

Application of Nitrogenous Fertilizer in Rice Production: A Review

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops. Nitrogen is one of the most important plant nutrients for rice. Different forms of nitrogenous fertilizer are the major sources of nutrients in rice production. Nitrogen affects various physiological and biochemical processes in plant cells that ultimately affect the growth and development and, thereby, the grain yield of rice. Rice production can be increased by applying nitrogenous fertilizer either as organic or inorganic fertilizer at an appropriate dose, time, method, and place. Soil testing is needed to assess the nutritional status of the soil as it is affected by crop nutrient uptake and removal. Nitrogenous fertilizers should be applied in multiple split doses depending upon the nutrient status of the soil, crop demand, and sources of nutrients. To reduce the nitrogen loss from rice fields, surface runoff, denitrification, ammonium volatilization, and leaching should be managed. Sustainable and environmentally friendly fertilizer management practices enhance the sustainable soil fertility status and, thereby, crop yields. This review article examines the impact of nitrogenous fertilizers on rice growth, development, and production, along with time and doses of nitrogen applications that will help agricultural technicians, academicians, farmers, and policy makers.

Keywords: growth, nitrogen, nitrogen deficiency, rice, yield

सारांश

धान (*Oryza sativa* L.) संसारको सबैभन्दा महत्त्वपूर्ण अन्न बाली मध्ये एक हो। नाइट्रोजन धानको लागि सबैभन्दा महत्त्वपूर्ण बिरुवाको पोषक तत्व हो। नाइट्रोजनयुक्त मलका विभिन्न रूपहरू धान उत्पादनमा पोषक तत्वहरूको प्रमुख स्रोत हुन्। नाइट्रोजनले बिरुवाका कोशिकाहरूमा भएका विभिन्न शारीरिक र जैव रासायनिक प्रक्रियाहरूलाई असर गर्छ जसले अन्ततः वृद्धि र विकासलाई असर गर्छ र यसरी, धानको दाना उत्पादनमा असर गर्छ। नाइट्रोजनयुक्त मललाई जैविक वा अजैविक मलको रूपमा उपयुक्त मात्रा, समय, विधि र स्थानमा प्रयोग गरी धान उत्पादन बढाउन सकिन्छ। माटोको पोषण अवस्थाको मूल्याङ्कन गर्न माटो परीक्षण आवश्यक छ किनभने यो बालीमा पोषक तत्वहरू लिने र हटाउने कार्यबाट प्रभावित हुन्छ। नाइट्रोजनयुक्त मलहरू माटोको पोषण अवस्था, बालीको माग र पोषक तत्वहरूको स्रोतको आधारमा धेरै विभाजित मात्रामा प्रयोग गर्नुपर्छ। धान खेतीबाट नाइट्रोजनको नोक्सान कम गर्न सतहबाट बहाव, डिनाइट्रिफिकेशन, अमोनियम वाष्पीकरण र लिचिडको व्यवस्थापन गर्नुपर्छ। दिगो र वातावरणमैत्री मल व्यवस्थापन अभ्यासहरूले दिगो माटोको उर्वरता स्थिति र यसरी, बाली उत्पादन बढाउँछ। यो समीक्षा लेखले धानको वृद्धि, विकास र उत्पादनमा नाइट्रोजन उर्वरकको प्रभावको जाँच गर्दछ, साथसाथै नाइट्रोजन अनुप्रयोगहरूको समय र खुराकहरू जसले कृषि प्राविधिकहरू, विधार्थीहरू, किसानहरू र नीति निर्माताहरूलाई मद्दत गर्नेछ। यस समीक्षात्मक लेखले धानको वृद्धि विकास र उत्पादनमा

नाईट्रोजन उर्बरकको प्रभावका साथ साथै नाईट्रोजनको व्यावहारिक प्रयोग गर्ने समय र मात्राका बारेमा विश्लेषण गर्दछ र यसले कृषि प्राविधिकहरू, विद्यार्थीहरू, किसानहरू र निती निर्माताहरूलाई मद्दत गर्नेछ।

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple crop for approximately half of the world's population; its production should be significantly increased to fulfill the demands of an expanding global population. The demand for rice is predicted to rise from 439 million tons (mt) in 2010 to 496 mt by 2020, 553 mt by 2035, and 623 mt by 2050 (FAO 2013, Timsina et al 2021). Rice production can be increased by using improved varieties, judicious fertilizer use, and irrigation with proper management practices (Gairhe et al 2018). Both macro- and microelements are essential for rice growth and development. Macroelements include nitrogen (N), phosphorous (P), and potassium (K). Secondary macronutrients include calcium (Ca), magnesium (Mg), and sulphur (S), while trace elements include iron (Fe), manganese (Mn), zinc (Zn), and others. A good fertilization strategy that incorporates both organic and chemical fertilizers while also boosting agricultural productivity and environmental quality should be created for sustainable agricultural production (Devkota et al 2019).

Nitrogen is an essential nutrient element for plants and is necessary for photosynthesis, growth and development, yield, quality, and biomass production in rice. Nitrogen promotes rapid plant growth and increases grain yield and quality by increasing tillering, leaf area development, grain formation, grain filling, and protein synthesis. Nitrogen is highly mobile within the plants and soil. During the early and mid-tillering, panicle initiation, booting, and grain development phases of ripening, N is the most typically required nutrient element. Increased N fertilizer within a particular range boosts net photosynthetic rate. However, excessive N fertilizer results in a decrease in photosynthetic capacity. Nitrogen affects the canopy population of leaves, which is the primary organ of photosynthesis. N has an important role in the creation of rice quality. According to the research of Bai (2019) and Li et al (2019), increasing N fertilization can help improve the nutritional quality and processing quality of rice, but excessive N fertilization can increase rice chalkiness and worsen the rice appearance quality, cooking and eating quality.

The optimal treatment in terms of rice growth and production was the application of half a dose of N fertilizer during planting time and the rest 42 days later (Gribaldi et al 2017). Increased N, P, and K levels (Sandhu and Mahal 2014), P levels, K levels (Arif et al 2010), and NPK levels (Arif et al 2010) improved crop N, P, and K uptake. Fertilizer administration should be based on plant tissue analysis and soil tests, either generated from different scientific models or studies of crop nutrient responses for sustainable, efficient, and environmentally friendly rice production. Soil analysis provides information on the state of nutrients in the soil as well as fertilizer suggestions for crops. Soil testing also reveals information on the soil's reaction, which helps to determine the type of fertilizer you use. This review study aimed to determine the impact of different fertilizer management strategies on rice growth, nutrient uptake, yield, and productivity.

Nitrogen deficiencies symptoms

The following types of soil are particularly susceptible to N deficiency: soils having very low soil organic matter content, soils with particular constraints on indigenous N supply, soils that are alkaline or calcareous, have poor soil organic matter status, and have a high potential for ammonia (NH₃) volatilization losses. Crops deficient in N are stunted and discolored. Plants that are poor in N have a low yield. Due to a deficiency of N, older leaves turn an orange-yellow color and die from the tip down; young leaves are thin, short, and rigid. Similarly, a deficiency of N causes a decrease in plant height and the number of tillers. The roots decrease in number and become slender and lengthy. Nitrogen deficiency is one of Asia's most prevalent rice concerns. It is frequent in all rice-growing soils where modern varieties are planted in the absence of adequate mineral N fertilizer. It frequently occurs during important growth stages of the plant, such as tillering and panicle initiation, when there

is a high demand for nitrogen. Nitrogen deficiency can also arise when a large amount of N fertilizer is applied at the wrong time or in the improper way.

Under high N stress, leaves can die. Except for the younger, greener leaves, the leaves of N-deficient plants are narrow, small, short, erect, and lemon-yellowish green. Other symptoms include reduced tillering and grain numbers. The visual symptoms of N deficiency are similar to those of S deficiency, but S deficiency is less prevalent and affects younger leaves or all the leaves on the plant first. Mild N deficiency is similar to Fe deficiency; however, the latter affects the emergence of the first leaf. To manage N deficiency, an optimum level of N should be used. Applying excessive levels of N to less responsive cultivars should not be recommended. Inbred rice cultivars absorb mineral nitrogen less efficiently than hybrid rice varieties. Therefore, appropriate plant spacing for specific varieties should be chosen. Crops with low plant densities do not make efficient use of nitrogenous fertilizers. Depending on the crop establishment strategy, adjust the number of splits and timing of N applications. Rice that has been transplanted and rice that has been seeded directly require distinct N management measures. Maintain proper water control, which means keeping the field saturated to prevent denitrification while avoiding N losses from water runoff over bunds immediately following fertilizer application. Long-term supplies of N from indigenous sources should be maintained or increased by proper organic matter management.

Disadvantages of excessive nitrogen fertilization

Excessive nitrogen fertilizer use has a residual effect on the soil and the environment. Excessive nitrogen fertilizer application exacerbates soil degradation and environmental pollution (Ladha et al 2016, Guo 2019 and Yu et al 2018). Excessive nitrogen application can cause soil acidification and deterioration of the soil environment, which has a negative impact on crop growth and production (Guo et al 2010, Schroder et al 2011). Excessive nitrogen fertilization can increase rice chalkiness and poor appearance quality, as well as poor cooking and eating quality (Zhang et al 2020). Excess N induces "luxuriant" growth, which attracts insects and/or diseases/pathogens to the plant. Excess nitrogen fertilizer raises plant tissue susceptibility and rice canopy density, both of which are linked to an increase in disease incidence and severity on the leaf and panicle blast. The rice plant's susceptibility to rice blast is increased by excessive nitrogen (Long et al 2000). Excessive nitrogen fertilizer application has resulted in low N use efficiencies and major environmental pollution (Cui et al 2016, Zhu et al 2016). Excess nitrogen during the reproductive stages of growth resulted in panicles with unfilled or partly filled grains (Thenabadu 1972, Ghoneim et al 2018).

Impact of nitrogenous fertilizers on rice growth and yield

The recommended dose of nitrogen for rice in Nepal is 100 kg/ha. Nitrogen should be broadcast. Nitrogen should be divided into three splits; 50% as basal and 25% each at tillering and 25% at panicle initiation stages (Baral et al 2019). In grain crops, plant height is not a production factor, but it does show the impact of various nutrients on plant metabolism. In consideration of N application rates, the highest plant height was observed when N was supplied at a rate of 205 kg/ha, whereas the lowest was observed when N was treated at a rate of 100 kg/ha (Abid et al 2015). Dry matter accumulation grew at a sluggish rate for the first 30 days after transplanting, and then increased at a rapid rate until harvest. The favorable effect of N on various critical physiological processes could be linked to the greater dry mass of N-treated plants. The number of productive tillers (tillers that bear panicles) rather than the overall number of tillers determines the rice plant's productivity. With the application of N, P, and K fertilizers, the number of paddy tillers increases dramatically. According to Akram et al (2007), the number of rice tillers increased as the N fertilizer rate was elevated.

The panicle number, panicle length, number of filled grains per panicle, and 1000-seed weight are affected by fertilizer applications. The number of panicles per square meter is affected by N, P, and K fertilizers. In terms of nutrient management strategies, panicles per m² are dynamic. Hasanuzzaman et al (2010) found that use of NPKS fertilizer extended the length of the panicles. Rice panicle length increased with increasing N supply, up to 90 kg N/ha (Heluf and Mulugeta 2006). The amount of

grains per panicle is affected by N, P, and K fertilizers. Grain numbers per panicle increased by 31.4, 23.9, and 48.2% after applying N, P, and K fertilizers, respectively, and panicle numbers increased by 55.1, 29.2, and 6.7% after applying N, P, and K fertilizers (Ye et al 2019). Fertilizer treatments alter the thousand grain weight, which is a genetic character. Chemical fertilizers combined with organic manure enhanced the 1000-grain weight (Yang et al 2004).

The impact of N fertilizers on grain yield varies from variety to variety. Yang et al (2004) found that mixing chemical fertilizers with farmyard manure or wheat straw under alternate soaking and drying conditions boosted rice plant N, P, and K uptake, as well as grain weight and production. Timsina et al (2021) compared three nutrient management strategies in rice in Nepal and recommended Nutrient Expert (NE) based nutrient management, which had significant effects over farmers' fertilizer practice (FP) and government recommendation (GR), to get positive changes in rice yield and economic performance under varied growing environments. The 1.86 t/ha gains in rice yield would be possible through the adoption of good agronomic practices, including fertilizer management (Devkota et al 2021).

Timing of nitrogen fertilization in rice

The chemical fertilizer recommendation is different for irrigated rice (100:30:30 kg N:P₂O₅:K₂O/ha) and rain-fed rice (60:20:20 N:P₂O₅:K₂O/ha) in Nepal (AICC 2016). Before the last puddling, apply 1/3 nitrogen dose as well as the full doses of phosphorus and potassium. The leftover nitrogen should be broadcast in two splits, one at three weeks after transplanting and the other at three weeks afterwards. According to Xiang et al (2013), rice has a high rate of N absorption during the jointing to booting stage, and adequate N supply during this critical stage is critical for enhancing rice yield. Hall et al (1968) utilized internode elongation as a guide to determine the appropriate morphological stage of development for nitrogen application (Hall et al 1968). Topdressing of N during the initiation of flag-leaf extension increases grain yield, owing to the improved physiological activity of the flag leaves in the middle and advanced stages of grain filling (Liu et al 2020). DAP (18% N, 46% P₂O₅) and MoP (60% K₂O) are basal fertilizers that should be used during rice transplanting. Urea (46% N) is a highly soluble fertilizer that should be applied as needed to crops. It can be used on rice 3–4 weeks after transplanting and then again after 7-8 weeks. In terms of rice growth and production, using half of the N fertilizer during planting time (and the remainder 42 days later) was the most effective treatment (Gribaldi et al 2017).

Based on this relationship, the level of greenness on the leaf is utilized as an indicator of N status. The leaf color chart (LCC) is a low-cost diagnostic tool for measuring rice leaf relative greenness as a metric of the plant's N status. The leaves' colors are matched to standard color charts. During the leaf color comparison process, farmers must visually compare rice leaves to LCC shades. Farmers must compare 6 to 10 leaves with the LCC level and calculate the average values. If the mean value represents a lower LCC reading, such as 1-2, it implies that the crop is severely N deficient and in desperate need of N nutrients and that nitrogenous fertilizer in a sufficient dose must be supplied right away. If the result of the reading is 2-4, it means that the crop requires a small amount of N. In such circumstances, a modest amount of N can be beneficial. However, LCC readings of 4.5–5 do not necessitate additional N supplies because the crop is generally dark-green or lush green in color at this LCC reading, indicating that there is no N deficiency. The use of N on the 4 and 5 LCC readings resulted in the highest yield (Gupta et al 2011, Krishnakumar and Stephan 2013, Mathukia et al 2014). In an experiment, Sen et al (2011) found that LCC of less than 5 resulted in increased rice output. Different colours of LCC are good indicators of N deficiency in rice plants as given in Figure 1.

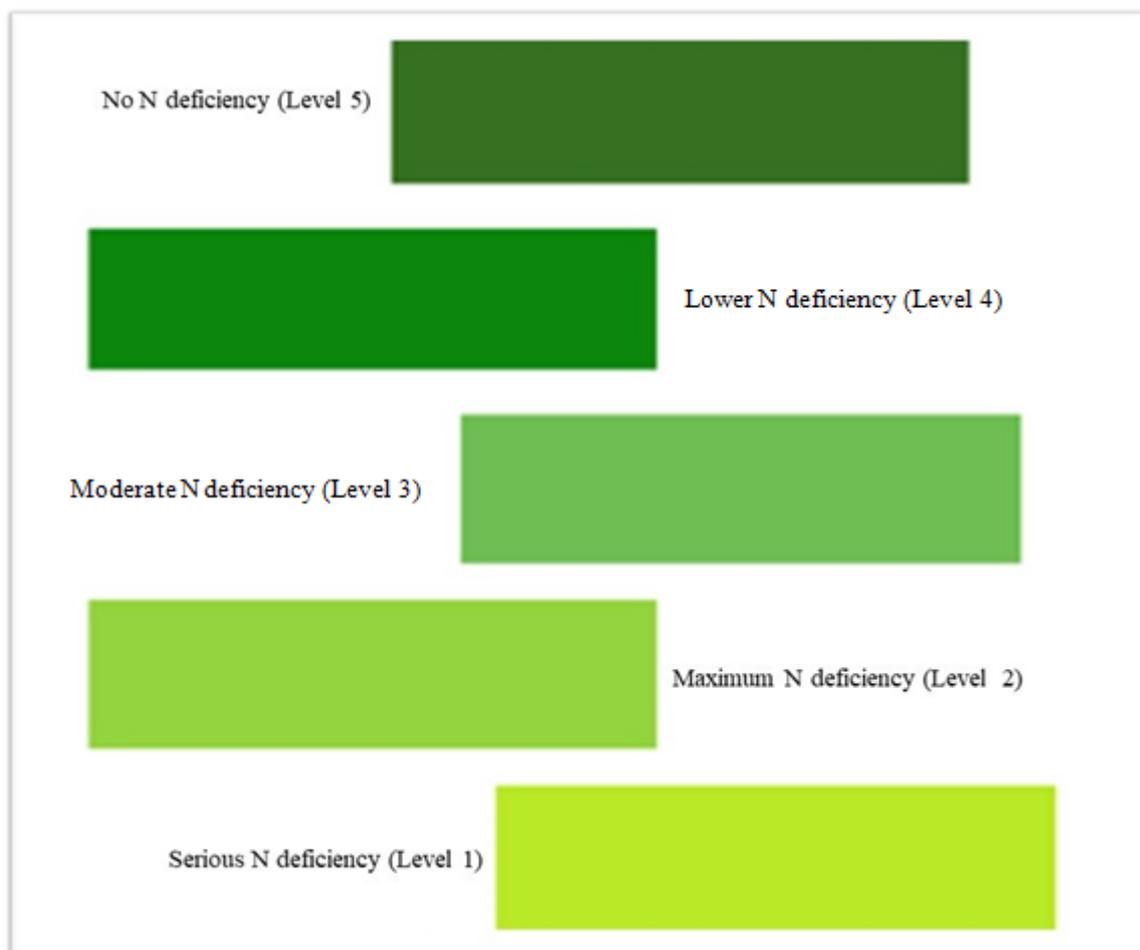


Figure 1: Different colours of LCC are well indicator of nitrogen deficiency in rice plant (Source: Modified from Leghari et al 2016)

Physiological response of rice to nitrogen fertilizers

Increased plant height was attributable to an increased rate of N translocation from culms to leaves, which leads to the production of photosynthates, which improves the transfer of nutrients to growing panicles (Singh et al 2014). In an experiment, Singh et al (2014) found that more tillers were owing to the increased availability of N, which was critical for cell division. Similarly, it was reported that the application of N @ 200 kg/ha produced the highest number of tillers and that N @ 0 kg/ha gave the lowest number of tillers (Meena et al 2003). The number of leaves per hill rose in tandem with nitrogen doses, which could be attributable to appropriate N feeding during the vegetative stage, which leads to improved root development and nitrogen absorption. Singh et al (2014) found that the enhanced translocation of N to the leaves results in a larger leaf area index at higher levels of N. N fertilizers have the primary impact of increasing the rate of leaf expansion, which results in enhanced canopy interception of daily solar energy and thus increased dry matter production. Similarly, Somasundaram et al (2002) showed an increase in LAI with increasing N fertilizer rates. In both field and pot environments, N applications improved grain production, number of grains per panicle, number of tillers, plant height, length of flag leaf, total dry matter and shoot dry matter, 1000 grain weight, and harvest index (Bahmaniar and Ranjbar 2007, Kumar et al 2008). Nitrogen helps to increase grain filling and sink size by reducing the number of degenerate spikelets and increasing the hull size.

Nitrogenous fertilizer application strategies

Multiple split applications and deep placement of nitrogenous fertilizer can increase rice yields and nitrogen use efficiency (NUE) while decreasing N losses (Yao et al 2018, Bandaogo et al 2015, Chen et al 2015). Nitrogenous fertilizer in three splits at around 20-25, 40-45, and 60-65 days after germination for short-duration varieties or four splits at around 20-25, 40-45, 60-65, and 80-85 days after germination for medium-duration varieties is appropriate (TNAU 2016). Nitrogen fertilizer application to rice, preferably as a top dressing between active tillering and panicle initiation, is the best strategy for increasing grain yield (Getachew and Nebiyu 2018). To boost rice yield, it is most effective to add N fertilizer at the panicle initiation stage (Ju et al 2021). The deep placement of N at 10–15 cm is considered optimum for better NUE and economic returns (Pan et al 2017, Meng et al 2017). When compared to traditional N fertilizer, the use of controlled-release urea (CRU) considerably boosted rice grain yield and nitrogen use efficiency (Chalk et al 2015, Ke et al 2017, Li et al 2017). A single CRU basal application is a promising alternative N management method for reducing time- and labor-intensive N application rates in rice cultivation (Chen et al 2020). CRU at 192 kg N/ha was an effective method for conserving N fertilizer, increasing soil N content, and improving NUE (Yang et al 2021).

Nitrogen loss from rice field

Leaching is the loss of soluble $\text{NO}_3\text{-N}$ as it moves with soil water, generally excess water, below the root zone. Leaching is one main pathway of N losses in paddy soil, which normally accounts for 0.1–4.9% of the applied N (Berlin et al 2014). Soils with a light texture, such as sandy, loamy sand, and sandy loam, encourage more leaching than soils with a coarse texture, such as loamy, clay, and clay loam. The more water percolates, the more N is lost by leaching. More leaching loss occurs when the rice field is kept under standing water for an extended period of time, as opposed to maintaining the field saturated or alternate soaking and drying. Irrigation on a regular basis results in a higher loss of N through leaching. Nitrogen loss is increased when nitrate-containing fertilizers such as Calcium Ammonium Nitrate (CAN), Potassium Nitrate (KNO_3), and Ammonium Nitrate (NH_4NO_3) are used. In light-textured soil, nitrogenous fertilizers applied on the surface promote higher nitrate loss. Higher doses of N fertilizer result in more leaching losses. Soils with low organic matter levels lose more N through leaching than soils with high organic matter levels. Leaching losses can be reduced by applying nitrogenous simple fertilizer in split applications. The loss of N from the leaching process can be managed by granular application of complex and compound fertilizers, keeping the rice fields moist and dry alternately, increasing the cation and anion retention capacity of soil by adding organic matter, using slow-release fertilizers such as karanj, neem, niger, or lac to coat urea, placement of urea mudball and Urea Super Granule (USG) in a specific area, and using nitrification inhibitors such as N-Serve and Thio urea.

Ammonia volatilization, denitrification, and leaching all contribute to the partial loss of N fertilizer applied to rice crops. These losses may result in pollution of the atmosphere, aquatic systems, and groundwater, among other things. These issues will never be totally solved. They can, however, be greatly lowered using a variety of ways (Choudhury and Kennedy 2005). Ammonia volatilization (AV) is one of the most common methods for N loss from a rice field, resulting in low N use efficiency and causes environmental pollution (Xu et al 2012). During the whole rice growth stage, total ammonia loss by ammonia volatilization ranged from 9.0 to 16.7% of the applied N (De-Xi et al 2007). Ammonia volatilization may even cause losses up to 60% of urea-N fertilizers applied to flooded soils (Russo 1996). In calcareous or alkali soils, direct application of ammonium sulfate ($(\text{NH}_4)_2\text{SO}_4$) and ammonium nitrate (NH_4NO_3) results in considerable volatilization loss of NH_3 . When prilled urea is applied in the midday or when the soil temperature is at its highest, there is high volatilization loss of NH_3 . Acid soil has a lower rate of volatilization than alkali soil. When NH_3 is applied under submerged conditions, however, acid soils enhance volatilization loss of NH_3 (Sahu and Samant 2006). The loss of volatilization can be avoided by applying urea at a deeper depth than at the surface. In a rice field, coated urea should be applied at a depth of 3 to 5 cm (Sahu and Samant 2006). Urea should be applied early in the morning or late in the evening. The application of urea deep

into the soil is always preferable to the application of urea on the surface. Ammonia volatilization losses from lowland rice can be decreased by using phenylphosphorodiamidate (PPD) to delay urease activity in flooded soils, and using algicides to assist stabilize changes in floodwater pH (De Datta et al 1987).

Denitrification is the reduction of nitrate or nitrite to gaseous nitrogen (usually N_2O and N_2). Around 10-40% of applied N is lost through the denitrification process (Sahu and Samant 2006). The presence of high organic matter, moisture regime, high temperature, soil type, and the presence of NO_3^- ion all favor denitrification loss. Because of the high temperature during the day, this loss is more during the day than at night (Sahu and Samant 2006). This type of loss can be avoided if the soil is kept effectively drained. Application of non-nitrate fertilizer, deep placement of ammonium form fertilizer, and correct water management methods can all help to prevent this loss. In acidic upland soils, N provided in the form of nitrate is also converted to nitrogen gas. This type of gaseous loss can be controlled with a moderate lime application (Sahu and Samant 2006).

In undulating areas, N loss through surface runoff occurs due to overflow flood water. Nitrogen is washed out by rain followed by fertilizer application, either through overflow or seepage. Excessive irrigation causes runoff loss through field bunds that are narrow and short in height. Nitrogen is lost through runoff through small holes or cracks in the bunds. Surface runoff loss is especially common in undulated and muddy areas. This type of loss is particularly common on hilly soils. Rain or irrigation water travels easily through the gradient, causing N to be lost along with the surface soil. N fertilizers lose roughly 7% of their N content to water bodies through surface runoff and subsurface leaching (Zhu and Sun 2008), and N runoff from paddy fields is one of the most significant sources of water pollution (Zhang et al 2016). Raising wide and elevated bunds can help to reduce runoff loss. Irrigation should be controlled according to the crop's water requirements. Before irrigation, crab holes and cracks along the bunds should be filled. Bunds placed at small intervals across the slope should be used to raise sloppy land. Fertilizers should be used in conjunction with organic manures.

Factors affecting the use of nitrogenous fertilizers in rice

Fertilizer is considered essential for crop production. The factors affecting fertilizer application in the rice field are given in Figure 2. Fertilizers can assist farmers in making a profit. Farmers can reduce unit costs and increase the margin of return over total cost by increasing fertilizer application on rice. The farmer should apply fertilizer in such a way that it yields the highest profit. Fertilizers used correctly can boost farm profits while also helping to maintain or improve soil quality. Agronomic, economic, and managerial issues all influence fertilizer use, and they must all be examined in conjunction with the crop to be fertilized, as well as subsequent crops and the farm as a whole. Because of the adverse nutrient/price ratio, commercial organic fertilizers enhanced yields but almost always resulted in negative economic returns. Farmyard manure along with inorganic fertilizer gave good yield responses and positive economic returns (Haefele et al 2010). Farmers' usage of fertilizers in rice fields is favorably influenced by lowland cultivation, irrigation, mechanization, farm size, improved crop varieties, land pressure, and the availability of non-farm income. Fertilizer application depends on the initial soil nutrient status. Increasing fertilizer application rates alone will not increase yields, and it won't work until high-yielding cultivars are used.

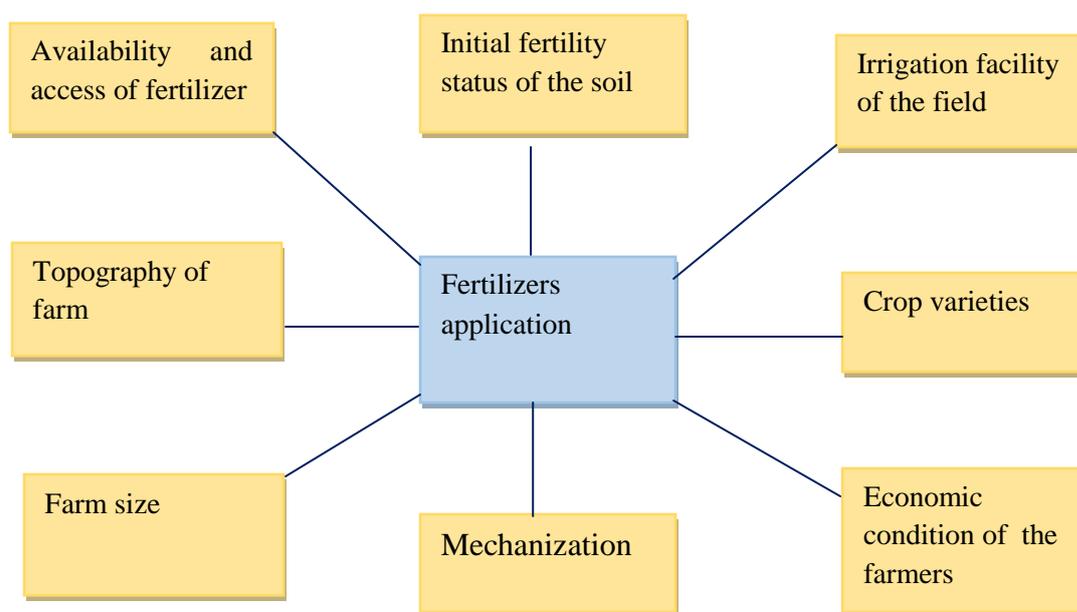


Figure 2: Factors affecting nitrogenous fertilizer use in a rice field

CONCLUSION

The time and methods of nitrogenous fertilizer application are strongly related to the growth, development, and yield of rice crops. Nitrogen applied in a rice field may be lost due to surface runoff, denitrification, ammonium volatilization, and leaching. To maximize N use efficiency and to increase the grain yield, farmers should apply multiple split applications, deep placement of fertilizers, and controlled-release urea. To maximize rice output, safeguard and maintain soil and environmental health, farmers should use nitrogenous fertilizer along with organic fertilizers. Based on the discussion above, it can be concluded that the recommended N application as a basal dose at planting, followed by split doses as top dressing at internode elongation and between tillering and panicle initiation stages, is an efficient way to increase rice growth, yield, and production.

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