl distillation set. With the help of Devarda’s alloy the reduced nitrate transformed into ammoniacal form, then collected in 2% boric acid. The colour of boric acid changed from pink to blue. Then the collected nitrogen sample with the boric acid was titrated with 0.02 N H_2SO4 solution. After the titration of the solution, the endpoint colour was again back to pink colour. From the burette reading the expended H_2SO_4 content was known. The nitrogen content is calculated from the normality basis with the help of this formula.

Calculation-

Amount of ammonium nitrogen (mg L^{-1}) = $\frac{14 \text{ x } N \text{ x } V_1}{V}$ x 1000

V_1 = volume of H_2SO_4 is used for the titration (ml)
N = normality of H_2SO_4
V = volume of leachate distilled in the distillation unit(ml)
Every time the normality was checked by titration with sodium carbonate of 0.1 N solution in the presence of methyl orange.

3.6.1.5 Dissolved Phosphorus

Dissolved phosphorus is measured by the blue colour method (Gales, 1966). About 5 ml leachate is pipetted into a 25 ml volumetric flask and 4 ml of ascorbic acid-ammonium molybdate-antimony potassium tartrate solution is mixed. The final volume is made to 25 ml by mixing with distilled water. The blue colour is formed due to the formation of the phosphomolybdate complex. The absorbance is measured in a spectrophotometer at 660 nm in the presence of a standard phosphorus solution. The phosphorus concentration is known from the standard calibration curve.

Calculation-

P (mg L^{-1}) = $\frac{R \times V}{V_1}$

R = the concentrations of P (mg L^{-1}) in the sample obtained from the spectrophotometer reading
V = volume made at colour
V_1 = volume of aliquot

3.6.1.6 Dissolved Potassium

Potassium concentration was measured with the help of a flame photometer at 767 nm wavelength calibrated with 0, 20, 40, and 60 ppm standard potassium solution (Jackson, 1973). The working standard was made from a 1000 ppm standard of potassium sulphate solution.

3.6.1.7 Dissolved Calcium

Dissolved calcium concentration was measured by titration with 0.01 N EDTA in the presence of calcon indicator (Schwarzenbach *et al.*, 1946). 5 ml leachate was taken in the conical flask and 8-10 drops of 16% NaOH, and 2-3 drops of calcon were added before titration, and the solution turned into pink colour. After titration with EDTA, the pink colour changed to sky blue. The amount of calcium was known from the reading of burette containing EDTA on a normality basis.

3.6.1.8 Dissolved Magnesium

Dissolved calcium + magnesium concentration was measured by titration with 0.01 N EDTA in the presence of EBT indicator (Schwarzenbach *et al.*, 1946). 5 ml leachate was taken in the conical flask and 8-10 drops of NH_4OH + NH_4Cl buffer, and 2-3 drops of EBT were added before titration. After titration, the pink colour was changed to sky blue. The amount of calcium + magnesium was known from the reading of burette containing EDTA on a normality basis. From the difference between the calcium + magnesium and calcium concentration, the magnesium concentration was known.

3.6.1.9 Dissolved Sulphur

Dissolved sulphur concentration was determined in a spectrophotometer with the help of a standard calibration curve(Chesnin and Yien, 1950). 5 ml leachate was taken in a 25 ml volumetric flask and 0.5 ml 6 N HCl, 0.5 ml gum acacia solution is added. After that 0.25 g of $BaCl_2$ is added. The turbidity caused by the formation of barium sulphate is measured with the help of a spectrophotometer at 420 nm wavelength. The calibration curve was made with 0, 4, 8, 12, 16, and 20 ppm sulphur solution. The sulphur concentration in the leachate is determined by this relation-

$$S\ (\text{mg L}^{-1}) = \frac{R \times V}{V_1}$$

R = the concentrations of S (mg L^{-1}) in the sample obtained from the spectrophotometer reading

V = volume made at colour

V_1 = volume of aliquot

3.6.1.10 Dissolved organic carbon

Dissolved organic carbon was determined by the volumetric method with chromic acid wet digestion (Rao *et al.,* 2013). For this 10 ml leachate was oxidized with 2 ml of potassium dichromate (0.1 N) and a mixture of sulphuric acid(H_2SO_4) and 5 ml orthophosphoric acid(H_3PO_4) in a conical flask at 100° centigrade for 30 minutes in the hot water bath. A hot blank sample was also analysed similarly. The conical flask was cooled down and 50 ml of distilled water was added with 2-3 drops of DPA (diphenylamine) indicator. It was titrated against 0.01 N FAS (ferrous ammonium sulphate) and a colour change from dark blue to olive green indicated the endpoint of the titration.

Calculation: -

$$\text{DOC (mg/L)} = \frac{(H_b - S) \times N_1 \times N_2 \times 3 \times 1000}{V_L}$$

Where,

H_b= Hot blank titration reading

S= Sample titration reading

N_1=Normality of FAS (0.01 N)

N_2= Normality of potassium chromate (0.1 N)

V_L= Volume of leachate used (10 ml)

3.6.2 Soil Sample Analysis

3.6.2.1 pH

The pH of the soil was measured in 1:2.5 (soil: water suspension) after equilibrating for 30 minutes, with the help of a glass electrode digital electrode pH meter (Jackson, 1973). The pH meter was standardized by the buffer of pH 4, 7, and 9.2 before the pH measurement.

3.6.2.2 EC

The soil water suspension prepared for determination pH, was used to estimate the electrical conductivity of the soil (Jackson, 1973). The soil suspension was allowed to settle till the supernatant became clear. Electrical conductivity was measured with an EC meter and expressed as dSm^{-1}.

3.6.2.3 Easily Oxidizable Organic Carbon

The organic carbon of soil is determined by chromic acid wet digestion, followed by titrimetric measurement of unreacted dichromate (Walkley and Black, 1934). 1 g of soil was taken in a 500 ml conical flask along with 10 ml of 1 N potassium dichromate and 20 ml concentrated sulphuric acid. The flask was shaken and kept in a dark environment for 30 minutes. About 200 ml of water, 5 ml of orthophosphoric acid, and 1 ml of diphenylamine indicator were mixed with the solution. Then it was titrated against 0.5 N ferrous ammonium sulphate solution. A blank sample is also done.

Calculation: -

$$\text{Organic carbon (\%)} = 10 \text{ x } \frac{(B-S)}{B} \text{ x } 0.003 \text{ x } \frac{100}{\text{wt of sample}}$$

Where B= titre value of blank

S= titre value of sample

3.6.2.4 Available Nitrogen

The available nitrogen content of the soil was determined by the alkaline potassium permanganate method (Subbiah and Asija, 1956). For this, 5 g soil was transferred to a distillation flask, and 5 ml distilled water, 1 ml liquid paraffin were added to control frothing. A few glass beads were added to prevent bumping and then 25 ml of 0.32% potassium permanganate solution was added along with 25 ml of 2.5% NaOH solution. The distillate was collected in a 250 ml conical flask containing 20 ml of 2% boric acid with the mixed indicator (0.5 g of bromocresol green, 0.1 g of methyl red in 100 ml of ethyl alcohol). The ammonia collected was titrated against 0.02 N sulphuric acid and from the titre value, the available nitrogen content in the soil was calculated.

3.6.2.5 Available Phosphorus

The available phosphorus content of the soil was determined by Bray and Curtz method (Bray and Curtz, 1945). Five grams of soil was taken in a 250 ml. conical flask, and a pinch of Darco G-60 and 50 ml of Bray reagent (0.03 N NH_4F + 0.025N HCl) were added to it. It was then shaken for 30 minutes on a mechanical shaker and the suspension was filtered through Whatman No. 42 filter paper. 5 ml of filtrate was transferred in a 25 ml volumetric flask and was acidified with 2.5 M H_2SO_4, to pH 5.0-, and 20-ml distilled water was added followed by 4 ml of reagent B. At first reagent A was prepared by using ammonium molybdate, antimony potassium tartrate, and H_2SO_4. Then reagent B was prepared from reagent A and ascorbic acid. After waiting for 10 min the intensity of the blue colour was measured on a spectrophotometer at 660 nm.

Calculation

Available phosphorus (kg ha^{-1}) = $\frac{\text{R x Volume of extract x 2.24 x } 10^{6}}{\text{Volume of aliquot x wt.(g)of soil x } 10^{6}}$

Where R= µg P in the aliquot (obtained from the standard curve)

3.6.2.6 Exchangeable Potassium

The available potassium content of the soil was determined by the flame photometer (1 N ammonium acetate extract) method (Hanway and Heidal, 1952). For this, five grams of soil was transferred to a 100 ml conical flask and 25 ml of 1 N ammonium acetate solution was added and shaken for 30 minutes. The suspension was filtered through Whatman No. 1 filter paper and potassium concentration in the filtrate was measured using flame photometer.

Calculation

Available K_2O (kg ha^{-1}) = $\frac{\text{C x V}}{\text{w}}$ x 2.24

Where, C is the Concentration of K (mg L^{-1}) in the extract as obtained from the standard curve

3.6.2.7 Exchangeable Calcium

The exchangeable Ca^{2+} was determined by complexometric titration (Schwarzenbach *et al.*, 1946). 10 g soil was taken in a conical flask with 50 ml of neutral normal ammonium acetate followed by shaking for 5 minutes. Then filtrated with Whatman no. 1 filter paper. About 1 ml extract and 5 ml distilled water were taken in the conical flask. To it 8-10 drops of sodium hydroxide and 2-3 drops of calcon indicator were added. The solution was titrated with 0.01 N of EDTA till the colour changed from pink to sky blue. From the burette reading, calcium content was calculated.

Calculations

Exchangeable Ca (meq 100 g^{-1} soil) = $\frac{\text{Normality ofEDTA x Vol. of EDTA consumed x 25 x 1000}}{\text{5 x 10 x ml of aliquot taken}}$

3.6.2.8 Exchangeable Calcium and Magnesium

Exchangeable Ca and Mg were extracted using neutral normal ammonium acetate and the exchanged ion was measured following the procedure outlined in Hesse (1970). For this, 10 g soil was taken in a conical flask and 50 ml of neutral normal ammonium acetate was added. The flask was equilibrated and the contents were transferred to a Buckner funnel and filtered. Ca and Mg were measured by complexometric titration. The exchangeable Ca^{2+} and Mg^{2+} were determined by complexometric titration, involving ethylene diamine tetra acetic acid (EDTA). About 1 ml of the extract was pipette out in a conical flask. To it, 5 ml of distilled water, 8-10 drops of buffer (NH_4OH + NH_4Cl) solution and 2-3 drops of Erichrome black-T indicator were added and titrated against standard (0.01N) EDTA solution till the colour changed from wine red to blue.

Ca^{2+} + Mg^{2+} was calculated as:

Exchangeable Ca^{2+} + Mg^{2+}(meq 100g^{-1}) = $\frac{\text{Normallity of EDTA x Volume of EDTA in titration x 25 x 1000}}{\text{5 x Amount of aliquot(ml)}}$

Exchangeable Mg (meq $100g^{-1}$) = Exchangeable Ca^{2+} + Mg^{2+} (meq $100g^{-1}$)-Exchangeable Ca^{2+}(meq 100 g^{-1})

3.6.2.9 Available Sulphur

Available sulphur content was measured by turbidimetric method (Chesnin and Yien, 1950). About 5 g of soil was taken in a conical flask and 25 ml of 0.15% calcium chloride was added and kept in a mechanical shaker for 30 minutes. The extract was collected from the filtration of content by the Whatman No. 42-filter paper. About 5 ml of extract was taken in a 25 ml volumetric flask. To it, 0.5 ml of gum acacia and 0.5 ml of 6N HCl was added. About 0.25 g of barium chloride was added to the solution and volume was made up to 25 ml. The turbidity caused by the formation of barium sulphate was measured with a spectrophotometer with a standard curve. From the standard curve reading, the sulphur content was measured.

3.6.2.10 Soil texture

Particle size analysis of soil samples done by hydrometer method as described by Bouyoucos (1962). About 50 g of soil sample was taken into a beaker and 50 ml of 6% H_2O_2 was added. The beaker was covered with a watch glass and placed in a water bath until the organic matter got oxidized; the beaker was removed and allowed to cool. The process was repeated until the frothing stopped. Then dispersing solution was prepared through by mixing 40 g sodium hexametaphosphate and 10 g sodium carbonate with 1000 ml water. Then 200 ml of distilled water and 100 ml of sodium hexametaphosphate were added to the beaker and kept overnight. On the next day, the content was transferred to a 1-liter measuring cylinder and the volume was made up to the 1 l mark. The suspension was tilted for 1 minute by placing a cap. The hydrometer was inserted into the suspension and the reading was taken at 40 seconds. The temperature of the suspension was also noted. The suspension was allowed to remain undisturbed and a second hydrometer reading was recorded after 2 hours. The sand, silt and clay were calculated and textural class was determined using USDA textural triangle.

Calculation: -

Corrected hydrometer reading = Hydrometer reading + (recorded temp °F-67) x 0.2

$$\text{Silt + Clay} = \frac{\text{Corrected hydrometer reading at 40 seconds}}{\text{Weight of soil}} \times 100$$

$$\text{Clay (\%)} = \frac{\text{Corrected hydrometer reading at 2 hours}}{\text{Weight of soil}} \times 100$$

Sand (%) = 100- [Silt (%)-Clay (%)]

Chapter 4 Results

The present study was undertaken to assess the leaching loss of nutrients and also to study the depth-wise distribution under different nutrient management options in maize and brinjal grown on an Alfisol in the lysimeter plots of the farm of ICAR-Research Complex for Eastern Region, Farming System Research Centre for Hill and Plateau Region, Ranchi Jharkhand. Maize and Brinjal were grown on the lysimeter plots from September 2022 to January 2023 period. Irrigation was given as per crop requirement in the furrow bed method based on visual observation and feel method. The volume of irrigated water and the volume of leachate was quantified. Every week leachate samples were collected and analyzed. The soil samples were collected after the harvest of rabi crops in the last week of January. The soil samples were processed and analyzed for different chemical properties in the depth of 0-60 cm. The results of the study were briefed in this chapter under the following headings:

- Effect of different nutrient management practices on leaching loss of major and secondary nutrients
- Effect of different nutrient management options on the depth-wise distribution of available nutrient contents in post-harvest soil samples

4.1 Effect of different nutrient management practices on leaching loss of major and secondary nutrients

4.1.1 Temporal variation in pH of the leachate

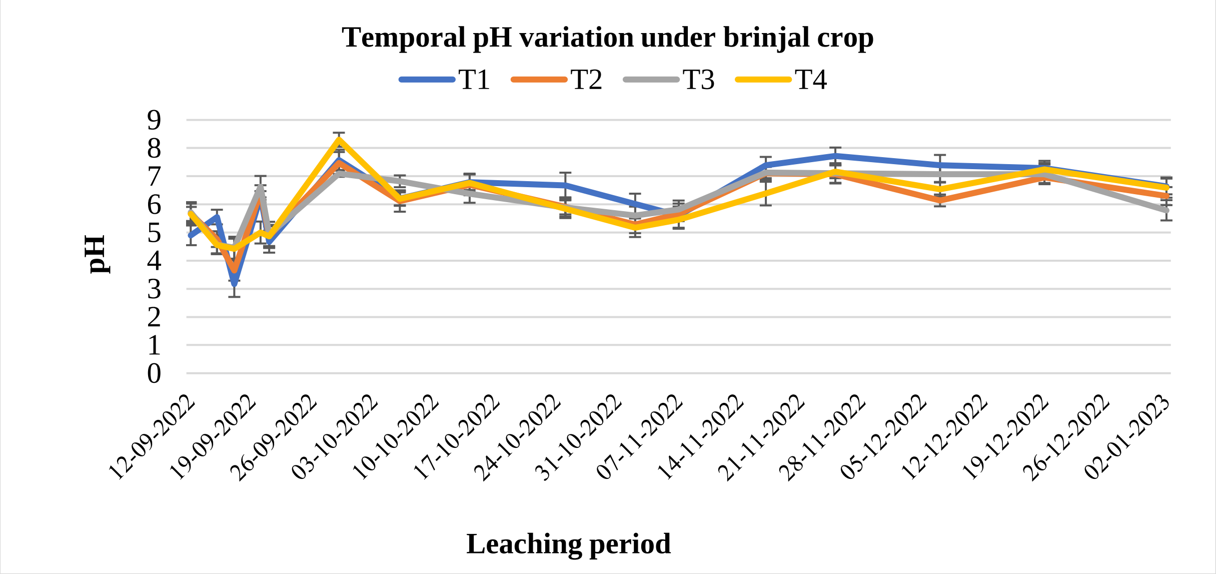

Figure 4.1 Effect of different nutrient management options on the temporal pH variation in brinjal crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

The pH of the leachate samples during the growing season of brinjal changed significantly (Fig. 4.1). The pH variation noted in all the nutrient management options was between 3.17 to 8.29. In the control treatment (T_1), pH varied from 3.17 to 7.72, whereas the pH value of inorganic (T_2), organic (T_3) and INM treatment (T_4) was from 3.65 to 7.47, 4.42 to 7.10 and 4.42 to 8.29, respectively. In all the nutrient management systems, the pH of leachate was initially low but increased in the later growth period. The initial low pH was around 5 to 6 in different nutrient management systems, then decreased around pH 3.5 to 4.5 in the second leaching. Afterwards, the pH value of the leachate sample increased and maintained neutrality in the later growing stages. Among the different nutrient management options, the pH of the leachate sample in the control treatment was higher compared to other treatments.

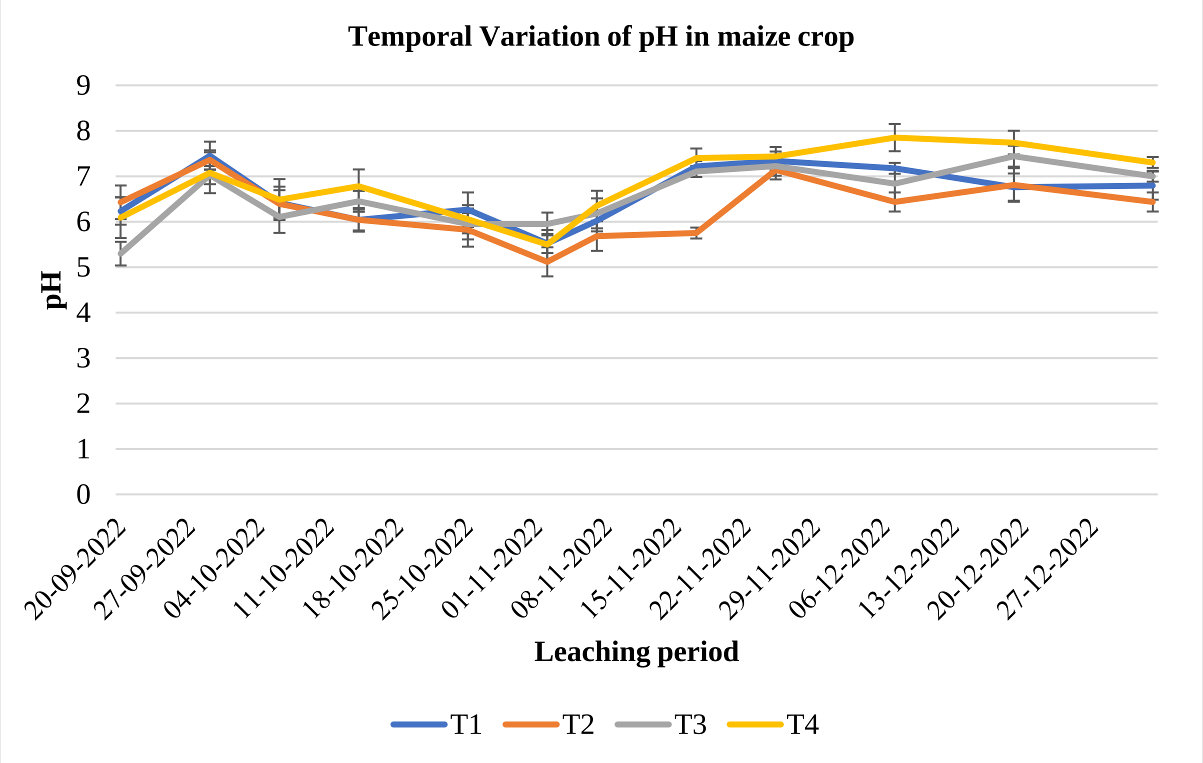

Figure 4.2 Effect of different nutrient management options on the temporal pH variation in maize crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

During the maize growing season, there was a considerable shift in the pH of the leachate samples (Fig. 4.2). All of the nutrient management methods had pH variations that ranged from 5.23 to 7.85. While the pH ranged from 6.25 to 7.41 in the control treatment (T_1), further it ranged from 5.12 to 7.36, 5.23 to 7.44, and 5.51 to 7.85 in the inorganic, organic, and INM treatments (T_2, T_3, and T_4, respectively), respectively. The pH of leachate was initially low in all fertiliser management systems but increased later in the development phase. In various nutrient management systems, the first leachate sampling showed low pH ranging from 5.1 to 6.2, while in the second leaching, the pH rose from 7.0 to 7.45. Afterwards, the pH level of leachate-maintained neutrality during the later stages of growth. Among the various nutrition management strategies, the pH of the leachate sample in the control treatment was higher compared to other treatments. Among both crops grown, the leachate from maize had a lower pH variation than brinjal.

4.1.2 Temporal variation in electrical conductivity of leachate

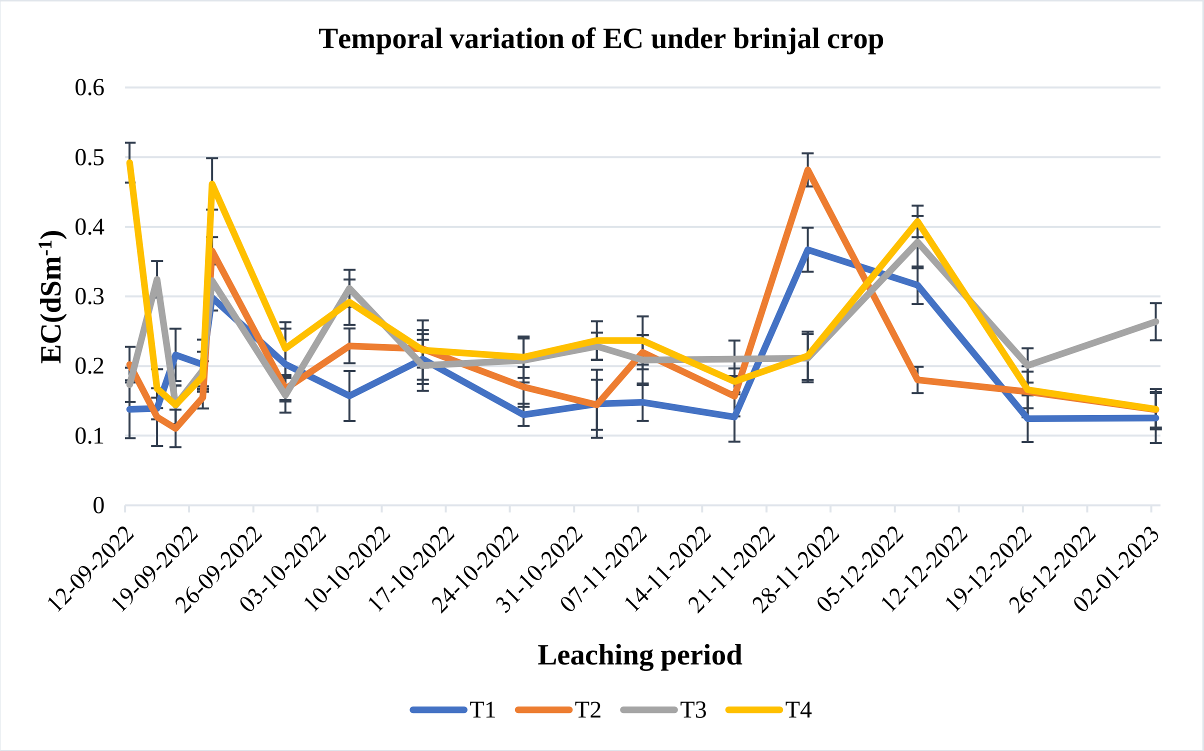

Figure 4.3 Effect of different nutrient management options on the temporal variation of EC (electrical conductivity) in brinjal crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

The EC (electrical conductivity) of leachate sample changed during the growth of brinjal in all the nutrient management options (Fig. 4.3). The EC value was initially higher in the leachate, decreased in the midseason and again increased in the later drier season. The EC variation in all the nutrient management options was between 0.11 to 0.49 dS m^{-1}. In the control treatment (T_1), electrical conductivity varied between 0.14 to 0.37 dS m^{-1}, whereas the electrical conductivity value of inorganic (T_2), organic (T_3) and INM treatment (T_4) was in between 0.11 to 0.48, 0.17 to 0.38, 0.14 to 0.49 dS m^{-}

$^{-1}$, respectively. The initial electrical conductivity was higher in the INM and organic treatment. Among the different nutrient management systems lowest electrical conductivity was found in the control treatment.

In all of the nutrient management strategies, the EC (electrical conductivity) of leachate sample altered as maize developed (Fig. 4.4). The EC value initially increased in the leachate, slightly dropped in the second leaching, and then climbed again in the subsequent dry season. The range of the EC fluctuation across all nutrient management strategies was from 0.13 to 0.35 dS m^{-1}. Electrical conductivity in the control treatment (T_1) ranged from 0.14 to 0.29 dS m^{-1}, whereas it ranged from 0.15 to 0.35, 0.19 to 0.28, and 0.25 to 0.38 dS m^{-1} for the inorganic, organic, and INM treatments (T_2, T_3, and T_4, respectively), respectively. The INM and organic treatments have higher initial electrical conductivities, while the control treatment had the lowest electrical conductivity. Among both crops, maize leachate had a lower electrical conductivity than brinjal leachate.

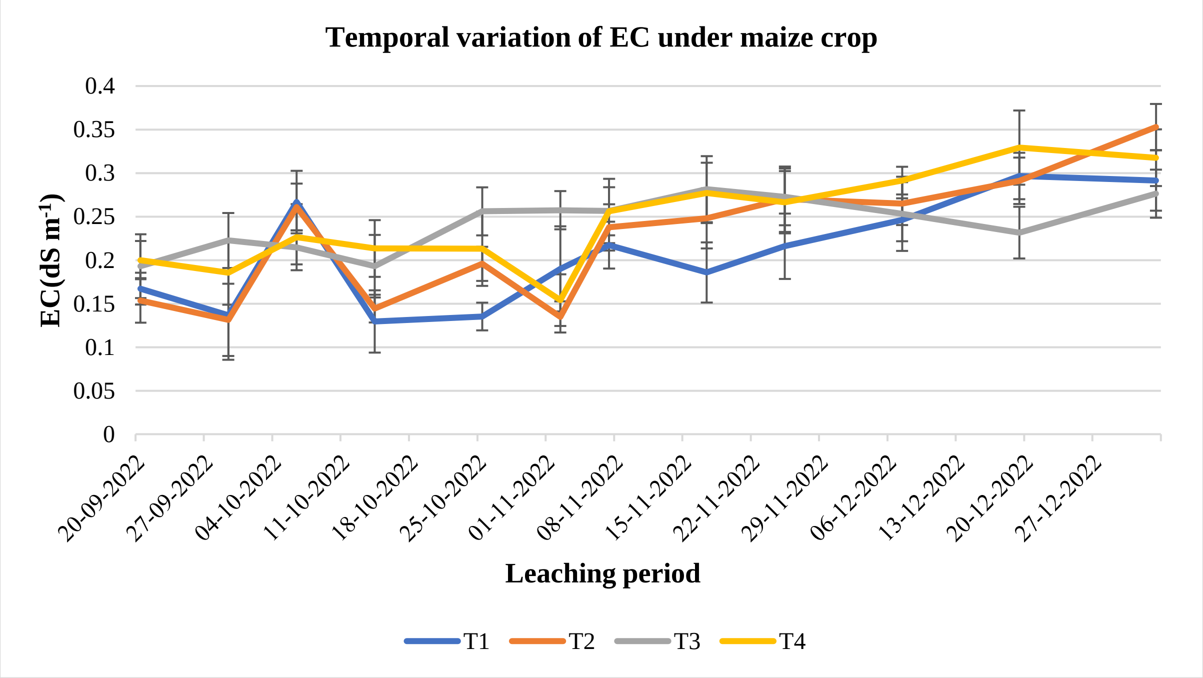

Figure 4.4 Effect of different nutrient management options on the temporal EC (electrical conductivity) variation in maize crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

4.1.3 Effect of different nutrient management options on temporal variation of mineral nitrogen

4.1.3.1 Effect on leaching loss of nitrate-nitrogen

The amount of nitrate-nitrogen present in the leachate under brinjal in different treatments was found highest in T_2 (inorganic) treatment followed by T_4 (INM) and T_3 (organic) treatment in the growing period (Fig. 4.5). The amount of nitrate-nitrogen present in the leachate of T_2 treatment varied between 0.56 to 3.70 kg ha^{-1}, whereas it ranged from 0.66 to 2.58, 0.58 to 2.08, and 0.58 to 1.57 kg ha^{-1} for the INM, organic, control treatments (T_4, T_3, and T_1, respectively), respectively.

The amount of nitrate that leached in the T_2 treatment was at its maximum during the first leaching period, at about 3.70 kg ha^{-1}, before declining over the course of the following five leaching periods, which contained 1.41, 1.54, 1.77, 1.49, and 0.66 kg ha^{-1}. The nitrate-nitrogen leaching then declined again with rates of 2.07, 1.25, and 1.24 kg ha^{-1} in the following three leaching periods after increasing dramatically for a second time in the seventh leaching period with 2.61 kg ha^{-1}. The nitrate leaching, however, surged in the eleventh leaching period, which included 2.7 kg ha^{-1}, before declining until maturity.

With a lower peak value during the growing season, the amount of nitrate-nitrogen leached in the T_4 treatment followed the same trend as the T_2 treatment. Around 2.58 kg ha^{-1} of nitrate was leached in the first stage of the extraction, with subsequent stages containing lower amounts (2.10, 1.44, 1.64, 1.54, and 0.66 kg ha^{-1}). Then, in the seventh leaching stage, which had about 1.73 kg ha^{-1} of nitrate, the leaching increased once more. After that, it gradually decreased in the following three leaching stages, which included 1.67, 1.49, and 1.19 kg ha^{-1}. In the eleventh leaching stage, nitrate leaching climbed once more to 1.85 kg ha^{-1}, and it then started to decline till harvest.

While slightly greater in the early stages in the T_3 and T_1 treatments, the nitrate-nitrogen leaching did not vary much in the growing periods and remained constant throughout the crop growth period.

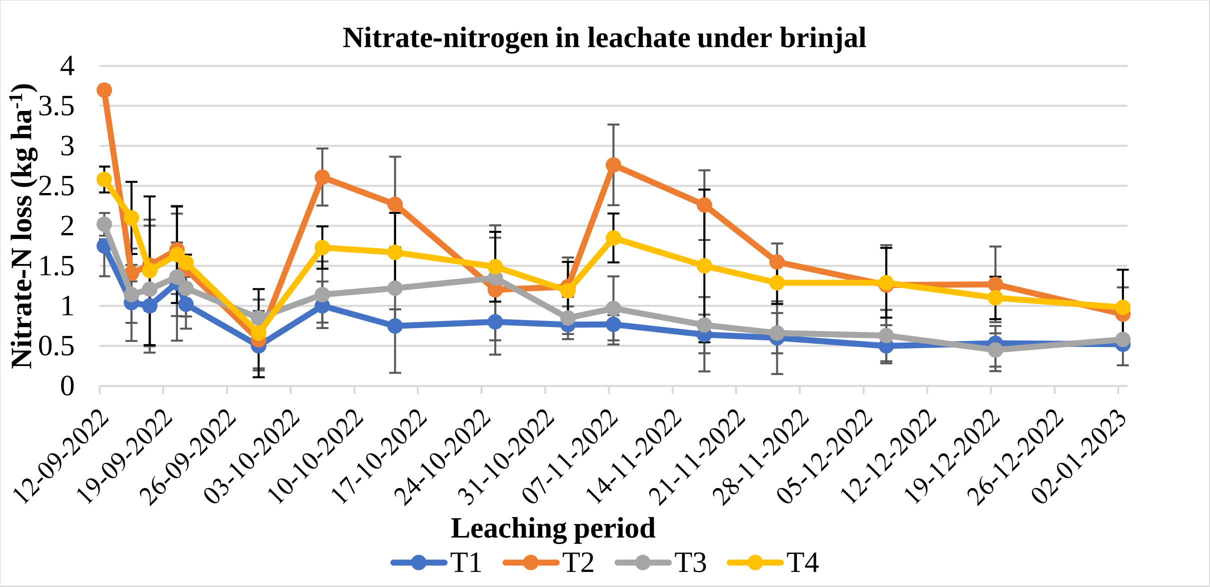

Figure 4.5 Effect of different nutrient management options on the temporal variation of nitrate-nitrogen (NO_3^--N) in brinjal crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

During the growing season, the T_2 (inorganic) treatment had the highest concentration of nitrate-nitrogen in the leachate under maize, followed by the T_4 (INM) and T_3 (organic) treatments (Fig. 4.6). The amount of nitrate-nitrogen found in the leachate of the T_2 treatment ranged from 0.09 to 3.06 kg ha^{-1}, while that of the INM, organic, control treatments (T_4, T_3, and T_1, respectively) ranged from 0.18 to 2.25, 0.09 to 1.90, and 0.11 to 1.70 kg ha^{-1}, respectively. Initially high at 2.79 kg ha^{-1} for the first leaching in the T_2 treatment, the amount of nitrate that leached dropped to 1.01 kg ha^{-1} for the second leaching before rising for the following two leachings. The fourth leaching produced the maximum amount of nitrate-nitrogen leaching (3.06 kg ha^{-1}), which then declined in the fifth and sixth leaching. Once more, nitrate-nitrogen leaching rose during the seventh leaching and then fell off. However, nitrate loss rose once more before maturity, reaching 1.35 kg ha^{-1} in the eleventh leaching. The amount of nitrate-nitrogen leached in the T_4 treatment followed the same pattern as the T_2 treatment but with a lower initial peak value during the growing season. In the first stage of the extraction, about 2.20 kg ha^{-1} of nitrate was leached, and this amount fell during the second leaching. The fourth, seventh, and eleventh leaching stages each produced a high of 2.25, 1.17, and 0.90 kg ha^{-1} of nitrate-nitrogen leaching. The nitrate-nitrogen leaching did not vary significantly during the growth seasons and remained constant throughout, although being slightly larger in the early stages in the T_3 and T_1 treatments.

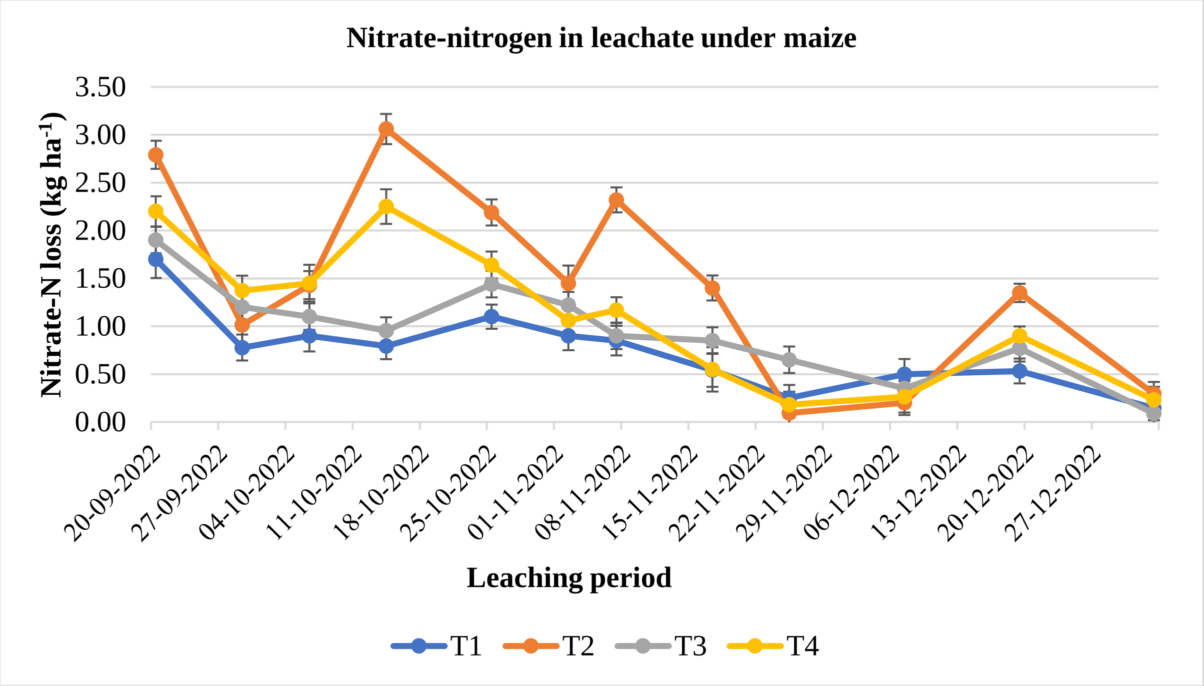

Figure 4.6 Effect of different nutrient management options on the temporal variation of nitrate-nitrogen (NO_3^--N) in maize crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

4.1.3.2 Effect on leaching of ammonium-nitrogen

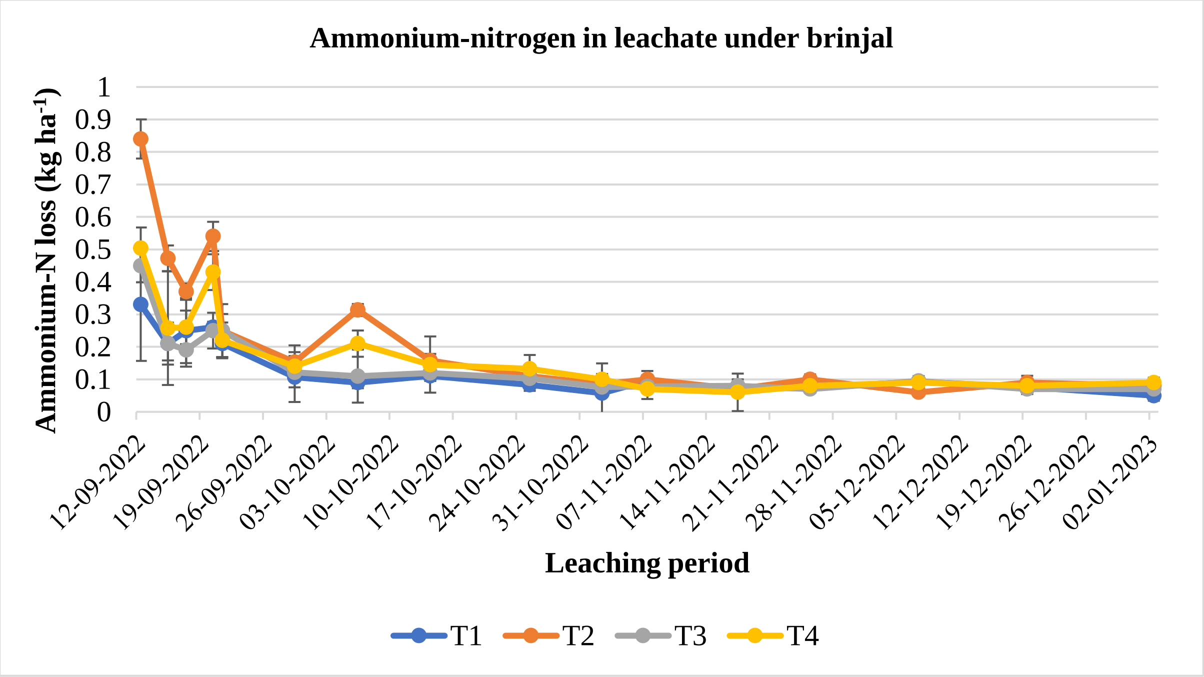

Figure 4.7 Effect of different nutrient management options on the temporal ammonium-nitrogen (NH_4^+-N) variation in brinjal crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

The soil ammonium-nitrogen loss from brinjal was initially substantial but decreased in the later phases of growth (Fig. 4.7). The T_2 treatment (inorganic), followed by the T_4 (INM) and T_3 (organic) treatments, had the largest ammonium-nitrogen loss. Ammonium-nitrogen loss in the T_2 treatment varied during the brinjal growing season, ranging from 0.09 to 0.84 kg ha^{-1} in the sixteen-leaching period. In the T_4 and T_3 treatments, the greatest ammonium leaching loss per period was 0.50 kg ha^{-1} and 0.45 kg ha^{-1}, respectively. In the first, fourth, and seventh leaching periods of the T_2 and T_4 treatments, three high leaching loss values were found.

The amount of ammonium-nitrogen lost in each leaching session in the T_3 and T_1 treatments was initially slightly high but gradually reduced and remained up a consistent loss of ammonium.

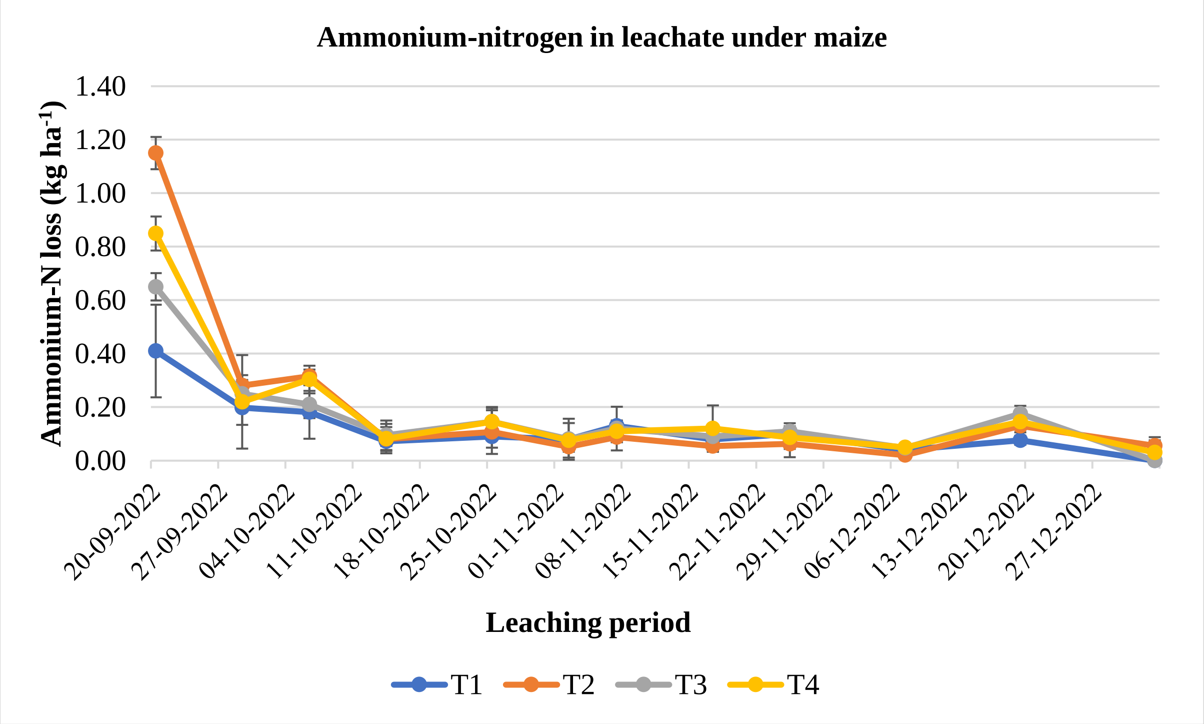

Figure 4.8 Effect of different nutrient management options on the temporal variation of ammonium-nitrogen (NH_4^+-N) in maize crop

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. The line graph represents mean ± SE.

Initially, significant ammonium-nitrogen leaching loss in maize soil was recorded and then gradually decreased as the plant matured (Fig. 4.8). The highest ammonium-nitrogen loss was observed in the T_2 treatment (inorganic), which was followed by the T_4 (INM) and T_3 (organic) treatments. During the twelve-leaching period, ammonium-nitrogen loss in the T_2 treatment varied during the brinjal growing season, ranging from 0.04 to 1.15 kg ha^{-1}. The largest ammonium leaching loss per period was 0.85 kg ha^{-1} in the T_4 treatment and 0.65 kg ha^{-1} in the T_3 treatment. Two substantial leaching loss values were discovered in the first and third leaching periods of the T_2 and T_4 treatments; for T_2, the values were 1.15 and 0.32 kg ha^{-1}, and for T_4, they were 0.85 and 0.30 kg ha^{-1}.

In both the T_3 and T_1 treatments, a consistent loss of ammonium throughout each leaching session, while the amount of ammonium-nitrogen lost was initially slightly higher.

4.1.4 Effect of different nutrient management options on leaching loss of primary nutrient

4.1.4.1 Effect on primary nutrient leaching under brinjal crop

The amount of nitrogen leaching loss under brinjal varied significantly between the treatments (Table 4.1). Nitrogen leaching loss under the brinjal crop ranged from 15.54 to 31.27 kg ha^{-1}. The highest amount of nitrogen leaching loss was noted at 31.27 kg ha^{-1} in the T_2 (inorganic) treatment and was followed by T_4 (INM) and T_3 (organic) treatment with 25.88 kg ha^{-1} and 18.73 kg ha^{-1}, respectively. The minimum nitrogen leaching loss was found as 15.54 kg ha^{-1} in T_1 (control). The amount of ammonium lost by leaching varies from 2.35 to 3.38 kg ha^{-1}. Though there was no significant difference in ammonium loss between T_1 and T_3 treatments, there was a higher amount of ammonium leaching in T_4 and T_2 treatments with 2.96 kg ha^{-1} and 3.38 kg ha^{-1}, respectively. There was a significant difference in nitrate leaching observed among the treatments and ranging between 13.19 to 27.89 kg ha^{-1}. The nitrate leaching loss of the T_2 and T_4 treatments was around 111% and 70% more than the loss in the T_1 treatment, respectively.

Among the treatments, phosphorus leaching loss in the brinjal was less than 0.5 kg ha^{-1}, and the highest loss observed was 0.48 kg ha^{-1} in the T_2 treatment which was followed by T_4 treatment with 0.36 kg ha^{-1}. There was no significant difference in the phosphorus leaching loss between the T_1 and T_3 treatments, which caused a loss of 0.19 kg ha^{-1}.

The leaching loss of potassium from the T_2 treatment was the highest at 19.97 kg ha^{-1}, which was approximately 120% greater than the leaching from the T_1 treatment. With 15.31 kg ha^{-1}, the potassium leaching loss in the T_4 treatment was relatively lower but still 68% higher than the leaching loss in the control treatment. Further, there was no discernible difference observed between the T_1 and T_3 treatments on leaching loss of potassium.

Table 4.1 Effect of different nutrient options on the leaching loss of primary nutrients under brinjal

Treatments	Nutrient management options	Nitrogen leaching loss (kg ha^{-1})	NH_4^+ leaching loss (kg ha^{-1})	NO_3^- leaching loss (kg ha^{-1})	Phosphorus leaching loss (kg ha^{-1})	Potassium leaching loss (kg ha^{-1})
T_1	Control	15.54^d	2.35^c	13.19^d	0.19^d	9.09^c
T_2	Inorganic	31.27^a	3.38^a	27.89^a	0.48^a	19.97^a
T_3	Organic	18.73^c	2.34^c	16.39^c	0.19^d	10.25^c
T_4	INM	25.88^b	2.96^b	22.92^b	0.36^b	15.31^b
SEm (±)		0.919	0.098	0.943	0.029	0.918
LSD(P=0.05)		2.833	0.303	2.905	0.089	2.827

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.1.4.2 Effect on primary nutrient leaching under maize crop

Comparatively less ammonium, nitrate, and available nitrogen leaching loss were found in maize compared to brinjal. Among the treatments, there were considerable differences in the amount of nitrogen that leached out under the maize (Table 4.2). Under the maize crop, nitrogen leaching losses ranged from 10.47 to 19.95 kg ha^{-1}. The T_2 (inorganic) treatment had the maximum nitrogen leaching loss at 19.95 kg ha^{-1}, followed by the T_4 (INM) and T_3 (organic) treatments with 15.49 kg ha^{-1} and 13.38 kg ha^{-1}, respectively. In T_1 (control), the lowest nitrogen leaching loss was discovered to be 10.47 kg ha^{-1}. Leaching results in an ammonium loss of 2.17 to 2.28 kg ha^{-1} among the different treatments. Even so, there was no discernible difference in the amount of ammonium lost across all treatments. The detected nitrate leaching varied significantly among the treatments, ranging from 8.19 to 17.76 kg ha^{-1}. Approximately 117% and 61% more nitrate were lost due to leaching in the T_2 and T_4 treatments, respectively, than in the T_1 treatment.

The phosphorus leaching loss in the maize varied among the treatments, with the T_1 treatment experiencing the lowest loss (0.23 kg ha^{-1}) and the T_2 treatment experiencing the highest loss (0.42 kg ha^{-1}) followed by T_4 treatment (0.32 kg ha^{-1}). The phosphorus leaching loss between the T_1 and T_3 treatments, which resulted in losses of 0.23 and 0.25 kg ha^{-1}, did not differ significantly. The amount of phosphorus lost by leaching was similar for both crops.

The T_2 treatment caused an average of 13.51 kg ha^{-1} of potassium to be lost by leaching, which was almost 80% greater than the T_1 treatment. With 11.31 kg ha^{-1}, the potassium leaching loss in the T_4 treatment was relatively lower but still approximately 51% higher than the leaching loss as compared to the control treatment. Further, there was no discernible difference was observed between the T_1 and T_3 treatments on the leaching loss of potassium. When compared to brinjal, maize showed decreased potassium leaching loss.

Table 4.2 Effect of different nutrient options on the leaching of primary nutrients under maize

Treatments	Nutrient management options	Nitrogen leaching loss (kg ha^{-1})	NH_4^+ leaching loss (kg ha^{-1})	NO_3^- leaching loss (kg ha^{-1})	Phosphorus leaching loss (kg ha^{-1})	Potassium leaching loss (kg ha^{-1})
T_1	Control	10.47^d	2.28	8.19^d	0.23^c	7.50^b
T_2	Inorganic	19.95^a	2.19	17.76^a	0.42^a	13.51^a
T_3	Organic	13.38^c	2.17	11.21^c	0.25^c	8.80^b
T_4	INM	15.49^b	2.22	13.2^b	0.32^b	11.31^{ab}
SEm (±)		0.822	0.213	0.457	0.017	1.097
LSD(P=0.05)		2.232	NS	1.409	0.053	3.380

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.1.5 Effect of different nutrient management options on secondary nutrient and water-soluble carbon leaching

4.1.5.1 Effect on secondary nutrient and water-soluble carbon leaching under brinjal crop

There was a significant difference among the treatments for calcium leaching loss in the brinjal growing season (Table 4.3). The highest amount of calcium leaching loss was observed at 23.81 kg ha^{-1} in the T_2 treatment (inorganic) and the lowest was noted at 15.69 kg ha^{-1} in the T_3 treatment (organic). Calcium leaching loss was noted at 18.73 and 19.21 kg ha^{-1} in T_4 (INM) and T_1 (control) treatments, respectively. The highest amount of magnesium leaching loss was observed in T_2 (11.13 kg ha^{-1}), followed by T_1 (10.56 kg ha^{-1}) and T_4 (9.36 kg ha^{-1}) treatment. The lowest magnesium leaching was found in organic treatment (8.36 kg ha^{-1}).

The highest sulphur leaching loss was observed at 19.66 kg ha^{-1} in the T_1 treatment, decreasing further in T_4 (14.70 kg ha^{-1}), T_3 (13.37 kg ha^{-1}) and T_2 (10.10 kg ha^{-1}) treatments. Water soluble carbon leached under brinjal crop did not vary significantly, found at 1.06, 1.26 and 1.10 kg ha^{-1} in T_2, T_3, and T_4

treatments respectively. The lowest amount of dissolved organic carbon leaching was found at 0.57 kg ha^{-1} in the T_1 treatment.

Table 4.3 Effect of different nutrient options on the leaching of secondary nutrients and water-soluble carbon under brinjal

Treatments	Nutrient management options	Calcium leaching loss (kg ha^{-1})	Magnesium leaching loss (kg ha^{-1})	Sulphur leaching loss (kg ha^{-1})	Dissolved organic carbon leaching loss (kg ha^{-1})
T_1	Control	19.21^{b}	10.56^{ab}	19.66^{a}	0.57^{b}
T_2	Inorganic	23.81^{a}	11.13^{a}	10.10^{c}	1.06^{a}
T_3	Organic	15.69^{c}	8.36^{c}	13.37^{b}	1.26^{a}
T_4	INM	18.73^{b}	9.36^{bc}	14.70^{b}	1.10^{a}
SEm ($\underline{+}$)		0.979	0.555	0.719	0.082
LSD(P=0.05)		3.015	1.711	2.214	0.253

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.1.5.2. Effect on secondary nutrient and water-soluble carbon leaching under maize crop

Compared to brinjal-growing areas, maize-growing areas showed less calcium and magnesium leaching loss. In the maize growth season, there was a significant difference among the treatments for calcium leaching loss (Table 4.4). The T_2 treatment (inorganic) had the largest calcium leaching loss at 14.68 kg ha^{-1}, whereas the T_3 treatment (organic) had the lowest at 9.79 kg ha^{-1}. Further calcium leaching loss at 11.67 and 13.15 kg ha^{-1} was observed in the T_4 (INM) and T_1 (control) treatments, respectively. With an average loss of 7.36 kg ha^{-1}, the magnesium leaching loss differential across the treatments was not statistically significant.

Sulphur leaching loss was more prevalent under maize than brinjal, and it was measured at 23.32 kg ha^{-1} in the T_1 treatment, declining to 16.32, 11.19, and 8.27 kg ha^{-1} in the T_3, T_4, and T_2 treatments, respectively. In T_1, T_2, and T_4 treatments, the amounts of dissolved organic carbon that were leached from the maize crop were 0.53, 0.87, and 0.93 kg ha^{-1}, respectively. The highest water-soluble carbon leached out was 1.16 kg ha^{-1} in the T_3 treatment.

Table 4.4 Effect of different nutrient options on the leaching of secondary nutrients and water-soluble carbon under maize

Treatments	Nutrient management options	Calcium leaching loss (kg ha^{-1})	Magnesium leaching loss (kg ha^{-1})	Sulphur leaching loss (kg ha^{-1})	Dissolved organic carbon leaching loss (kg ha^{-1})
T_1	Control	13.15^{ab}	7.37	23.32^{a}	0.53^{c}
T_2	Inorganic	14.68^{a}	7.83	8.27^{c}	0.87^{b}
T_3	Organic	9.79^{c}	7.02	16.32^{b}	1.16^{a}
T_4	INM	11.67^{bc}	7.20	11.19^{c}	0.93^{ab}
SEm ($\pm$)		1.078	0.525	1.019	0.066
LSD(P=0.05)		3.321	NS	3.140	0.202

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2 Effect of different nutrient management options on the depth-wise distribution of available nutrient contents in post-harvest soil samples

4.2.1 Effect of different nutrient management options on the depth-wise distribution of major soil chemical properties in post-harvest soil

4.2.1.1 Effect on pH variation in the post-harvest soil

A significant difference in pH was noticed in the mean effect of treatment and the mean effect of depth in the post-harvest soil under the brinjal in lysimeter (Table 4.5). The highest mean pH value was noted in the T_3 treatment (5.74) followed by the T_4 treatment (5.38). The lowest pH value was found 5.06 in the T_2 treatment. There was a sharp variation between 0-15, 15-30 and 30-45 cm soil layer in the soil profile. The highest mean pH value was found at 5.92 in the topsoil layer and further decreased in the D_2(5.42) and D_3(5.01) layers. There was also a significant interaction effect was observed in between soil depth and treatments. The highest pH value was 6.57 in the top soil layer of T_3 treatment (organic).

Table 4.5 Effect of different nutrient management options on depth-wise distribution pH in post-harvest soil of brinjal in lysimeter

Soil pH					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	5.70^{c}	5.16^{fg}	4.87^{i}	5.03^{ghi}	5.19^{C}
T_2	5.41^{d}	5.07^{fgh}	4.86^{i}	4.91^{hi}	5.06^{D}
T_3	6.57^{a}	6.02^{b}	5.24^{e}	5.13^{fg}	5.74^{A}
T_4	6.01b	5.42^{e}	5.07^{fgh}	5.01^{ghi}	5.38^{B}
Mean depth	5.92^{A}	5.42^{B}	5.01^{C}	5.02^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.027	0.027	0.054		
LSD(P=0.05)	0.077	0.077	0.153		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same capital letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

The post-harvest soil within the maize in lysimeter showed a significant variation in pH among the mean effects of treatment and the mean effects of depth (Table 4.6). The T_3 treatment was shown to have the highest mean pH value (5.57), followed by the T4 treatment (5.37). The pH 5.09 was discovered to be the lowest pH value in the T_2 treatment. The soil profile showed a strong gradient between the 0–15, 15–30, and 30-45 cm soil layers. The D_2 (5.40) and D_3 (5.06) layers had the lowest mean pH values, whereas the top soil layer had the highest mean pH value of 5.83. Additionally, there was a significant interaction impact between soil depth and treatments. The organic T_3 treatment of the top soil layer had a pH value of 6.47, which was the highest.

Table 4.6 Effect of different nutrient management options on depth-wise distribution pH in post-harvest soil of maize in lysimeter

Soil pH					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	5.78^{b}	5.36^{cd}	4.98^{efg}	5.05^{efg}	5.29^{B}
T_2	5.07^{efg}	4.93^{fg}	5.16^{def}	5.22^{cd}	5.09^{C}
T_3	6.47^{a}	5.87^{b}	5.07^{efg}	4.88^{g}	5.57^{A}
T_4	6.02^{g}	5.43^{c}	5.03^{efg}	5.02^{efg}	5.37^{B}
Mean depth	5.83^{A}	5.40^{B}	5.06^{C}	5.04^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.042	0.042	0.084		
LSD(P=0.05)	0.118	0.118	0.237		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.1.2 Effect of different nutrient management options on the depth-wise distribution of electrical conductivity

There was no significant difference in the mean effect of treatments in the electrical conductivity of post-harvest soil in the brinjal in lysimeter (Table 4.7). A significantly higher value of electrical conductivity was found in the top soil layer (0.77 dS m^{-1}) compared to lower depths. It was visible that electrical conductivity in soil decreased with an increase in soil depth. No significant interaction effect was noticed in between treatments and depths variation within the soil profile.

Table 4.7 Effect of different nutrient management options on depth-wise distribution EC (electrical conductivity) in post-harvest soil of brinjal in lysimeter

EC (dS m^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	0.73	0.63	0.71	0.65	0.68
T_2	0.79	0.58	0.71	0.70	0.69
T_3	0.79	0.67	0.55	0.72	0.68
T_4	0.76	0.60	0.69	0.73	0.69
Mean depth	0.77^{A}	0.62^{C}	0.67^{BC}	0.70^{B}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.028	0.028	0.056		
LSD(P=0.05)	NS	0.156	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT);

In the maize in lysimeter, there was no discernible difference among the mean effects of treatments on the electrical conductivity of post-harvest soil (Table 4.8). Even so, the electrical conductivity of top soil layer was found to be much higher (0.71 dS m^{-1}) than that of lower depths. It was evident that as soil depth increased, electrical conductivity in the soil reduced. No significant interaction effect between treatment and soil profile depths was found.

Table 4.8 Effect of different nutrient management options on depth-wise distribution EC (electrical conductivity) in post-harvest soil of maize in lysimeter

EC (dS m^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	0.73	0.58	0.66	0.63	0.65
T_2	0.70	0.68	0.56	0.57	0.62
T_3	0.73	0.66	0.64	0.58	0.65
T_4	0.69	0.72	0.55	0.73	0.68
Mean depth	0.71^A	0.66^B	0.60^C	0.63^{BC}	0.65
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.024	0.024	0.049		
LSD(P=0.05)	NS	0.069	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.1.3 Effect of different nutrient management options on the depth-wise distribution of easily oxidizable organic carbon

In the post-harvest soil under brinjal in lysimeter, it was noted a mean effect of treatment with a higher amount of organic carbon in the T_3 treatment (0.43%) compared to T_4 (0.42%) and T_2 (0.40%) treatments (Table 4.9). Easily oxidizable organic carbon decreased significantly with the increase in depth. The highest amount of organic carbon was found in D_1 (0.57%) and decreased respectively in D_2 (0.39%), D_3 (0.35%), and D_4 (0.31%). There was a significant interaction effect observed between the treatment and profile layers. The highest oxidizable organic carbon was found at 0.70% in the topsoil layer of the organic treatment.

Table 4.9 Effect of different nutrient management options on the depth-wise distribution of easily oxidizable organic carbon in post-harvest soil of brinjal in lysimeter

OC (%)					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	0.49^{cd}	0.39^{efg}	0.34^{fghij}	0.29^{j}	0.38^{C}
T_2	0.50^{c}	0.36^{fghi}	0.40^{ef}	0.32^{ij}	0.40^{BC}
T_3	0.70^{a}	0.39^{efg}	0.34^{fghij}	0.31^{ij}	0.43^{A}
T_4	0.61^{b}	0.43^{cd}	0.33^{ghij}	0.31^{ij}	0.42^{AB}
Mean depth	0.57^{A}	0.39^{B}	0.35^{C}	0.31^{D}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.009	0.009	0.018		
LSD(P=0.05)	0.025	0.025	0.050		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

In the soil within the lysimeter of maize, the T_3 treatment (0.43%) showed a mean effect of treatment with a higher amount of organic carbon compared to the T_4 (0.40%) and T_2 (0.39%) treatments (Table 4.10). With the increase in depth, the amount of easily oxidizable organic carbon drastically decreased. The mean effect of depth of D_1 accounted for the highest content of organic carbon (0.56%) and reduced respectively in D_2 (0.35%), D_3 (0.34%), and D_4 (0.31%). The treatment and profile layers had a notable interaction effect. The topsoil layer of the organic treatment noted the highest amount of easily oxidizable carbon (0.71%).

Table 4.10 Effect of different nutrient management options on the depth-wise distribution of easily oxidizable organic carbon in post-harvest soil of maize in lysimeter

OC (%)					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	0.44^{d}	0.37^{e}	0.34^{ef}	0.27^{f}	0.36^{C}
T_2	0.51^{c}	0.34^{e}	0.36^{e}	0.33^{ef}	0.39^{B}
T_3	0.71^{a}	0.35^{e}	0.32^{ef}	0.32^{ef}	0.43^{A}
T_4	0.57^{b}	0.35^{e}	0.33^{ef}	0.33^{ef}	0.40^{B}
Mean depth	0.56^{A}	0.35^{B}	0.34^{BC}	0.31^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm ($\pm$)	0.010	0.010	0.019		
LSD(P=0.05)	0.027	0.027	0.055		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.2 Effect of different nutrient management options on the depth-wise distribution of primary nutrients

4.2.2.1 Effect on depth-wise variation of available nitrogen

The mean effect of treatments on available nitrogen was significantly higher in the T_2 (214.2 kg ha^{-1}) and T_4 (213.3 kg ha^{-1}) treatments compared to T_3 (199 kg ha^{-1}) and T_1 (165.6 kg ha^{-1}) treatments in the postharvest soil of brinjal (Table 4.11). A notable mean effect of depth was also visible; the highest amount of available nitrogen in D_2 (220.9 kg ha^{-1}) and decreased respectively in D_1 (201.3 kg ha^{-1}), D_3 (185.5 kg ha^{-1}) and D_4 (183.4 kg ha^{-1}). The interaction effect of nutrient management options and soil depth showed the highest available nitrogen in the 15-30 cm soil layer (D_2) of inorganic treatment (T_2).

Table 4.11 Effect of different nutrient management options on the depth-wise distribution of available nitrogen in post-harvest soil of brinjal in lysimeter

Available nitrogen (kg ha^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	162.0^{i}	180.3^{g}	154.6^{i}	165.4^{hi}	165.6^{C}
T_2	219.5^{bcd}	245.0^{a}	196.8^{ef}	195.6^{f}	214.2^{A}
T_3	208.0^{def}	231.4^{b}	180.5^{g}	176.2^{gh}	199.0^{B}
T_4	215.8^{cd}	226.8^{bc}	210.1^{de}	196.4^{ef}	212.3^{A}
Mean depth	201.3^{B}	220.9^{A}	185.5^{C}	183.4^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	2.276	2.276	4.552		
LSD(P=0.05)	6.437	6.437	12.874		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

In the post-harvest soil of maize, the mean effect of treatments on the available nitrogen was considerably higher in the T_2 (219.0 kg ha^{-1}) than in the T_4 (209.4 kg ha^{-1}), T_3 (204.7 kg ha^{-1}) and T_1 (177.6 kg ha^{-1}) treatments (Table 4.12). The mean effect of soil depth showed the amount of accessible nitrogen was at its peak in D_2 (221.7 kg ha^{-1}), and it declined in D_1 (203.5 kg ha^{-1}), D_3 (196.1 kg ha^{-1}), and D_4 (189.5 kg ha^{-1}). This indicated a considerable mean influence of depth. Comparing the interaction effect of treatments and soil depth, the maximum amount of accessible nitrogen was found in the 15–30 cm soil layer (D_2) of the inorganic treatment (T_2), out of all the soil layers and nutrient management methods.

Table 4.12 Effect of different nutrient management options on the depth-wise distribution of available nitrogen in post-harvest soil of maize in lysimeter

Available nitrogen (kg ha^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	159.7^{g}	190.6^{def}	183.0^{ef}	177.2^{f}	177.6^{C}
T_2	222.0^{b}	255.9^{a}	202.0^{cd}	196.1^{cde}	219.0^{A}
T_3	211.6^{bc}	220.8^{b}	197.3^{cde}	189.1^{def}	204.7^{B}
T_4	220.5^{b}	219.5^{b}	202.0^{cd}	195.7^{cde}	209.4^{B}
Mean depth	203.5^{B}	221.7^{A}	196.1^{BC}	189.5^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm ($\pm$)	2.54	2.54	5.08		
LSD(P=0.05)	7.18	7.18	14.36		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.2.2 Effect on depth-wise variation of available phosphorus

In the post-harvest soil of brinjal, the lysimeter showed a significant mean effect of treatments, soil depth and interaction effect on the available phosphorus (Table 4.13). The mean effect of treatments showed the highest amount of available phosphorus in T_2 treatment, though there was not much difference between T_4 and T_3 treatments. Further, the mean effect of soil depth on the available phosphorus content was more in the topsoil layer (33.30 kg ha^{-1}), and decreased significantly in the lower depth of soil profile. The interaction effect of treatment and soil depth recorded the highest content of available phosphorus in the top layer of T_2, T_3 and T_4 treatments.

Table 4.13 Effect of different nutrient management options on the depth-wise distribution of available phosphorus in post-harvest soil of brinjal in lysimeter

Available phosphorus (kg ha^{-1})					
	Soil depths				
Treatments	D$_1$	D$_2$	D$_3$	D$_4$	Mean treatment
T$_1$	21.81^{bcd}	14.61^{f}	17.62^{ef}	11.88^{g}	16.48^{D}
T$_2$	36.87^{a}	25.33^{b}	25.14^{b}	24.06^{bc}	27.85^{A}
T$_3$	37.33^{a}	21.33^{bcde}	21.50^{bcde}	18.35^{de}	24.63^{B}
T$_4$	37.19^{a}	24.29^{bc}	20.36^{cde}	21.48^{bcde}	25.83^{B}
Mean depth	33.30^{A}	21.39^{B}	21.16^{B}	18.94^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm ($\pm$)	0.583	0.583	1.167		
LSD(P=0.05)	1.650	1.650	3.300		

T$_1$: N0P0K0 (Control); T$_2$: 100% RDF as inorganic; T$_3$: 100% RDF as organic; T$_4$: 50% RDF as inorganic + 50% RDF as organic. D$_1$: 0-15 cm depth; D$_2$: 15-30 cm depth; D$_3$: 30-45 cm depth; D$_4$: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

The study in the lysimeter revealed that a substantial mean effect in the amount of available phosphorus among treatments, within the soil profile, and their interaction in the post-harvest soil of maize (Table 4.14). The mean effect of treatments showed no significant difference among the T$_4$, T$_3$ and T$_2$ treatments, while the lowest phosphorus content was found in the control plot. The mean effect of soil depth noted that the topsoil layer (30.32 kg ha^{-1}) had a higher available phosphorus level, while the bottom soil profile had a much smaller amount. Comparing the interaction effect of treatment and soil depth, it was observed that the T$_2$, T$_3$, and T$_4$ treatments had the highest concentration of available phosphorus in the surface soil.

Table 4.14 Effect of different nutrient management options on the depth-wise distribution of available phosphorus in post-harvest soil of maize in lysimeter

Available phosphorus (kg ha^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	25.47^{b}	13.16^{cd}	11.77^{d}	9.49^{d}	14.97^{B}
T_2	32.28^{a}	24.16^{b}	16.76^{c}	16.47^{c}	22.42^{A}
T_3	31.67^{a}	24.04^{b}	16.15^{c}	15.88^{c}	21.93^{A}
T_4	31.88^{a}	26.04^{b}	16.03^{c}	15.74^{c}	22.42^{A}
Mean depth	30.32^{A}	21.85^{B}	15.18^{C}	14.39^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.613	0.613	1.227		
LSD(P=0.05)	1.735	1.735	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.2.3 Effect on depth-wise variation of available potassium

In the post-harvest soil under both crops, a notable mean effect of treatment, depth and interaction was found (Table 4.15 and 4.16). The mean effect of treatments on the highest amount of available potassium was found in the T_3 treatment (209.7 kg ha^{-1} in brinjal and 195.3 kg ha^{-1} in maize). The mean effect of soil depth on available potassium decreased significantly with increase in soil depth. The highest available potassium was recorded at the top layer of the profile (206.9 kg ha^{-1} in brinjal and 199.9 kg ha^{-1} in maize). Comparing the interaction effect, the highest available potassium was noticed in the upper layer of organic and INM treatments.

Table 4.15 Effect of different nutrient management options on the depth-wise distribution of available potassium in post-harvest soil of brinjal in lysimeter

Available potassium (kg ha^{-1})					
	Soil depths				
Treatments	D$_1$	D$_2$	D$_3$	D$_4$	Mean treatment
T$_1$	155.7^{gh}	142.0^{hi}	135.7^{ij}	124.4^{j}	139.4^{D}
T$_2$	201.9^{cd}	178.3^{ef}	166.7^{fg}	155.2^{gh}	175.5^{C}
T$_3$	240.3^{a}	226.1^{ab}	200.8^{cd}	171.7^{fg}	209.7^{A}
T$_4$	229.7^{ab}	217.0^{bc}	190.3^{de}	160.8^{fg}	199.4^{B}
Mean depth	206.9^{A}	190.9^{B}	173.3^{C}	153.0^{D}	
	Treatment (T)	Depth (D)	T x D		
SEm ($\pm$)	2.869	2.869	8.114		
LSD(P=0.05)	8.114	8.114	16.228		

T$_1$: N0P0K0 (Control); T$_2$: 100% RDF as inorganic; T$_3$: 100% RDF as organic; T$_4$: 50% RDF as inorganic + 50% RDF as organic. D$_1$: 0-15 cm depth; D$_2$: 15-30 cm depth; D$_3$: 30-45 cm depth; D$_4$: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

Table 4.16 Effect of different nutrient management options on the depth-wise distribution of available potassium in post-harvest soil of maize in lysimeter

Available potassium (kg ha^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	146.9^{fg}	138.5^{ghi}	129.2^{hi}	125.0i	134.9^{D}
T_2	194.8^{bc}	170.2^{de}	166.5^{de}	141.3^{gh}	168.2^{C}
T_3	234.0^{a}	199.1^{b}	182.5^{cd}	165.7^{e}	195.3^{A}
T_4	223.8^{a}	189.9^{bc}	173.0^{de}	160.0^{ef}	186.7^{B}
Mean depth	199.9^{A}	174.4^{B}	162.8^{C}	148.0^{D}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	2.651	2.651	5.301		
LSD(P=0.05)	7.497	7.497	14.994		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.3 Effect of different nutrient management options on the depth-wise distribution of secondary nutrients

4.2.3.1 Effect on depth-wise variation on exchangeable calcium

A significant mean effect of treatment, depth and interaction was found in the exchangeable calcium content in the post-harvest soil of brinjal in lysimeter (Table 4.17). Within the mean effect of treatments, a higher content of exchangeable calcium was found in the T3 treatment (4.68 cmol(p^+) kg^{-1}) and lowest in the inorganic treatment (3.69 cmol(p^+) kg^{-1}). Among the mean effect of soil layers, the highest exchangeable calcium was noted in D_1(4.57 cmol(p^+) kg^{-1}) and decreased with an increase in soil depth. The interaction effect of treatment and soil depth showed the highest exchangeable calcium in the topsoil layer of organic treatment (5.98 cmol(p^+) kg^{-1}).

The exchangeable calcium concentration in the post-harvest soil in the maize in lysimeter showed a significant mean effect of treatment, depth, and interaction (Table 4.18). The mean effect of T_3 treatment had the highest exchangeable calcium content among the treatments (4.26 cmol(p^+) kg^{-1}), while the T_1 treatment had the lowest (3.53 cmol(p^+) kg^{-1}). The mean effect of soil depth on maximum amount of exchangeable calcium was found in soil layer D_1 (4.30 cmol(p^+) kg^{-1}), and it further declined as soil depth increased. The interaction effect of treatment and soil depth recorded the maximum exchangeable calcium concentration (5.36 cmol(p^+) kg^{-1}) in the topsoil layer with organic treatment.

Table 4.17 Effect of different nutrient management options on the depth-wise distribution of exchangeable calcium in post-harvest soil of brinjal in lysimeter

Exchangeable calcium [cmol(p^+) kg^{-1}]					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	4.11^{cde}	3.69^{ef}	3.65^{ef}	3.56^{f}	3.75^{C}
T_2	3.79^{def}	3.77^{def}	3.62^{f}	3.59^{f}	3.69^{C}
T_3	5.98^{a}	4.84^{b}	4.17^{cd}	3.72^{def}	4.68^{A}
T_4	4.40^{c}	4.16^{cd}	4.25^{c}	3.75^{def}	4.14^{B}
Mean depth	4.57^{A}	4.11^{B}	3.92^{B}	3.65^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.062	0.062	0.125		
LSD(P=0.05)	0.176	0.176	0.353		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

Table 4.18 Effect of different nutrient management options on the depth-wise distribution of exchangeable calcium in post-harvest soil of maize in lysimeter

Exchangeable calcium [cmol(p$^+$) kg^{-1}]					
	Soil depths				
Treatments	D$_1$	D$_2$	D$_3$	D$_4$	Mean treatment
T$_1$	3.74^{def}	3.57^{def}	3.30^{f}	3.52^{def}	3.53^{C}
T$_2$	3.96^{bcd}	3.86^{bcde}	3.47^{ef}	3.46^{ef}	3.69^{BC}
T$_3$	5.36^{a}	4.29^{b}	3.93^{bcde}	3.45^{ef}	4.26^{A}
T$_4$	4.16^{bc}	3.92^{bcde}	3.83^{bcde}	3.34^{f}	3.81^{B}
Mean depth	4.30^{A}	3.91^{B}	3.63^{C}	3.44^{C}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.061	0.061	0.122		
LSD(P=0.05)	0.173	0.173	0.346		

T$_1$: N0P0K0 (Control); T$_2$: 100% RDF as inorganic; T$_3$: 100% RDF as organic; T$_4$: 50% RDF as inorganic + 50% RDF as organic. D$_1$: 0-15 cm depth; D$_2$: 15-30 cm depth; D$_3$: 30-45 cm depth; D$_4$: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.3.2 Effect on depth-wise variation of exchangeable magnesium

The exchangeable magnesium content was found below the critical limit in every soil layer of all the treatments. In the soil of the brinjal in lysimeter, there was a significant mean effect of depth in exchangeable magnesium content (Table 4.19). Though in the control treatment, a lower amount of exchangeable magnesium was present (0.32 cmol(p$^+$) kg^{-1}) but no notable variation was found in the mean effect of inorganic, organic and INM treatments. The mean effect of soil depth showed the higher amount of magnesium in the lower depth compared to upper soil layers though the variation was very small.

There was a considerable mean effect of depth in exchangeable magnesium content in the postharvest-soil of the maize in lysimeter (Table 4.20). Although there was less exchangeable magnesium in the control treatment (0.27 cmol(p$^+$) kg^{-1}), there was no discernible difference among the mean effect of inorganic, organic, and INM treatments. The mean effect of soil depth recorded more magnesium in the lower soil layers than the upper soil layers although the difference was relatively small. The interaction effect of treatment and soil depth for both crops of brinjal and maize was non-significant.

Table 4.19 Effect of different nutrient management options on the depth-wise distribution of exchangeable magnesium in post-harvest soil of brinjal in lysimeter

Exchangeable magnesium (cmol(p^+) kg^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	0.25	0.28	0.30	0.45	0.32^{B}
T_2	0.45	0.50	0.53	0.60	0.52^{A}
T_3	0.45	0.47	0.53	0.63	0.52^{A}
T_4	0.51	0.51	0.55	0.56	0.53^{A}
Mean depth	0.42^{C}	0.44^{C}	0.48^{B}	0.56^{A}	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.013	0.013	0.025		
LSD(P=0.05)	0.035	0.035	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

Table 4.20 Effect of different nutrient management options on the depth-wise distribution of exchangeable magnesium in post-harvest soil of maize in lysimeter

Exchangeable magnesium [cmol(p^+) kg^{-1}]					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	0.17	0.25	0.27	0.40	0.27^C
T_2	0.40	0.46	0.54	0.57	0.49^A
T_3	0.40	0.46	0.51	0.54	0.48^{AB}
T_4	0.36	0.41	0.48	0.54	0.45^B
Mean depth	0.33^D	0.40^C	0.45^B	0.51^A	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.012	0.012	0.025		
LSD(P=0.05)	0.035	0.035	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT); values noted with the same small letter, interaction effect are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

4.2.3.3 Effect on depth-wise variation of exchangeable sulphur

There was a significant mean effect of treatment and mean effect of depth in the available sulphur content in the post-harvest soil of the brinjal in lysimeter, but there was no significant interaction effect in 0.05 level of probability (Table 4.21). The highest amount of available sulphur was found in the mean effect of T_1 (32.62 kg ha^{-1}), but there was no notable difference observed between organic and inorganic treatments. The mean effect of soil depth showed that the highest available sulphur was recorded in the surface soil and gradually decreased with the increase in soil depth (ranged from 30.91 kg ha^{-1} to 23.13 kg ha^{-1}).

The readily available sulphur content in the post-harvest soil of the maize in lysimeter showed significant mean effects of treatment and depth, but there was no interaction impact at the 0.05 level of probability (Table 4.22). The mean effect of T_1 had the highest concentration of sulphur (33.70 kg ha^{-1}), but there was no discernible difference between the organic and inorganic treatments. The mean effect of soil depth on accessible sulphur content among the soil layers fell from 36.09 to 23.06 kg ha^{-1} as soil depth increased.

Table 4.21 Effect of different nutrient management options on the depth-wise distribution of available sulphur in post-harvest soil of brinjal in lysimeter

Available sulphur (kg ha^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	40.77	33.05	27.08	29.58	32.62^A
T_2	27.93	31.35	23.54	22.17	26.25^B
T_3	29.62	23.37	21.59	21.31	23.97^B
T_4	25.32	20.22	19.99	19.44	21.24^D
Mean depth	30.91^A	27.00^B	23.05^C	23.13^C	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.973	0.973	1.946		
LSD(P=0.05)	2.752	2.752	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT)

Table 4.22 Effect of different nutrient management options on the depth-wise distribution of available sulphur in post-harvest soil of maize in lysimeter

Available sulphur (kg ha^{-1})					
	Soil depths				
Treatments	D_1	D_2	D_3	D_4	Mean treatment
T_1	40.15	33.76	30.32	30.58	33.70^A
T_2	33.73	22.89	21.78	19.86	24.57^B
T_3	36.74	27.23	20.31	19.47	25.94^B
T_4	33.75	27.64	22.15	22.35	26.47^B
Mean depth	36.09^A	27.88^B	23.64^C	23.06^C	
	Treatment (T)	Depth (D)	T x D		
SEm (±)	0.902	0.902	1.803		
LSD(P=0.05)	2.550	2.550	NS		

T_1: N0P0K0 (Control); T_2: 100% RDF as inorganic; T_3: 100% RDF as organic; T_4: 50% RDF as inorganic + 50% RDF as organic. D_1: 0-15 cm depth; D_2: 15-30 cm depth; D_3: 30-45 cm depth; D_4: 45-60 cm depth. Within a column, values indicated by the same letters are not significantly different at the 0.05 level of probability by Duncan's multiple range test (DMRT);

5.1 Effect of different nutrient management practices on temporal variation of leaching

5.1.1. Changes in leachate pH

The pH was initially lower during the growth stages, but it increased over subsequent leaching periods to remain neutral. Leachate pH might be decreased initially through the addition of additional nutrients. James *et al.* (2001) discovered that when fertiliser treatment increased, the pH of begonias' leachate fell. The authors hypothesised that this resulted from the plants absorbing more cations due to the greater fertiliser concentrations, which left more anions in the leachate. These anions, including nitrate and chloride, can cause the pH of leachate to decrease. In a column investigation, Pal (2018) noted an increase in leachate pH in the subsequent leaching phase attributing that the pH of the soil leachate increased as a result of organic matter breakdown.

5.1.1 Variation in leachate electrical conductivity

In all treatments for both crops of brinjal and maize, electrical conductivity was higher in the early phases of leaching, dropped in midseason, and increased once more in maturity. Due to external nutrient supplies and the mineralization of organic matter, crop development started with a higher nutritional content. According to Conover *et al.* (1992), electrical conductivity (EC) of leachate increased with fertilization. The authors concluded that the corresponding EC level increased with increasing fertilizer rate, which caused greater concentration of dissolved nutrients in the water. These nutrients raised the EC of the leachate when they are introduced to a growth medium. In addition, Van Iersel (2001) noted that the increased application of fertilizer had increased electrical conductivity. They found that if the fertilizer EC was 2.5 dS m^{-1} or higher, the leachate EC of plants fertilized with constant fertilizer concentrations increased throughout the trial, remained stable in the 1.5 dS m^{-1} treatment, and fell in the 0.5 dS m^{-1} treatment. Electrical conductivity is considerably increased by internal nutrition sources created by the mineralization of organic matter. This was confirmed by Garbowski (2019), who looked at how pine bark leachates changed over the course of 10 days in terms of their electrical conductivity (EC). They discovered that the mineralization of the pine bark correlated with the large long-term increase in the EC of the leachates. Due to the prevailing dry season, the electrical conductivity of leachate increased in the later phases of growth. The electrical conductivity (EC) of leachate might rise during dry seasons. This is because, due to the decomposition of organic matter in the soil following oxidation process contributing to higher concentration of dissolved salts and other substances. The concentration of salts and other elements increases when there is less water in the soil, raising the EC of the leachate. The electrical conductivity of leachate from two landfills on Long Island, New York, was much higher during drier seasons than during wetter seasons, as reported by Kimmel *et al.* (1977). According to the authors, drier seasons result in lower watertables, which in turn allows more leachate to come into touch with the soil and other materials that can increase electrical conductivity.

5.1.2 Variation in mineral nitrogen in the leachate

During the crop growth stages, there were significant changes in ammonium and nitrate-nitrogen over time. Both ammonium and nitrate levels showed an initial higher concentration of nitrogen leaching. This might be a result of the nutrient source from the organic, INM, and inorganic treatments in the initial stages. Although the primary agricultural practice thought to be accountable for major nutrient leaching is the use of mineral fertilizers (Zhou *et al.,* 2006), loss of nutrients also occurs when organic fertilisers are applied. In other investigations of perennial grass crops, increased NO_3^--leaching was found to vary throughout the first phase of crop establishment (McIsaac *et al.,* 2010; Diaz-Pines *et al.,* 2016). In a radioisotope-induced leaching investigation, Ghiberto *et al.* (2015) found that the abundance of ^{15}N was higher than the isotope's natural abundance during the times when mineral N concentrations peaked, then decreased until the end of cycle. Furthermore, soils with increased N input that do not apply organic manure, such as in T_2, may have a high infiltration rate and a limited capacity to retain nutrients, which favours N-leaching loss (Huddell *et al.,* 2020). Compared to the organic treatment, INM and inorganic treatments had a higher level of N-leaching intensity, which resulted from more nitrogen leaching in both ammoniacal and nitrate forms, which increased the amount of mineral nitrogen present in the soil. Since ammonium can be temporarily trapped in the negative sites of clays resulting slow mobility than that of nitrate, while, nitrate is more prone to leaching due to non-fixation in the negative sites of clay mineral. The leaching of nitrate is therefore far more intense than the leaching of ammonium. According to Hussain *et al.* (2020), variations in NO_3-leaching, which were directly related to N fertilization, were the main causes of variance in overall N leaching rates. The earlier study also observed that NH_4^+ leaching made up a very minor portion of overall N leaching when compared to NO_3^-. Blum *et al.* (2013) reported similar findings and demonstrated that 92.3% of the leached mineral N was in the form of NO_3^-. After the initial higher leaching intensity in the T_2 and T_4 treatments, the nitrate and ammonium leaching increased in the mid-seasons, displaying two peaks due to the difference in time of application of nitrogen fertilisation rates. Following the application of fertilisation rates, the severity of nitrogen leaching peaked shortly after urea application. The greater application of inorganic fertiliser sources may be the cause of the increased leaching intensity in T_2 compared to T_4 treatment.

5.2 Effect of different nutrient management practices on leaching loss of nutrients

5.2.1 Effect on mineral nitrogen leaching

Due to the presence of a larger application of inorganic nitrogen, the nitrogen leaching was higher in the inorganic treatment compared to other treatments. Ghiberto *et al.* (2015) noted that the treatment fertilized with 100 kg N ha^{-1} had a high amount of leached N from both native and fertilizer sources and was significantly greater than the non-fertilized treatment. According to Thorburn *et al.* (2013), an increase in the quantity of N applied as fertilizer was connected with an export of DIN (dissolved inorganic nitrogen). Since there are more negative sites in the soils as a result of organic matter application causing less nitrogen leaching during organic and INM treatments, while ammonium nitrogen is temporarily fixed. The presence of organic N-sources in the soil stimulated microbial growth, causing temporary immobilization of N in the microbial biomass, which resulted in less N-leaching loss from T_3 treatment (Lehmann and Schroth, 2002). According to Cole *et al.* (2004), nitrification intensified in the presence of a more diversified biotic population, which increased the quantity of nitrogen contained in the leachate. The ammoniacal nitrogen promptly oxidized to nitrate form following the application of nutritional source fixed in the clays and became unavailable to leach, which caused very low ammoniacal nitrogen among the treatments. The fast conversion of the NH_4^+-N into NO_3^- would have made it vulnerable to leaching (Ghiberto *et al*., 2015). When compared to INM and organic treatments, the inorganic treatment considerably increased the amount of nitrate leaching. The result of the present investigation finds supports from Ulen (1999), who observed that 70–90% of the total nitrogen, was lost in the form of NO_3–N, with 1% being NH_4–N in lysimetric experiment.

5.2.2 Effect on phosphorus leaching

The T_1 treatment without an external phosphorus supply showed the lowest levels of phosphorus leaching. The organic treatment included phosphorus with a similar decreased leaching value. Organic matter reduces phosphate leaching and improves aggregate stability in the sandy soils. The inorganic treatment was shown to have the highest level of phosphorus leakage. The leaching behaviour of phosphates was not significantly affected in the short term by the modifications in the farming strategy (Meissner *et al.,* 1998). The organic nutrient sources released phosphorus slowly over time as a result of mineralization while higher application of inorganic phosphorus sources increased phosphate solubility. The release of phosphorus during organic and INM treatment meets the needs of the plants and reduces leaching intensity. Ulen (1999) noted that the application of high-manured soil (0.48 mg l^{-1}) and a greater source of inorganic fertilizer (3.54 mg l^{-1}) resulted in higher PO_4-P concentrations in leachate in the sandy soil. When compared to other nutrients, phosphorus has a reduced leaching loss due to its extremely poor soil mobility. In addition, phosphate is very reactive and strongly binds to the mineral present in soil as, calcium phosphate, iron phosphate, manganese phosphate, and other elements (Naik *et al.* 2015). The phosphorus leaching in all the treatments of the present investigation was very low, which was attributed to the fixation of released phosphorus from applied fertilizer and manure by oxides of iron and aluminium. (Naik and Das 2020; Thangasamy *et al.,* 2005).

5.2.3 Effect on potassium leaching

Compared to INM and organic nutrient management systems, the inorganic treatment showed greater potassium leaching. The inorganic nutrient sources act as an easily soluble source of potassium and releases potassium. The potassium leaching potential increases as the K^+ contents in the soil solution increase. On the other hand, organic sources serve as nutrient buffer stocks as it releases nutrients gradually when the levels of nutrient solution in the soil drop. Slow mineralization and gradual potassium release from organic sources help to limit nutrient losses. Additionally, organic materials contain negative sites that raise CEC by retaining cations and lowering their mobility and leaching susceptibility. Meissner *et al.* (1998) reported that the potassium leaching from the root zone is influenced by the quantity of mineral fertilizer used, the fixing of this element to clay particles, the saturation of the soil with this element, and the volume of seepage water. Due to the significant affinity for K adsorption on the clay exchange complex, the additional organic manure application enables the plant to utilize K for an extended period and lowers K-leaching loss (Bhandari *et al.,* 2002).

5.2.4 Effect on calcium and magnesium leaching

The inorganic treatment had the highest levels of calcium leaching among the treatments. The INM and organic treatments showed less calcium leaching. In an Oxisol, larger concentrations of Ca were discovered to travel in the upper 30 cm, according to Gillman *et al.* (1989). Lehmann *et al.* (2002) measured leaching levels of Ca between 10 and 40 kg ha^{-1} and Mg between 2 and 15 kg ha^{-1} over the course of 38 days of the experiment while applying various fertilizers. Cahn *et al.* (1993) have achieved comparable results in the past. The pH of the soil significantly affects the leaching loss of calcium with increased solubility of Ca from the decreased soil pH. The calcium leaching was observed to be greatest in the inorganic treatment, than the control treatment, which was attributed to the low soil pH in the inorganic treatment. Calcium leaching diminished in the organic and INM treatments because organic matter acts as a buffering agent, raising the pH of the soil and keeping it at a neutral level. The amount of negative sites in organic matter is higher; these sites trap cations and slow down their flow during leaching. Additionally, organic matter and divalent cations like calcium and magnesium formed a strong bond reducing the movement of cations. Mg ions are more easily leached than Ca ions because they are absorbed less securely by the soil colloids due to their thicker water mantle. According to lysimeter studies, up to 29% of the additional Mg given through fertilization was leached during maize growing (Wong, 1992). The magnesium content in the leachate did not differ significantly, while magnesium leaching from the inorganic treatment was considerably greater. According to Meissner *et al.* (1998), the volume of seepage water, the saturation of magnesium in soil, and the availability of mineral fertilizer salts were the main determinants of magnesium leaching. The extreme weathering and poor cation-exchange capacity of soil, along with evidence predominance of kaolinite in the mineral fraction, can be used to explain the overall low retention of the cations and anions in the soil indicated above (Ghiberto, 2009).

5.2.5 Effect on sulphur leaching

The sulphur leaching was highest in the control treatment because there was no potential for long-term net immobilization of SO_4^{2-} into organic S in agricultural systems where soil organic matter was low (Knights *et al.,* 2001). Even though there was no discernible difference between the inorganic, organic, and INM treatments, the leaching under maize was somewhat higher in the organic treatment. Since there was no external source of sulphur in any of the treatments, the plant growth was reduced in control, which resulted in a lower sulphur uptake than other treatments and recorded a relatively higher sulphur leaching loss. A good source of sulphur is organic matter, which releases sulphur throughout the mineralization process and causes more sulphur loss in INM and organic treatment than the inorganic treatment. According to Riley *et al.* (2002), the concentrations of S in the drainage water from soils that had not been treated with sulphur ranged from 1.3 to 17 mg l^{-1}.

5.2.6 Effect on dissolved organic carbon leaching

Decomposition of organic materials and excretion from the root biomass release soluble organic matter. Due to the increased development of root biomass, more organic carbon was released from the inorganic, organic, and INM treatments. With the adoption of an intensive cropping system, dissolved organic carbon leaching increased (Vinther *et al.,* 2006). The types of crops grown and ploughing appear to have an impact on the leaching of dissolved organic carbon. Vermicompost and inorganic fertilizer, external sources of nutrients, promote plant development and stimulate root excretion. INM, organic, and inorganic treatments did not significantly differ from one another, but the organic treatment produced a higher amount of soluble organic carbon because of more soluble organic matter was present in the added vermicompost. A high DOC load from agricultural grasslands was reported by McTiernan *et al.* (2001), who hypothesized that it was caused by the enhanced biomass production brought about by N fertilization. According to Autio *et al.* (2016), there is a positive correlation between DOC concentration and the percentage of organic soil or peatland in a watershed. A positive correlation between DOC load and SOC content of surface soil was discovered by Manninen *et al.* (2018). Royer *et al.* (2007) observed that the mean DOC content in subsurface drainage water was 6.5 mg l^{-1}, which was lower than the concentration in surface runoff (12.7 mg l^{-1}) in corn and pasture cropping system. DOC leaching rates (kg ha^{-1} yr^{-1}) and volume-weighted mean concentrations (mg l^{-1}) among cropping systems averaged 15.4 and 4.6, respectively, according to Hussain *et al.* (2020). Due to higher amounts of sesquioxides present in the subsurface layer than other experiments, the leaching of dissolved organic carbon was reduced. According to Kaiser *et al.* (1996), the iron and aluminium (hydro)oxides are the most significant sorbents for dissolved organic matter in soils. Parfitt *et al.* (1997) discovered losses of dissolved inorganic carbon (DIC) from pastures of 14.7 g m^{-2} yr^{-1} and 0.7 g m^{-2} yr^{-1}, as well as a decrease in soil pH (H_2O) from 5.6-5.9 under pastures to 5.3-5.5 under pine forests due to more intense acidification in the latter.

5.3 Effect of different nutrient management practices on nutrient contents in post-harvest soil samples

5.3.1 Effect on major soil chemical properties

The organic treatment was shown to have the greatest mean pH value in both crops across all nutrient management methods. As a buffer, organic matter regulates soil pH to prevent acidification. Jiang *et al.* (2018) emphasised the crucial role of organic matter in acid buffering and Al^{3+} adsorption even in very acidic forest soils (pH 4.2), and they hypothesised that old forest soils with a very low pH still had a stronger ability to resist acid deposition without increasing Al^{3+} concentrations in soil solutions or streams. According to Hao *et al.* (2020), traditional N fertilisation raised soil acidification rates by about 50% without significantly increasing grain yield when compared to optimised N fertilisation. This outcome is consistent with earlier research that found that soil pH declined more rapidly as N treatment rates increased (Zhang *et al.,* 2009; Guo *et al.,* 2010; Schroder *et al.,* 2011; Tian and Niu, 2015). In comparison to the topsoil layer, the pH of the deeper soil profile decreased significantly. This could be a result of increased exchangeable aluminium-induced subsoil acidity. In the Alfisol virgin landscape, Gebrekidan *et al.* (2001) similarly discovered a pH decline with increasing profile depth. The mean electrical conductivity did not significantly differ between the treatments. However, the topsoil layer had a noticeably higher electrical conductivity than the other soil depths in the profile. This might be due to enhanced electrical conductivity in the topsoil caused by water evaporation and migration of salts and water from the lower soil profile. El-Naggar *et al.* (2021) measured the electrical conductivity of the soil profile and found that the topsoil layer had a higher electrical conductivity than the lower soil profile. In both crops, the organic treatment had the highest concentration of easily oxidizable organic carbon, followed by the INM and the inorganic treatment. Vermicompost application raised the level of organic carbon in organic treatment. In nutrient-deficient soils, root weight often increases in a quadratic manner with the addition of chemical fertilizers (Fageria *et al.,* 2011). Increasing nutrient supplies in the soil may also decrease root length but increase root weight in a quadratic fashion. Chen *et al*. (2020) reported a moderate N fertilization rate (240 kg ha^{-1}) increased root length, root surface area, and root biomass in most soil layers and significantly increased total root growth and total root biomass by more than 36.06% compared to the control treatment. Higher root growth may increase soil organic matter by decomposition. The organic carbon content in the different soil layers in the soil profile varied significantly and decreased from the topsoil layer to lower depths respectively. As a result of greater organic matter inputs and its decomposition, Alfisols also have larger levels of organic carbon in the surface horizon (Groenendijk *et al.,* 2002; Samndi and Jibrin, 2012). According to Gebrekidan *et al.* (2001), A horizon of the abandoned land had 79 and 76% more depleted OC and TN than the virgin land, respectively. In southwestern Ethiopian soil that had been subjected to conventional oxen ploughing for 25 years, Solomon *et al.* (2002) showed a reduction in OC and TN below a horizon of 55 and 53%, respectively.

5.3.2 Effect on available primary nutrients

Although the available nitrogen level was found highest just beneath the top soil layer, available nitrogen content gradually decreased as soil depth increased. According to Anas *et al.* (2020), total soil nitrogen and organic carbon differ in the soil profile and both decrease with soil depth. The available nitrogen concentration varied significantly between the treatments as well. Due to the application inorganic fertilizer, which is a rapidly available source of nutrients, the INM and inorganic treatments had the highest available nitrogen concentration. According to Trandel *et al.* (2018), plants grown with synthetic nitrogen sources are more easily assimilated than by plants grown in organic. In comparison to the control treatment, the external nutrition source considerably boosted the available nitrogen content in the organic, inorganic, and INM treatments.

The available phosphorus content differs significantly between the control and other treatments as well. Li *et al.* (2022) reported that both phosphite and phosphate fertilizers boosted the total phosphorus (TP) and accessible phosphorus (AP) concentrations of soil. The external nutrient supply increases the available P content of the soil. Inorganic nutrient management increases the amount of phosphorus that is readily available in the soil when compared to organic treatment. This might be caused by organic matter, which promotes phosphorus mobility and uptake by plants and decreases sesquioxide phosphorus adsorption and fixation.

The presence of lower organic carbon content in the subsoil layer reduced the available pool of nutrients. Additionally, phosphorus is fixed into an inaccessible state by the sesquioxides found in the subsoil layer. Highly weathered soils create preferable bidentates with iron (Kim *et al.,* 2011) and aluminium oxides (Li *et al.,* 2013) due to their acidity under natural conditions. The concentration of P adsorbed onto Al- and Fe-oxides increased with binding the acidic regions, where these minerals contributed to as much as 50% of the total adsorbed (Devau *et al.,* 2009). One of the main factors limiting crop yield was the P retention by Fe and Al oxides in tropical and subtropical soils (Igwe *et al.,* 2010).

The available potassium content was higher in the organic treatment and INM due to higher holding capacity in the organic matter, thus reducing the leaching potential of potassium. Wang *et al.* (2001) observed that the organic matter significantly increased the initial fast rate of K adsorption and has more readily accessible adsorption sites for K compared to the mineral component of the soil. The availability of potassium was increased through the continuous mineralization of organic materials, which released potassium at a consistent pace. Organic acids (humic and fulvic) from organic fertilizer and their breakdown caused some potassium-containing soil minerals to dissolve (AL-Jabori *et al.* 2011). On the other hand, the potassium was immediately released from the inorganic nutrition source, leading to more leaching. The type of anions and cations present in the chemical fertilizers can have an impact on the leaching of K. Due to the activity of accompanying ions, the inorganic K sources have the potential to alter K leaching (Heidari and Jalali, 2015). The topsoil layer had a high availability of potassium, which gradually reduced as soil depth increased. This might be due to the lower organic carbon content in the subsoil layer reducing the holding capacity compared to the topsoil layer. Furthermore, the decreased soil pH in the subsoil layer increased the mobility of potassium, which resulted in higher leaching from the subsoil layer compared to the topsoil. According to Negassa *et al.* (2001), virgin soil noted a larger decline in potassium levels through the soil profile than cultivated soil.

5.3.3 Effect on secondary nutrients

The exchangeable calcium content significantly varied between the treatments with the highest amount present in the organic followed by INM. As organic matter makes a strong bond with the divalent cation, thus decreases the mobility, and reduces the leaching potential of calcium. At various pH levels, the organic matter displays more stable aggregation with Ca^{2+} than with Na^{+} cations (Galicia *et al*., 2021). Additionally, vermicompost has a substantial amount of calcium, which significantly increased the calcium pool. Gupta *et al.* (2022) mentioned that vermicompost contains calcium and magnesium on an average of 20-70 meq $100g^{-1}$. The inorganic nitrogen fertilizer increased the acidity of the soil and increased the Ca-mobility in the soil, thus causing a higher reduction in the exchangeable calcium content. According to Rajendram *et al.* (2020), the amount of nitrate-N leaching increased with an increasing rate of N fertilizer, which was linked to a 100% increase in the leaching of calcium. The amount of exchangeable calcium decreased significantly as depth increased. The low calcium in the subsoil layer was attributed to the lower level of organic matter in the soil profile. Further, the lower pH of the subsoil layer, which makes calcium more mobile and resulted in more leaching from the subsoil layer. Negassa *et al.* (2020) reported that the exchangeable Ca concentration in the A horizon of virgin land was seven and four times higher than that of abandoned and cultivated fields, respectively. For both virgin and cultivated fields of Alfisols, the distribution of exchangeable Ca tended to decline from surface to subsurface horizons (Negassa *et al.,* 2001). Although there was more exchangeable magnesium present in different nutrient management options compared to the control, there was no significant distinction in exchangeable magnesium content among inorganic, organic, and INM treatments, which was attributed to higher root excretion levels increased the organic matter content and thus less difference observed.

The control treatment had a higher available sulphur concentration compared to other treatments. As both the crops of brinjal and maize did not receive any external sulphur application while being grown, the inorganic, organic, and INM grown plants absorbed more sulphur than the control crop. Thus, the control treatment recorded more sulphur which was readily available. Additionally, it was discovered that the amount of accessible sulphur decreased as soil depth increased. The reduced availability of sulphur with increase in soil depth was attributed to lower organic matter levels. Rakesh *et al.* (2020) observed that the available-S declined in soil was the result of increased as availability of organic carbon and available-P.

Chapter 6 Summary and Conclusions

The process by which vital nutrients being washed away or dissolved from the soil and transported downward through the soil profile by water—typically as a result of heavy rainfall or irrigation—is referred to as nutrient leaching. This process may result in the loss of precious nutrients, which are crucial for plant growth and productivity. The scanty information on the leaching behaviour of primary nutrients under crop growing conditions in the Indian sub-continent was the reason behind this present study titled "**Leaching loss of nutrients under different nutrient management options in maize and brinjal grown on an Alfisol".** This investigation was carried out to fulfil the following objectives: (i) To quantify the effect of different nutrient management practices on leaching loss of major and secondary nutrients from soil under brinjal and maize crop, (ii) To study the depth-wise distribution of available nutrient contents in post-harvest soil samples. To study these objectives, the leaching experiment was carried out at ICAR-RCER, FSRCHPR, Ranchi during the year 2022-23. During the study, 4 different treatments namely control (unfertilized), inorganic (inorganically fertilized), organic(vermicompost) and INM (equal amount of inorganic and organic) were undertaken. The crops (maize and brinjal) were grown in lysimeter plots with 5 replication blocks in a randomized block design. During the crop growing period, collected leachates were analyzed and quantified for major nutrients. After the maturity of crops, the post-harvest soil samples were collected from different depths (0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm) and analyzed for primary and secondary nutrients present in available and exchangeable forms.

Salient observations which were found during the study are summarized below:

- In all the nutrient management options, the pH of leachate was initially low but increased in the later growth period and maintained neutrality towards end of crop growth stages. In the different nutrient management options, the pH of the leachate sample in the control treatment was higher compared to other treatments. Among the crops grown, the leachate from maize had a lower pH variation than brinjal.
- The electrical conductivity (EC) was initially higher in the leachate, which decreased in the midseason and again increased in the later drier season. The INM and organic treatments have higher initial ECs, while the control treatment had the lowest value. Among the crops grown, leachate under maize crop had a lower EC than brinjal.
- The amount of nitrate-nitrogen (NO_3-N) present in the leachate in different treatments was found highest in inorganic treatment followed by INM and organic treatments in the growing period. In the leachate of both inorganic and INM treatments, three recognizable leaching peaks were identified. The NO_3-N leaching did not vary significantly during the growth seasons and

it remained constant throughout, although being slightly larger in the early stages in the T_3 (organic) and T_1 (control) treatments.

- Initially, significant amount ammonium-nitrogen (NH_4-N) leached from the soil under maize and then it gradually decreased as the plant approached towards maturity. The highest NH_4-N loss was observed in the inorganic treatment, followed by INM. In both T_3 and T_1 treatments, a consistent loss of NH_4-N was noticed throughout in each leaching event, while the amount of NH_4-N lost was slightly higher at the beginning.
- The highest amount of nitrogen (NH_4-N + NO_3-N) leaching loss was noted at 31.27 and 19.95 kg ha^{-1} in the inorganic treatment under brinjal and maize, respectively followed by T_4 (INM) and T_3 (organic) treatments. The nitrogen leaching from brinjal and maize was around 101% and 51% higher than the control plots, respectively. Brinjal showed higher leaching loss of nitrogen.
- The NH_4-N contributed approximately 15-20% of total mineral nitrogen loss, and the rest was contributed by NO_3-N. The variations in leaching loss of NH_4-N were negligible compared to NO_3-N under different nutrient management options. The inorganic treatment resulted in a little higher NH_4-N loss.
- The leaching loss of NO_3-N from soil under inorganic and INM treatments were around 110-115% and 60-70% more than that from the control plots, respectively.
- The leaching loss of phosphorus (P) was very low compared to NH_4 or NO_3. The leaching loss of P from soil varied among the treatments, with the control treatment showed the lowest loss and the inorganic treatment had the highest loss followed by the INM treatment.
- The leaching loss of potassium (K) from the inorganic treatment was the highest, which was approximately 80-120% greater than the leaching from the control treatment. The leaching loss of K from soil under the INM treatment was relatively lower but still 50-70% higher than the control treatment. Further, there was no discernible difference was observed between the control and organic treatments on the leaching loss of K.
- There was a significant difference among the treatments with respect to leaching loss of calcium (Ca) in the growing season. The highest amount of Ca leaching loss was recorded in inorganic treatment, while it was recorded the lowest in organic treatment. Calcium leaching loss was intermediate in both INM and control treatments.
- Though there was not much difference noticed between the leaching of magnesium (Mg) from soil in different nutrient management, the highest one was observed in inorganic, followed by control and INM treatments.
- The leaching loss of sulphur (S) from soil was more prevalent under maize than brinjal. Among the nutrient management options, the leaching loss of S was noted in the control treatment followed by organic, INM and inorganic plots.

- In the post-harvest soil samples, the highest soil pH was observed in organic treatment followed by INM. The lowest soil pH was recorded in the inorganic plot. There was a significant variation in pH within the soil profile, it was higher in the topsoil which gradually decreased to the lower soil layer.
- The electrical conductivity (EC) of soil was observed highest in the top soil and then it decreased gradually down the profile.
- Easily oxidizable organic carbon (EOC) content in soil was higher in the organic followed by INM and inorganic treatments. The EOC content decreased down the soil depths; in between 0-15 and 15-30 cm soil layer, EOC content decreased sharply (around 35%); thereafter it decreased gradually.
- The available nitrogen (AN) content in soil was comparatively higher in INM and inorganic treatments. The AN content decreased with the increase in soil depth though it was observed the highest in the second depth (15-30 cm).
- With the increase in soil depth, the available phosphorus (AP) and potassium (AK) contents in soil decreased significantly. The organic nutrient management system supported highest amount of AK followed by INM and the inorganic management systems.
- Exchangeable calcium (Ex-Ca) content gradually decreased within the soil profile. The higher amount of Ex-Ca in the postharvest soil was found in the organic followed by INM; it was lower in inorganic and control treatments.
- The available sulphur (AS) content in soil was higher in the control treatment compared to others and gradually it decreased within the soil profile.

It also noticed that soil acidity which increased by the application of inorganic fertilizer, decreased significantly the cation content on profile, increased the leaching of cations. It also concluded that root system had a vital effect of leaching of nutrients. Soils under maize crops caused a lower leaching loss compared to the soil under brinjal due to presence of fibrous root system in maize, which covered a higher soil volume in the topsoil than the taproot system of brinjal. Considering all the results obtained, it can be concluded that the organic and INM treatments significantly decreased the leaching loss of nutrients as compared to the inorganic system. The leaching of cations (Ca, K) could be minimized by increased addition of organic matter, and thus improved soil nutrient holding capacity. Modification of soil pH could be possible due to addition of organic matter, which in turn might improve plant growth and nutrient availability. The INM emerged as a sustainable system which could be promoted among the farming community to prevent nutrient leaching, enhance nutrient use efficiency and productivity of maize and brinjal grown in Alfisol of Ranchi.

Chapter 7 Abstract

Leaching loss of nutrients under different nutrient management options in maize and brinjal grown on an Alfisol

The use of chemical fertilizer has been increased several folds in the last few decades to enhance crop productivity, which intensified the leaching loss of nutrients. The nutrient loss from the application of inorganic fertilizer reaches the groundwater through the leaching of soluble nutrients deeper into the soil profile. To comprehend the mobilization, adsorption, and nutrient leaching losses, the present study was undertaken in the experimental field of ICAR- RCER, FSRCHPR, Ranchi, Jharkhand to quantify the nutrient leaching and nutrient distribution within the soil profile of post-harvest soil under different nutrient management options. The leachate was quantified from the non-weighing lysimeter with different nutrient management options comprising of control (T_1), inorganic (T_2), organic (T_3), and integrated nutrient management (INM) (T_4) under maize and brinjal crops. The inorganic (T_2) treatment registered the highest amount of nitrogen (both nitrate and ammonium form) leaching, causing 31.27 and 19.95 kg ha^{-1} in brinjal and maize, respectively. The ammonium-nitrogen contribution was approximately 15-20% of total mineral nitrogen loss, while the rest was in nitrate form. The leaching loss of potassium from the inorganic treatment was observed highest and resulted in 19.97 and 13.51 kg ha^{-1} loss in brinjal and maize, respectively. The inorganic treatment caused higher calcium leaching loss and accounted for 23.81 and 14.68 kg ha^{-1} in brinjal and maize, respectively. In the post-harvest soil sample, pH, EC (electrical conductivity), EOC (easily oxidizable organic carbon), AN (available nitrogen), AP (available phosphorus), AK (available potassium), Ex-Ca (exchangeable calcium), AS (available sulphur) were observed highest in the topsoil and then decreased gradually with the increase in soil depth though available nitrogen content was observed highest in 15-30 cm soil layer. Exchangeable calcium and available potassium content were found highest in organic treatment and reflected a stronger bonding of cation with organic matter. From the present investigation, it can be concluded that INM practice enhanced the overall soil fertility and sustainability by increasing the available nutrient content among all the nutrient management options and decreasing the leaching loss of nutrients.

Keywords: *Leaching; Alfisol; Maize; Brinjal; INM; sustainability*

सारांश

विभिन्न पोषक तत्व प्रबंधन विकल्पों के अंतर्गत एल्फीसॉल मिट्टी में मक्का एवं बैंगन फसल में पोषक तत्वों की निक्षालन क्षति

फसल उत्पादकता बढ़ाने के लिए पिछले कुछ दशकों में रासायनिक उर्वरक का उपयोग कई गुना बढ़ गया है, जिससे पोषक तत्वों की लीचिंग हानि तेज हो गई है। अकार्बनिक उर्वरक के प्रयोग से होने वाली पोषक तत्वों की हानि घुलनशील पोषक तत्वों की मिट्टी की गहराई में लीचिंग के माध्यम से भूजल तक पहुंचती है। एकत्रीकरण, सोखना और पोषक तत्वों की लीचिंग हानियों को समझने के लिए, वर्तमान अध्ययन आईसीएआर-आरसीईआर, एफएसआरसीएचपीआर, रांची, झारखंड के प्रायोगिक क्षेत्र में किया गया था ताकि फसल के बाद की मिट्टी के प्रोफाइल के भीतर पोषक तत्वों की लीचिंग और पोषक तत्व वितरण की मात्रा निर्धारित की जा सके। पोषक तत्व प्रबंधन विकल्प. मक्का और बैंगन की फसलों के तहत नियंत्रण (टी 1), अकार्बनिक (टी 2), कार्बनिक (टी 3), और एकीकृत पोषक तत्व प्रबंधन (आईएनएम) (टी 4) सहित विभिन्न पोषक तत्व प्रबंधन विकल्पों के साथ गैर-वजन वाले लाइसीमीटर से लीचेट की मात्रा निर्धारित की गई थी। अकार्बनिक (टी2) उपचार में नाइट्रोजन (नाइट्रेट और अमोनियम दोनों रूपों) की उच्चतम मात्रा में निक्षालन दर्ज किया गया, जिससे बैंगन और मक्का में क्रमशः 31.27 और 19.95 किलोग्राम प्रति हेक्टेयर हुआ। अमोनियम-नाइट्रोजन का योगदान कुल खनिज नाइट्रोजन हानि का लगभग 15-20% था, जबकि शेष नाइट्रेट के रूप में था। अकार्बनिक उपचार से पोटेशियम की लीचिंग हानि सबसे अधिक देखी गई और इसके परिणामस्वरूप बैंगन और मक्का में क्रमशः 19.97 और 13.51 प्रति किलोग्राम हेक्टेयर की हानि हुई। अकार्बनिक उपचार के कारण कैल्शियम की अधिक मात्रा में लीचिंग हानि हुई और बैंगन तथा मक्के में क्रमशः 23.81 तथा 14.68 किग्रा प्रति हेक्टेयर हुई। कटाई के बाद के मिट्टी के नमूने में पीएच, ईसी (विद्युत चालकता), ईओसी (आसानी से ऑक्सीकरण योग्य कार्बनिक कार्बन), एएन (उपलब्ध नाइट्रोजन), एपी (उपलब्ध फास्फोरस), एके (उपलब्ध पोटेशियम), एक्स-सीए (विनिमय योग्य कैल्शियम), एएस (उपलब्ध सल्फर) ऊपरी मिट्टी में सबसे अधिक देखा गया और फिर मिट्टी की गहराई में वृद्धि के साथ धीरे-धीरे कम हो गया, हालांकि उपलब्ध नाइट्रोजन सामग्री 15-30 सेमी मिट्टी की परत में सबसे अधिक देखी गई। कार्बनिक उपचार में विनिमेय कैल्शियम और उपलब्ध पोटेशियम सामग्री उच्चतम पाई गई और कार्बनिक पदार्थ के साथ धनायन के मजबूत बंधन को दर्शाया गया। वर्तमान जांच से, यह निष्कर्ष निकाला जा सकता है कि आईएनएम अभ्यास ने सभी पोषक तत्व प्रबंधन विकल्पों के बीच उपलब्ध पोषक तत्व सामग्री को बढ़ाकर और पोषक तत्वों की लीचिंग हानि को कम करके समग्र मिट्टी की उर्वरता और स्थिरता को बढ़ाया है।

कीवर्ड: *लीचिंग; अल्फिसोल; मक्का; बैंगन; आईएनएम; वहनीयता*

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